YSLME Project Phase II

Develop regional strategy for using wetlands as nutrient sink project

Case study report

Prepared by

Guoxiang Liao and Weizhi Lu

National Marine Environment Monitoring Center

April 2019

Table of Contents

Executive Summary

The present case study in this research project which builds on knowledge using wetland as nutrient sinks for improving the ecosystem health of the Yellow Sea for replication of good practices. The report contains the findings of four case studies into good practice in detailing the design, implementation modalities, results and services of wetland and species in removing nutrients from the projects, and cost-benefits of such projects. It follows on from the previous review report.

The four cases participating in the present case studies are:

- Chapter 1. Wuyuan Bay restoration project: Return fish and salt ponds to bays and coastal marshes (Xiamen, Fujian Province);
- Chapter 2. Ningbo Water and Environment Project: Using wetland for tertiary treatment associated with sewage treatment plants (Ningbo, Zhejiang Province);
- Chapter 3. Use species and aquaculture to achieve the co-benefits of sustainable harvest and environmental performance in China (Longhai, Fujian Province);
- Chapter 4. Nutrient bio-extraction in coastal areas of China through restoration (Yellow River Delta, Shandong Province).

The main body of the four case studies was including the design in theory and practice, monitoring system, results and services of wetland and species in removing nutrients from the projects, and cost-benefits of such projects. Some of the main themes following from chapter 1 to chapter 4 include project background, project description, implementation modalities, results, and service improved. Each part of these case studies was meld closely with the key finding from other parts of the project.

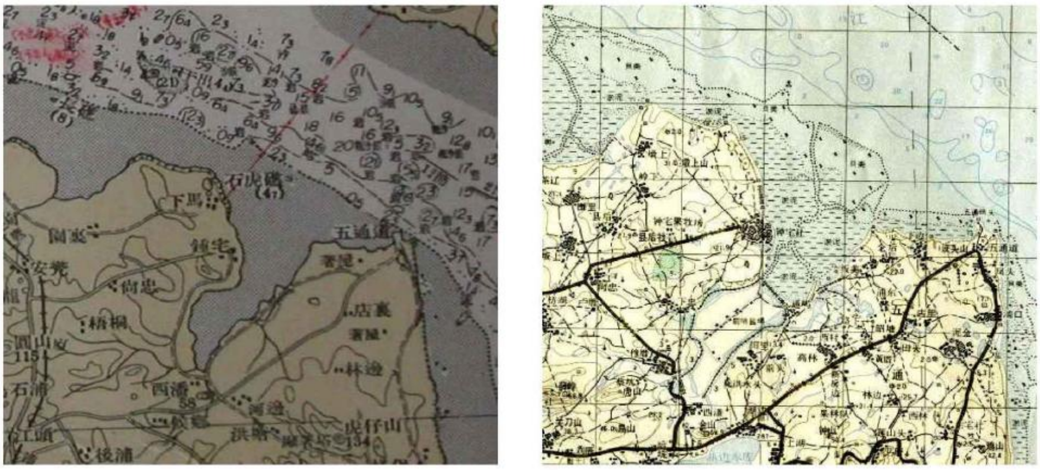
Chapter 1. Case Study I: Wuyuan Bay restoration project: Return fish and salt ponds to bays and coastal marshes

The present case study chapter takes Wuyuan Bay in Xiamen as the research area as an example, which applies the established coastal wetland ecological restoration effect evaluation and evaluation method system to the practice of ecological restoration effectiveness evaluation. This chapter firstly outlines the background of Wuyuan Bay ecological restoration, including the historical changes of Wuyuan Bay, the ecological environment problems before the restoration, and then we will briefly introduce the main engineering measurement implemented in the restoration activities, after that we will elaborate the detail results and service improvement after coastal wetland restoration. Based on the results and the benefits, we can put forward a brief cost-benefit measurement during the coastal wetland measurements, which will be adapted to the ecological restoration or coastal wetland management or protection in the future.

1.1 Background

1.1.1 Historical changes of Wuyuan Bay

Wuyuan Bay is located in the northeastern area of Xiamen, Fujian Province, China, which was called Zhongzai Bay before the restoration program started. Historically, Wuyuan Bay wetland ever hosted 83 bird species of 13 families and 66 genera, and 5 are CITES (Convention on International Trade in Endangered Species of Wild Flora and Fauna) appendix II species and three are CITES Appendix III species (Liu and Chen, 2004). However, the water in the bay was ever connected with the sea, but the dike construction for reclamation in the late 1950s and 1970s (“Five-Eight Dike” and “Seven-Nine Dike”) changed the bay into a lake (Huang, 2012). Moreover, the un-exchangeable water body and pollution from agricultural, maricultural and industrial sources had made the bay water quality seriously bad. The zooplankton species diversity was very low. There were no large copepods but only small ones recorded, and the predominant species was *Oithona brevicornis* which was an indicator species of the eutrophication. Moreover, natural wetland had been seriously degraded by farming and maricultural activities. Wetland landscape patches shrank a lot with very high fragmentation, and ecological services also decreased sharply, for example, the content of organic carbon, sulfide and heavy metal in sediment severely exceed the environment permit (Huang, 2012; Liu and Chen, 2004).



A 1947 年五缘湾地形地貌状况

（海湾内尚没有海堤建成）

B 1960 年五缘湾地形地貌状况

（海湾中部的五八海堤建成）

C 1993 年五缘湾彩红外图片

（湾口的七九海堤建成）

D 2005 年初五缘湾卫片图

（湾口两侧已实施了填海造地）

Fig. 1.1 History changes of Wuyuan Bay

(*adapted from* Huang, 2012)

1.1.2 1.1.2 Ecological environment before restoration implement

Before the ecological restoration, the garbage in the inner area of Wuyuan Bay was piled up at random, and the salt works outside the old seawall became a large-scale garbage dump of surrounding villages and enterprises. There are also many small and medium-sized garbage dumps in Zhongwan, Neiwan, and Tongyu. The untreated sewage was discharged arbitrarily, and the water flow was also not smooth. The water environment quality and sediment quality in Wuyuan Bay were extremely poor, and the organisms were the species mainly resistant to pollution. The details of the environment described as follows:

a) The hydrodynamic conditions were extremely poor. In the late 1950s and 1970s, the construction of two seawalls in Wuyuan Bay turned the original free-flowing seawater into the inner lake, and the agriculture, salt and aquaculture industries occupied most of the original water. The water velocity in the dike was close to zero, and the exchange capacity between the water body and the outer seawater in Wuyuan Bay approaches zeroes. Moreover, the siltation in Wuyuan Bay was serious, and the water depth was generally shallow.

Fig. 1.2 Poor hydrodynamic condition in Wuyuan Bay

(*adapted from* Huang, 2012)

b) Poor environmental quality. The extent of eutrophication by the water was serious. Before the ecological restoration, the sewage in the surrounding area was discharged without treatment, and the sewage flowed. Water bodies in Wuyuan Bay were affected by agricultural non-point source pollution, aquaculture pollution and pollution from other sources in different degrees, resulting in the overall quality of Wuyuan Bay water body. The average concentration of inorganic nitrogen and active phosphate, and the inorganic nitrogen content in all survey sites far exceeds the four standards of seawater quality. The active phosphate content of the above survey sites exceeds the four criteria. The water environment quality of the inner pool of the original Five-Eight Seawall was the worst, the water body was dark and black, and many water surfaces were covered by the water hyacinth. It was completely dehydrated, and the dissolved oxygen in some water points was zero.

The sediment was seriously polluted. From the average value of each survey station, the contents of organic carbon, sulfide and heavy metals were higher. The average value of organic carbon content was 3.8%, which surpass the second class of super-sediment quality (Chen et al., 2012). The average values of sulfide, Cu and Zn and content are respectively 1725.4×10^{-6}, 216.9×10^{-6}, 669.5×10^{-6}, which was far beyond the three categories of sediment standards. The high value of each pollutant was mainly concentrated in the inner side of the original Five-Eight embankment. In general, the level of pollution on the inner side of the original Five-Eight embankment was relatively serious (Huang, 2012).

c) Low-biodiversity Biomes. The number of species of zooplankton and benthic organisms were small, and the trend of miniaturization of the species was obvious. Moreover, there were many pollution-tolerant species in class composition. A total of 71 Phytoplankton species was recorded. Because the survey sites were distributed in different water plaques, there were many freshwater species in the species composition. There was a high density of *Euglena gracilis*, which were mainly found at the top of Wuyuan Bay (which is now the surrounding waters of Huxin Island). Because *Euglena* is an indicator of polluted wastewater, it is common in organic pollutants. Its presence indicated that the local waters of Wuyuan Bay before the renovation, especially at the top of the bay, were affected by the discharge of sewage from the upstream discharge.

A total of 12 zooplankton species were found here, including ten copepods, one ranunculus, and one krill species. There were no large copepods in the bay. The short-horned long-legged swords of the small copepods account for an absolute majority in the bay. This species is a common species and dominant species in the pupal and eutrophic waters. Benthic organisms: A total of 57 large benthic organisms were identified, including chironomids, oligochaetes, larvae, kidney locusts, and a small number of glandular snails.

d) Disturbed landscape. The ecological landscape of the wetland landscape in the area was extremely disturbed by human activity. The original coastal wetland landscape was replaced by artificial or semi-natural landscapes such as farmland, vegetable plots, breeding ponds, and construction land for villages and towns. The landscape patch area was reduced, the degree of fragmentation was high, and the ecological service function was degraded.

1.2 Project description and implementation modalities

To restore the wetland and improve the sustainable development of the coastal area around Wuyuan Bay, the municipal government of Xiamen initiated the restoration project since 2001. The restoration processes included base data collection, setting the restoration goals, restoration measures selection, restoration practice, monitoring, and management. The restoration project included series actions as follows, dredging the sediment of the Wuyuan Bay, demolishing the original dikes, implicating the sewage interception project, and sending in the sewage to the sewage treatment plant through the pipe network. Moreover, building uninhabited ecological islands, bay shore revetments, landscape greening projects, wetland parks also incorporated into the restoration project.

The ecological restoration and construction of Wuyuan Bay were planned as a whole, which included realizing regional ecological restoration and construction and setting the systematicity of the program. Through the full communication and exchange with government decision-makers and key stakeholders, the overall needs of ecological land in Wuyuan Bay, the rational layout of wetland ecological patches, and related regional ecosystem restoration goals will be implemented and integrated into Wuyuan Bay. The restoration area controlled by detailed planning, conservation planning for important habitats, and engineering design. On this basis, the ecological restoration and construction of Wuyuan Bay had designed natural ecological conservation projects such as wetland parks and uninhabited ecological islands, and linked other construction projects with the overall ecological restoration objectives, such as seawall openings and dredging in the inner bay, low water level dam project, guilt coast revetment construction project and Huanwan Road construction, *etc*.

1.2.1 Seawall opening and inner bay dredging

***Firstly*,** the wetland restoration designers proposed to restore the initial size of the bay, aiming at restoring the ecological and environment according to the engineering construction. Based on the feasibility analysis, several alternative preliminary plans were identified from the perspective of the bay size and the trend of the revetment line.

Secondly, numerical simulation method of hydrodynamics were identified by the numerical models such as tidal field, water point movement and water exchange, the influence of each construction scheme on the tidal field and the tidal volume of the surrounding sea area is analyzed, and the water trajectory and the water exchange capacity in the bay are simulated, then the designers propose water quality assurance measures after the completion of the project.

Finally, the specific requirements were put forward based on numerical simulation calculations and analysis, which included the perspective of Gulf environmental quality maintenance, social economy and feasibility of engineering construction, the width of the gulf, the size of the bay, the coastline of the bay, the water depth of different blocks in the bay, etc. Through the above steps, the bay is dredged from year to month, and the original seawall is opened. The seawater in the bay and the seawater outside the bay are freely connected, and the area of shallow bay wetlands in the

Wuyuan Bay area is expanded. After completion, the outer bay of Wuyuan Bay was dredged to yellow zero meters, and the inner bay was dredged to meters. To maintain the proper water level in the inner bay, a low water level dam is built between the inner bay and the outer bay.

1.2.2 Conservation of original habitat

The original Wuyuan Bay is a pile of jagged habitats including ocean, tidal flat, shrimp pond, fish pond, swamp, grassland, rice paddy, woodland, cultivated land, and mountain. Numerous habitats such as hills, tidal flat, and villages provide places for many organisms to incubate, forage and rest. Through the analysis of the importance of habitats in the area, there are four main ones that deserve special attention:

The first is Tongyu Freshwater Wetland Habitat. This area is a freshwater wetland between Tongyu and the villages of Meimei, Pudong, Tianzhong, Tiantou, Xicun, and Qiantou, with high landscape heterogeneity. The area is distributed in the area of *Phyllostachys pubescens* - Bitter lang tree - Horseshoe gold cluster protection forest belt, Acacia on the island of Tongyu - Vitex - small canopy clusters, beautiful hackberry - chicken claw - willow cluster, wetland. There are water candle communities, round fruit dams, and inhabited rare birds such as gray ostriches. Among them, the beautiful Park Grove is a typical type of island-type vegetation in Xiamen Island.

The second habitats are Jinshan woodland and its eastern water body. The area is an ecological corridor leading to the Wuyuan Bay from the lakeside reservoir. The Jinshan woodland mainly consists of acacia tree-rockweed-mangling group, Masson pine-rockweed-mangling group, vegetation cover. With coverage of more than one, plant biodiversity is abundant. The hilly woodland of Jinshan is the breeding of egrets. In the land, the population of the parental birds only has a protective effect on the breeding ground of the Jinshan heron.

The third habitat is acacia forest and bitter forest on the south side of the housing village and the north bank of Wuyuan Bay. The region has the highest landscape heterogeneity. The species is rich in abundance, and there are Acacia trees - Maluan Dan - Willow Leaf Cluster, Acacia Tree - Iron Mangan Gold -Willow stalks, bitter scorpion-Ma Habitats, rich birds and natural plants are difficult to build by human measures. The protection and development of this forest land are of great significance for the protection of bird diversity and stability.

The last habitat is the below woodland and the ancient valley ditch habitat. The area belongs to the coastal windbreak forest belt, and the forest belt is wide and canopy, with which had a high degree, less interference by humans, retaining relatively good natural characteristics.

1.2.3 Construction of wetland park

Before the ecological restoration and construction, Wuyuan Bay is a messy shrimp pond and a relatively open coastal wetland. Since the opening of the seawall has increased the sea area in the bay, the shallow water area such as the original marine aquaculture has decreased, and the freshwater area has also decreased. For Xiamen Island, with the further expansion of the reclamation in the northeastern part of the area, the area of coastal wetlands will gradually decrease, and the protection and ecological construction of freshwater habitats in the area and the reconstruction of shallow water wetlands in the bay are very important. Therefore, the ecological restoration and construction of the Wuyuan Bay Wetland should be as close as possible to the diversified wetland types such as shallow seas, tidal flat wetlands, river wetlands, lake swamp wetlands, and constructed wetlands. In general, the wetland ecological types in the Wuyuan Bay area can be divided into three categories.

The distribution of each type of wetland is shown in the following categories: the first category, shallow sea, and tidal wetlands, mainly distributed in the inner bay of Wuyuan Bay and ecological islands, and the northern end of the wetland park. The second category, brackish water wetlands, mainly distributed in the area between freshwater wetlands and bays, is affected by tidal water and is also affected by the discharge of upstream fresh water. The third category, freshwater wetlands, accounts for Wuyuan Bay. Most of the wetlands on the south side include freshwater river wetlands connecting lakeside reservoirs, lake and marsh wetlands that continue the original lake pond pits, and constructed wetlands (maze area and sewage purification area) constructed for sewage purification.

The Wetland Park plans to design the following subdivision: The wetland core protection area covers an area of 12 hectares. Its main purpose is to protect and restore the shallow grassland habitat in the restoration area, provide feeding grounds and habitats for the waders, and partially replace Wuyuan Bay. The original ecological service function of the wetland; the peripheral conservation area (including the wetland arbor conservation area, wetland vegetation conservation area and the park forest conservation area) can not only provide appropriate buffer areas for the core area to reduce the disturbance of human activities to wildlife, but also provide suitable leisure areas to meet the needs of tourists to explore the wetland ecology of the park. The main function of Park Grove Conservation Area is to protect the typical island-type vegetation of Xiamen and the habitat of many birds; the ecological recreation area is located on the north shore of the core protection area, with water raft facilities to allow visitors to enjoy the view of the core area of the wetland. Also, according to its topography and function, different areas of the park are divided into ecological science area, ecological purification area, wetland river exploration area and ecological wetland sightseeing area to meet the needs of wetland park for popularization, water purification, river fun, and wetland leisure.

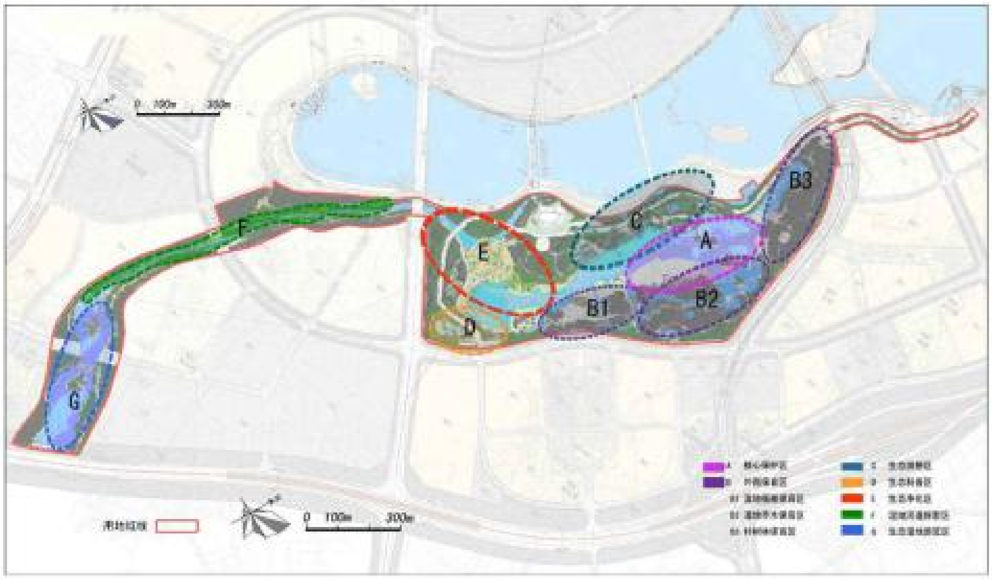


Fig. 1.3 The map of functional ecological zoning in wetland park

(*adapted from* Huang, 2012)

1.2.4 Public participation and education

The ecological conservation and ecological construction of Wuyuan Bay wetland not only serves the surrounding residents but more importantly, it can better convey the awareness of ecological protection and promote the ecological protection of other areas. The bird-watching competition in Wuyuan Bay, the organization of wetland days and other activities, as well as the children's parent-child nature education and the natural ecological experience of college students, have gradually highlighted the natural ecological science education function of Wuyuan Bay Wetland. Excellent ecological science education requires a better natural ecological base, which will also promote the further improvement of the ecological construction quality of Wuyuan Bay.

1.3 Results and service improve

1.3.1 Water quality

The water in Wuyuan Bay nearly two years after the restoration was generally of above Grade 2 water quality as referred to “China’s Seawater Quality Standards”. Recreation of the ever-existed wetland has achieved a beautiful wetland park with high plant diversity and more birds. According to the flow structure of wetland water system, the distribution of major pollution sources and the positioning principle of manual intensive treatment measures, three representative monitoring points were set, and pH, NH_3-N, TN, TP, and COD were selected as tracking indicators, and the results are shown in Table 1 and Fig. 1.4. We can find that before the restoration, the grade of surface water standard in wetland drainage was bad V and the main water quality indexes of NH_3- N, TN, TP, and COD were average V class standard of 6, 7.6, 5, 7.6 times than those mentioned above. The water body is in the state of severe eutrophication, the color of local water area changes from light green to grey-green to dark green and finally becomes dark green and stinky. After one year of intensive treatment and three months of maintenance and debugging, the water environment quality was gradually improved. The monitoring results investigated in July 2009 showed that the main water quality indicators, NH_3-N and COD, were higher than the category V standard of surface water, respectively up to 1.3 and 33.4 mg/L. TN and TP decreased by more than 60% and 70%. The sludge still released nitrogen, phosphorus, and other nutrient salts after sewage interception, so the water quality in this area was still in the recovery stage.

Table 1 Water quality results during the restoration in Wuyuan Bay wetland Park (*adapted from (Chen et al., 2011)*)

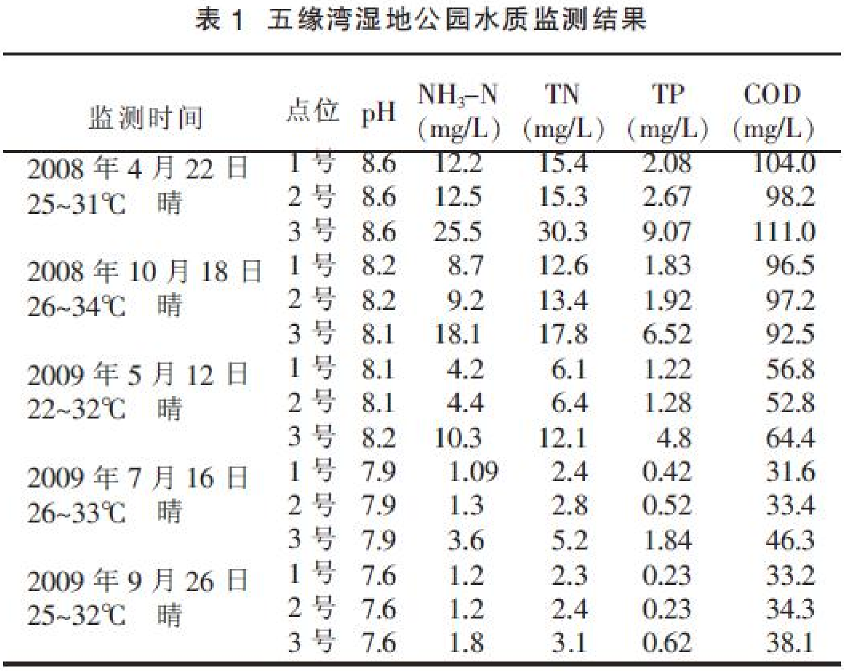


表1　五缘湾湿地公园水质监测结果

监测时间	点位	pH	NH_3-N (mg/L)	TN (mg/L)	TP (mg/L)	COD (mg/L)
2008年4月22日 25~31℃　晴	1号	8.6	12.2	15.4	2.08	104.0
	2号	8.6	12.5	15.3	2.67	98.2
	3号	8.6	25.5	30.3	9.07	111.0
2008年10月18日 26~34℃　晴	1号	8.2	8.7	12.6	1.83	96.5
	2号	8.2	9.2	13.4	1.92	97.2
	3号	8.1	18.1	17.8	6.52	92.5
2009年5月12日 22~32℃　晴	1号	8.1	4.2	6.1	1.22	56.8
	2号	8.1	4.4	6.4	1.28	52.8
	3号	8.2	10.3	12.1	4.8	64.4
2009年7月16日 26~33℃　晴	1号	7.9	1.09	2.4	0.42	31.6
	2号	7.9	1.3	2.8	0.52	33.4
	3号	7.9	3.6	5.2	1.84	46.3
2009年9月26日 25~32℃　晴	1号	7.6	1.2	2.3	0.23	33.2
	2号	7.6	1.2	2.4	0.23	34.3
	3号	7.6	1.8	3.1	0.62	38.1

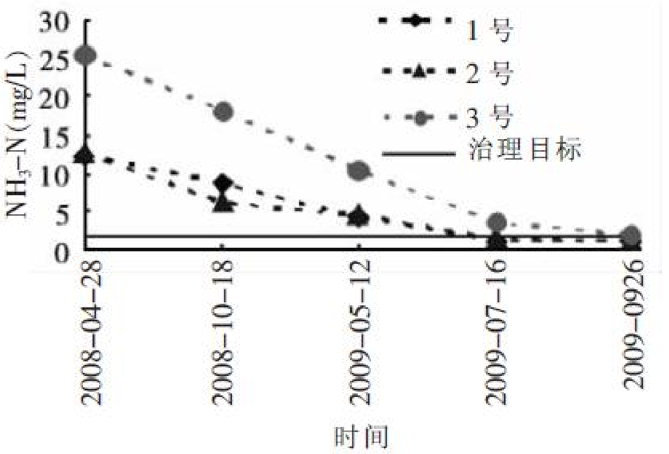


图 2　NH_3-N 变化曲线

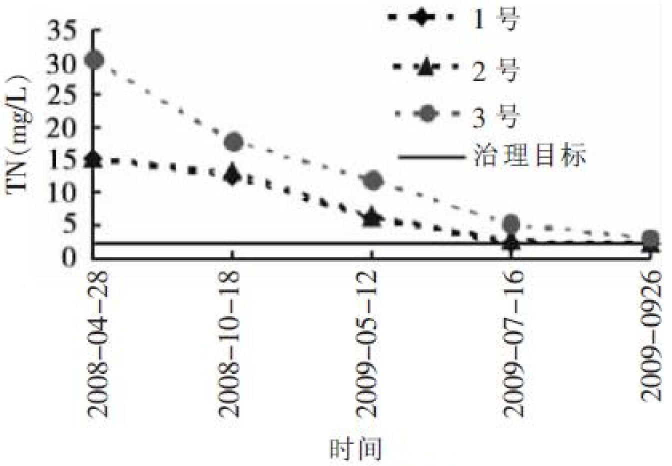


图 3　TN 变化曲线

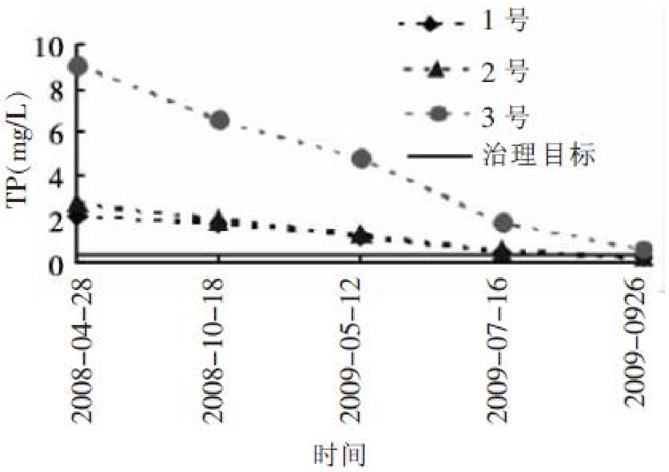


图 4 TP 变化曲线

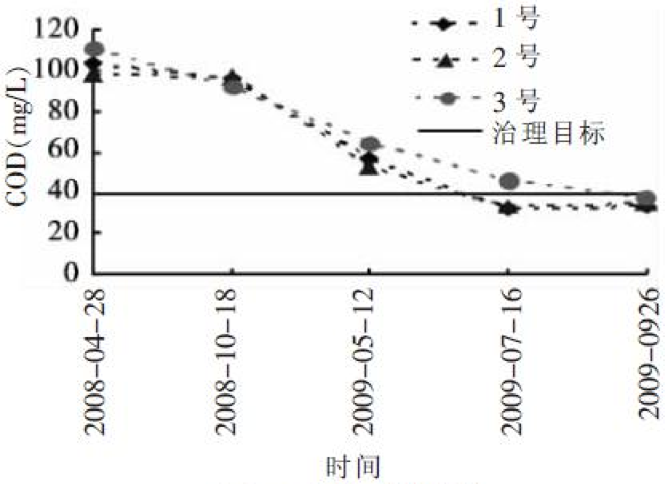


图 5 COD 变化曲线

Fig. 1.4 the changes of NH_3-N, TN, TP, and COD during the restoration in Wuyuan Bay wetland Park (*adapted from Cheng et al., 2011*)

After the restoration, the main water quality indexes including NH_3-N, TN, TP, and COD all met the requirements of category V of surface water, and the water quality and ecological environment quality of wetland parks were significantly improved. After restoration measures such as decontamination and desilting, the quality of seawater has been greatly improved. The content of inorganic nitrogen in seawater had decreased by 72% when compared to 2004. Similarly, the content of active phosphate had decreased by 85% when compared to 2004. The survey results in 2011 showed that the sediments in Wuyuan Bay were of good quality, and all the indexes at each station were in line with the standards of sediment quality. However, the sediment quality of the Wuyuan Bay before ecological restoration was relatively poor. The survey results in spring 2004 showed that the average content of organic carbon and cadmium exceeded the standard of grade II, and the content of sulfide, copper, and zinc exceeded the standard of grade III.

1.3.2 Biotic community

The biodiversity of the biotic community can be acted as an excellent index for the restoration in Wuyuan Bay, here we described them from benthic species, waterbirds, and vegetations.

Benthic species: In the fall of 2005, 57 benthic species were recorded, belonging to 5 families and 39 families, with the most link animals (31 species), followed by arthropods (12 species). Dominant species are *Neanthes glandicincta*, *Capitella capitata*, *Potanilla reniformis*, *Pillucina neglecta*, *Cerithidea cingulata*, *Cerithidea microptera*, *Batillaria zonalis*. Shannon's diversity index (H') was 0.72. Results of the survey in autumn 2011: 87 species of macrobenthos belong to 8 families and 57 families, among which the most species are polychaetes (44 species). They are followed by arthropods (29 species). Dominant species were *Pista brevibranchia*, *Leonnates persic*a, *Nephtys polybranchia*, *Amaeana trilobata*, *Prionospio malmgreni*, *Tharyx sp.*, *Ruditapes philippinarum*, *Pareurystheus amakusaensis*, *Melita longidactyla*, *Upogebia wuhsienweni*. Shannon's diversity index (H') was 2.53. After the ecological restoration of Wuyuan Bay, both the species number and diversity index of benthic organisms have been greatly improved.

Waterbirds: The changes of birds before and after the restoration of Wuyuan Bay were assessed by 2006 as the time line. Before the recovery (2002-2006), 54 species of water bird were recorded, with a maximum number of 124. Thirty-three species of water bird was recorded in Wuyuan Bay after ecological restoration (2007-2011), with a maximum number of 482 (Table 2). Although the number of water birds increased greatly after ecological restoration, the number of species decreased by 21 compared with that before restoration; this is mainly due to the ecological restoration project in artificial upright or terraced hard revetment replaced the natural coastline. It is difficult to form shallow wetland ecological space around the shoreline, and inter-tidal mudflats disappear, which caused the waders to lose their natural foraging and habitat, leading to a decline in diversity. This can be said to be the fifth edge bay ecological restoration project in the existence of major regret.

Table 2 Changes of water birds community before and after Wuyuan Bay restoration (*adapted from Huang et al., 2015*)

Time	Species	Record maximum
Before restoration (2002-2006)	54	124
After restoration (2007-2011)	33	482

Vegetation: Based on the analysis of satellite remote sensing image interpretation, it can be concluded that the vegetation coverage of wuyuan bay increased from 7.2% to 18.3% before the ecological restoration, and the green rate increased greatly. Based on the field investigation, it was found that local species were mainly used in vegetation species composition, such as pushu and ficus lobelia. In the process of ecological restoration, local species were mostly used for artificial afforestation. There was no large-scale substitution of foreign species for local species in the Wuyuan Bay area.

1.3.3 Landscape pattern

It can be seen from the results of satellite remote sensing interpretation that after the ecological restoration of Wuyuan Bay, both the salt field and the breeding pond have been cleared, and the area of the green garden has increased greatly. At the same time, with the increasing development and utilization intensity of Wuyuan bay area, the area of construction land and traffic road increases greatly. Compared with 2005, the proportion of natural landscape of Wuyuan Bay after ecological restoration increased by 5.23%, mainly due to the significant increase in the water area and island area, including the water area from 152.22 hm^2 to 2012.21 hm^2 and the island area from 0.40 hm^2 to 6.45 hm^2. And landscape diversity index and evenness index were lower, mainly due to the strength of the five yuan bay area development and construction in recent years, increasing construction land and artificial landscapes, such as traffic area is increasing rapidly, the proportion structure differences between landscape types of elements on the rise, the human disturbance makes the landscape diversity and evenness is reduced, this development will lower landscape anti-interference ability, thus resulting in a loss of stability of landscape.

1.4 Cost-benefits analysis and lessons from current coastal wetland restoration

This restoration project in Wuyuan Bay, Xiamen is a pioneer practice in bay restoration of China, and this experience has taught several lessons which will be possibly useful for planners, managers and development workers associated with bay restoration programs in China:

(1) Sufficient ecological, socio-economic and management-related information was collected before project planning, and degradation analysis was fully conducted. Information covered socio-economic development; diverse land uses water quality, sediment quality, biological parameters including phytoplankton, zooplankton, macrobenthic in the waters and plants around the bay. Severe degradation was concluded. Baseline information demonstrated that the major causes for bay ecosystem degradation were a hydrological situation (un-exchangeable water body originated from two dikes constructed in the late 1950s and 1970s) and pollution from diverse sources, e.g., agriculture, salt mining and mariculture (Liu and Chen, 2004; Liu et al., 2009).

(2) Objectives and performance criteria were clear, brief, achievable and measurable. The objectives of Wuyuan Bay restoration project were: (i) to improve the environmental quality of Wuyuan Bay wetland; (ii) to preserve and maintain the high biodiversity, and typical natural landscapes in this area; and (iii) found natural ecology science education and experience-distribution base for public education and awareness improvement. Performance criteria included the water exchange volume, water body size, coastline length, water quality, plant diversity and area around the bay and sewage collection capability, etc. All these parameters were clear and

measurable (Liu and Chen, 2004; Liu et al., 2009).

(3) Restoration scheme covered restoration design, schedule, and cost. Especially, stakeholders were well involved in. Baseline information demonstrated that the major causes of wetland degradation were a hydrological situation (un-exchangeable water body) and pollution from diverse sources (Liu and Chen, 2004; Liu et al., 2009). Accordingly, three restoration measures of priority were adopted:

(i) Improvement of the hydrological situation between December 2005 and June 2007. The dike constructed in the 1950s and 1970s were removed to ensure the water exchange between the bay and the outer sea. Dredging was also carried out to further ensure the efficiency of water exchange.

(ii) Management and control of sewage discharge. The sewage collection system around Wuyuan Bay was constructed from 2005 to 2007 to prevent the bay from sewage discharge. At the same time, the agricultural, industrial and maricultural sources for pollution were removed from the areas around the bay.

(iii) Preservation and recreation of typical habitats. Four typical habitats were preserved or recreated, including one wetland and three woodlands with the wetland recreated. Mariculture infrastructures in the bay area have been removed since 2005.
Especially, during the restoration effort from planning to implementation, performance assessment and management in Wuyuan Bay, all identified stakeholders including direct users, governments and academic institutions, were all involved in (Liu et al., 2009). It has been well documented that multiple use conflicts are common in these areas due to competition among diverse stakeholders associated with these ecosystems. Creative partnerships formation and community involvement have been proven to be crucial to successful ecosystem restoration.

(4) Scientific, environmental impact assessment was carried out before restoration implementation. 3S (Geographic Information System GIS, Remote Sensing RS, and Global Position System GPS) were used in planning land and water uses in Wuyuan Bay. Modeling for hydrology, water quality improvement, biodiversity improvement

anticipation, sewage capacity, and visitor capacity were all carried out (Liu and Chen, 2004; Liu et al., 2009). At the same time, measures for natural landscape protection, important species conservation, and cost-effective implementation were proposed according to risk assessment.

(5) The monitoring program was developed, and adaptive management was applied during the whole restoration process. The monitoring program was developed, and parameters covered hydrology, biological factors (aquatic ecology and land ecology), water and sediment quality, and landscape (Liu et al., 2009). Based on the monitoring results, adaptive management was used during the restoration effort in Wuyuan Bay. The formal consultation and planning process involved a series of meetings, some with all identified stakeholders (direct users, governments and academic institutions), and others focusing on more specific issues and followed a logical process of problem identification, agreement, and negotiation of management strategies (Liu et al., 2009).

(6) Public education and results dissemination have well done. A series of theme-based activities have been carried out in Wuyuan Bay since 2007. Especially, World Ocean Week in Xiamen was held every year from 2005, and Wuyuan Bay was selected as one center for part of activities since 2007, such as sports fishing, artificial releasing and sailing competition, etc. Results of this restoration project have been extensively distributed to people from all over the world (World Ocean Week). At the same time, activities of bird watching and earth protection education were also held inWuyuan Bay from 2006 (Liu et al., 2009).

Chapter 2. Case Study II: Ningbo Water and Environment Project: using wetland for tertiary treatment associated with Sewage treatment plants

2.1 Background

Ningbo is located on the East China Sea, approximately 175 km south of Shanghai on the southern edge of Hangzhou Bay. Ningbo Municipality is part of Zhejiang Province but is classified as a "sub-provincial municipality" which means it is a separate economic planning unit and is not administratively controlled by the provincial government. The Ningbo Water Supply component will cover the six urban districts in Ningbo which together are termed the "City" with a total population of 2.5 million people. The urban districts are Haishu, Jiangdong, Jiangbei, Zhenhai, Beilun, and Yinzhou Districts. The present wastewater treatment project will cover the suburban county of Cixi, located north of Ningbo City and bordering on Hangzhou Bay, where Cixi has approximately 1.2 million residents. Ningbo has a humid subtropical monsoon climate with an annual average temperature of 16.9 ^{o}C (max 36.3 ^{o}C and min –5.0 ^{o}C) and precipitation of 1128 mm. The urban area of Ningbo City is located in the flat plain of Yongjiang River basin with an average elevation of 3.0 m. Yinzhou District, which is a more rural area in Ningbo City, is a low hilly area with an average elevation of 100-450 m. The main river system is the Yongjiang River system, including two major tributaries (Yuyao River and Fenghua River) and densely distributed small rivers and canal systems.

The project objective is to facilitate the expansion of water and wastewater services in Ningbo City and Cixi County, and thereby protect public health, improve the environment, and sustain the area's rapid economic growth. Ningbo Municipality is located near Hangzhou Bay and comprises six districts, three county-level cities (one of which is Cixi) and two rural counties. Ningbo City generally refers to the six districts. At appraisal in December 2004, Ningbo City faced a two-dimensional water crisis-frequent shortages and poor water quality-which impeded economic growth and endangered public health. The core urban area of Ningbo City was served by the Ningbo Water Supply Company (NWSC), established about 80 years ago, while about 25 township water supply companies served populations located around Ningbo City. The companies drew water primarily from highly polluted local rivers and used outdated treatment technology that diminished the quality of piped water. Due to the lack of storage reservoirs and reliance on local rivers, Ningbo City often experienced water shortages during the dry season. With the City's rapid economic expansion, the demand for water was increasing at about 5 to 10% per year. In spite of an aggressive water conservation program, the duration and the intensity of the shortages were increasing. In response, the Ningbo Municipal Government had formulated a plan to develop a new safe and reliable water supply project. The long-term plan of the Ningbo Municipal Government was to expand the new water supply to all residents of Ningbo City by incorporating the surrounding township water supply companies within NWSC.

Cixi City, located on the shore of Hangzhou Bay, also had a rapidly expanding economy. At appraisal, only 10% of its wastewater in the city was treated, and heavy pollution loads were flowing directly to the environmentally sensitive Hangzhou Bay, creating environmental and public health concerns, and inhibiting potential investments. In 2004, a new company, Cixi Municipal Sewerage Company (CMSC), was established, to be responsible for all wastewater collection and treatment facilities. The new CMSC management faced the dual challenge of starting up a new company and managing a large capital works program designed to provide coverage to all urban areas and industries by 2010. Against this back-drop, the Ningbo Municipal Government requested Bank assistance for the Ningbo Water and Environment Project.

2.2 Project Description

Ningbo Water and Environment Project were to facilitate the expansion and quality of water and wastewater services in an economically efficient and environmentally sustainable manner, thereby protecting public health, improving the environment, and supporting economic growth. The key performance indicators agreed at appraisal, to measure results were: (i) increase in the percentage of water supplied from high quality and reliable water sources and treatment plants in Ningbo City from 10% to 75%; (ii) increase the percentage of wastewater collected and treated in Cixi City from 10% to 65%.

The Project will include the following three components. The total estimated cost is US$324million, with US$164 million in IBRD financing. The Project Management Office (PMO) will be under the Planning Commission, and the two implementing agencies will be the Ningbo Water Supply Company (NWSC) and the Cixi Sewage Company Limited (CSCL). The construction content in the present project contains the three components which had fulfilled:

Part 1. Constructed Wetland (estimated cost at appraisal: US$7.12 million).
The project was designed to support the creation of a new wetland to provide 100,000 m^3/day of tertiary water treatment for a new wastewater treatment plant financed by Ningbo Water and Environment Project (NWEP) on 86 hectares of recently reclaimed land provided by the Cixi City Government. The constructed wetland was to be a combination of vegetated submerged gravel bed and free surface water wetland.

Part 2. Establishment of a Wetland Center (estimated cost: US$8.0 million).
The Wetland Center was planned to cover 43.5 square kilometers of tidal and non-tidal lands and buffer strips and contain a visitors' center for wetland education and research. Its primary function, in addition to recreational tourism, was to demonstrate the viability of efforts to restore the area’s ecological functions and improve water quality in surrounding canals by natural wetland treatment.

Part 3. Design and Management Assistance (estimated: US$2.0 million).
This financed included three activities: (i) engineering design of the Constructed Wetland and Wetland Center; (ii) provision of management assistance for the Wetland Center; and (iii) training and information dissemination activities provided by a consortium of NGOs and universities.

2.3 Implementation modalities

Cixi government understands the importance of the coastal habitat and intends to conserve significant wetland areas and promote eco-tourism. A conceptual design for the wetland conservation program has already been developed, and Cixi Government intends to apply for GEF funds under the World Bank GEF East Asia Seas Pollution Reduction Program (scheduled for FY06) to undertake more sophisticated eco-system planning. Tertiary treatment consisting of chemical coagulation and filtration was originally proposed for the Cixi wastewater treatment plant (WWTP) but was subsequently replaced with an engineered wetland which will reduce operating cost and complexity.

2.3.1 Cixi Wastewater Management

Current Situation: Cixi City is composed of the central city with around 300,000 inhabitants, seven small cities with populations ranging from 25,000 to 100,000, and ten towns with around 25,000 or fewer residents. Also, there are areas of recently developed and rapidly expanding industrial estates along the coastline. Only 10% of the wastewater generated in Cixi City currently receives wastewater treatment, which is provided by the Jiaochangshan central city wastewater treatment plant. The WWTP collects wastewater from an area of around l0km2, comprising only one-third of the central city area. The current capacity of the WWTP is 20,000 m^3/d, but there are plans to expand the plant to 45,000 m^3/d by 2010. Municipal sewerage from the central city and each town is discharged directly into the river and canal network, with the result that most of the canals and main river networks are polluted to class V standards or worse. In addition to causing environmental problems, the lack of comprehensive wastewater management is inhibiting economic development as industries are reluctant to move into estates without proper environmental management. The project will finance the following components, which are essentially the entire five-year investment program for the Cixi Municipal Sewerage Company (CMSC).

Wastewater Treatment Plants: The CMSC service area is divided into three zones, each of which will have a wastewater treatment plant: (i) existing Jiaochangshan WWTP in the central city (45,000 m^3/d); ii) the NWEP-financed Northern WWTP which will have a Phase 1 capacity of 100,000 m^3/d, and iii) the NWEP-financed Eastern WWTP which will have a Phase 1 capacity of 50,000 m^3/d. The WWTP will discharge into the inland canal network, and thus require a high level of treatment to minimize eutrophication and other water quality problems as the canals have a relatively low assimilative capacity. Discharge into Hangzhou Bay through an outfall is not an economically viable option given the large tidal variation and shallow water along the Cixi coastline. The WWTPs are designed to meet Class 1A discharge standards, which are essentially 10 mg/l BOD and SS, with the removal of nutrients to 15 mg/l total-nitrogen and 0.5 mg/l of phosphorus.

The proposed treatment process is a modified reverse A20 process, with tertiary treatment. In the reserve A20 process, the anoxic stage is placed ahead of the anaerobic stage, to remove nitrates first and achieve the anaerobic conditions necessary to remove phosphorous in the second stage. The project will fund a technical assistance program for CMSC to build up its operational capacity to tackle the operationally complex A process. Tertiary treatment will be through an engineered wetland. The preliminary design for the engineered wetland will be finalized after loan effectiveness.

Sludge from the treatment plants will be dewatered through gravity thickening followed by centrifuges. A total 67,000 ^{3} of sludge, with a moisture content of 78%, will be generated per year from the two plants. The sludge will be transported to nearby municipal landfill sites in trucks with air-tight tanks. The sludge from the Northern plant will be disposed in the Cixi West landfill, and the sludge from the Eastern plant will be disposed of in the Eastern landfill. The Western landfill was expanded and upgraded in 2002, and currently has ten empty cells which will use impermeable liners and leachate treatment systems. Cixi City plans to upgrade the Eastern landfill in 2005 and utilize impermeable liners and leachate treatment systems for the four remaining cells. Upgrading of the Eastern landfill is included in the EMP. The Western landfill is forecast to reach full capacity around 2012, and Eastern landfill will reach capacity in 2015. Since the two landfills will be full after only 5-7 years of wastewater treatment plant operation, the EMP calls for the Cixi Municipal Sewerage Company to develop a sludge management plan to consider alternative long-term options for sludge management. Monitoring of sludge quality is also included in the EMP to ensure that the sludge can be safely disposed of in a municipal landfill.

2.3.2 Institutional Development and Capacity Building

Package A: Design Review and Advisory Services for NWSC and CMSC: To assist with three major tasks: (i) ensure preparation of ICB bid documents meet Bank standards, efficiency, and economy of works; (ii) develop and implement a construction management program based on sound engineering practice; and (iii)install adequate health, safety and quality assurance procedures.

Package B: NWSC Central Control and Monitoring Technical Assistance: Provide advice to NWSC: (i) to enhance the functionality of the existing monitoring and control systems, including the most recent upgrading of the systems carried out between mid-2004 and mid 2005; and (ii) in carrying out a study on a pilot area of the distribution system to learn how to best optimize the whole distribution system.

Package C: Utility Price and Regulatory Technical Assistance: To strengthen the capacities of the Price Management Division (PMD) within the Ningbo Development Planning Commission, the State Asset Management Commission, and the Urban Management Bureau (UMB), to carry price and service regulation in the entire water sector, including water, wastewater, raw water, etc. Phase 1 would focus on the regulatory framework at the municipal level, including counties and Ningbo City, while Phase 2 would concentrate primarily on specific water tariff adjustments in Ningbo City.

Package D: Technical Assistance to Develop Water Supply Strategic Plans: It will include assistance to revise the Ningbo City Integrated Water Supply Plan through an open and participatory process, involving all stakeholders, while encompassing least-cost analysis of short and- long term planning options, and satisfying utility and regulatory policy goals. A second component would support the preparation of the NWSC Strategic Plan, which would include the following elements: (i)resource plan, based upon the Ningbo City Water Resources Plan; (ii) capital plan to optimize and detail the capital investment needs over the short term, and identify medium and long term capital investment needs; (iii) financial plan, to integrate with the capital plan, analyze and identify financing sources, and assess tariff impacts; (iv) town and industrial water supply plan, to enable NWSC to best provide service; (v) management plan, which considers decision-making processes, administrative procedures, accounting systems, and management information systems; and (vi) human resources plan.

Package E: CMSC Technical Assistance: will consist of four main activities: (i) institutional strengthening, focusing on organizational structure, human resource management and planning, business planning, and improving the company's capacity to meet its regulatory obligations; (ii) financial management systems, including accounting, billing and collection systems, financial planning, determination of tariff requirements, and developing a modern financial information system; (iii)wastewater treatment plant operations including wastewater and sludge process operations; operational safety; and overall plant management; and (iv) industrial pollution control, including discharge permitting program and procedures; industrial wastewater monitoring; data management; and formal procedures for regulatory control.

2.4 Results and service improve

Project development objectives were satisfactorily achieved. Ningbo City has, indeed, expanded water supply, which is both safe and 97% reliable. Cixi has adequate wastewater treatment capacity, with tertiary treatment, to treat most of the wastewater generated. These improvements have resulted in arresting Chemical Oxygen Demand (COD), and Biochemical Oxygen Demand (BOD) discharges of 2,439 tons and 711 tons, respectively, in the first year (2010) after completion of the treatment plants. Achievements measured through the two key performance indicators are described below:

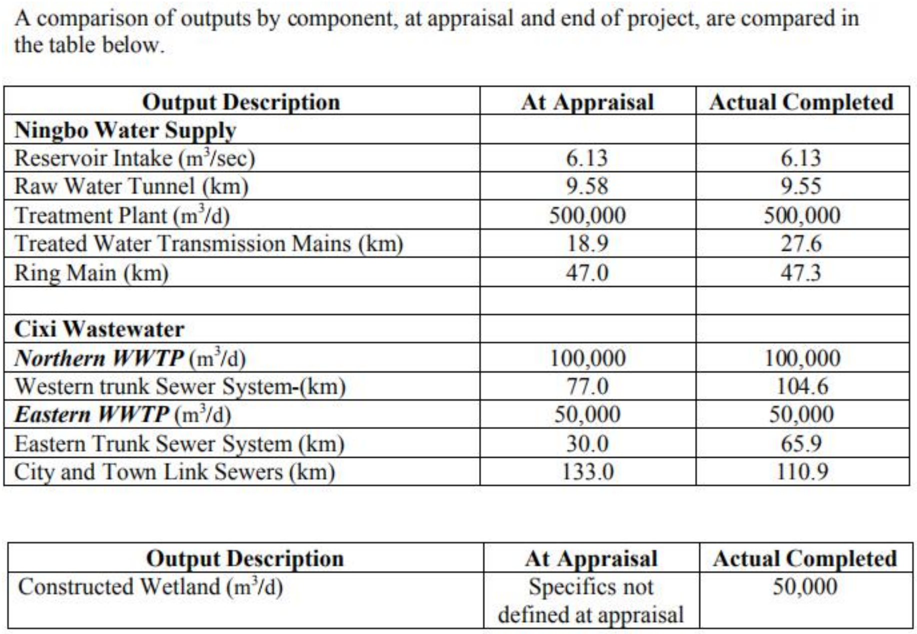
Increase in the domestic water supply from high quality and reliable water sources in Ningbo City. The percentage of high quality, reliable water supply in Ningbo City, rose from the 2005 baseline of 10% to 83%, surpassing the target of 75%. By loan closure, nine of the 25 townships had already switched to the new water supply underwater sales agreements with NWSC; construction of new water distribution systems to service five townships in Beilun and Zhenhai was also in progress at loan closure.

Increase in the percentage of wastewater treated in Cixi City. The wastewater treated in Cixi City increased from about 10% to 65.4%, meeting the indicator target (see Annex 2). The WWTPs and the eastern wetlands now meet the discharge standards, namely, Class 1B and Class 1A, respectively.

2.4.1 Outputs by Component

Ningbo Water Supply: (i) a water intake tower in Jiaokou reservoir and a 9.6 km raw water conveyance tunnel; (ii) a water treatment plant (WTP) at Maojiaping with capacity of 500,000 m^3/d ; (iii) a water transmission system, including a new 47.3 km ring main and a 30.2 km of transmission pipes from Maojiaping WTP to the ring main; (iv) central automatic control system; (v) strategic business plan for NWSC; and (vi) the Ningbo integrated water supply plan. The installed water supply capacity increased by 500,000 m^3/d. Nearly 90 percent of the city's population (2.8 million) now enjoys high-quality water, in contrast to 23 percent (1.2 million) in 2006. The new water source meets Chinese drinking water standards (see Annex 8, Table 1) for Class 1-II and has a reliability of about 97%.

Cixi Wastewater: (i) two WWTPs with a total treatment capacity of 150,000 m^3/d comprising the 100,000 m^3/d northern WWTP and the 50,000 m^3/d eastern WWTP; (ii) engineered wetlands to enhance final effluent quality of WWTPs to Class 1A standards; (iii) 280 km of main and link sewers, including 58 pumping stations; and (iv) management information system; institutional and organization plan, and (v) business plan and operating procedures. The target was met through the construction of two WWTPs with a combined capacity of 150,000 m^3/d, about 280 km of sewers and 58 pumping stations. The collection network now covers the urban areas in the administrative region of Cixi City and several townships. Capacity utilization at loan closure was 63.3% and is projected to increase as more township secondary, and tertiary sewers are completed in about three years.



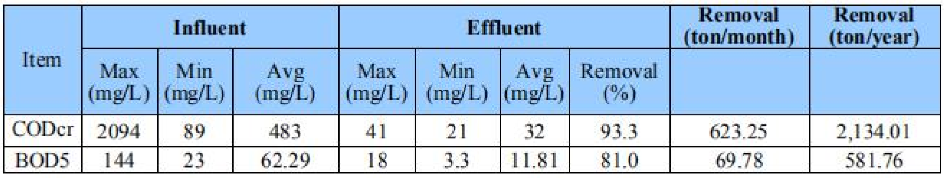
A comparison of outputs by component, at appraisal and end of project, are compared in the table below.

Output Description	At Appraisal	Actual Completed
Ningbo Water Supply		
Reservoir Intake (m^3/sec)	6.13	6.13
Raw Water Tunnel (km)	9.58	9.55
Treatment Plant (m^3/d)	500,000	500,000
Treated Water Transmission Mains (km)	18.9	27.6
Ring Main (km)	47.0	47.3
Cixi Wastewater		
Northern WWTP (m^3/d)	100,000	100,000
Western trunk Sewer System-(km)	77.0	104.6
Eastern WWTP (m^3/d)	50,000	50,000
Eastern Trunk Sewer System (km)	30.0	65.9
City and Town Link Sewers (km)	133.0	110.9

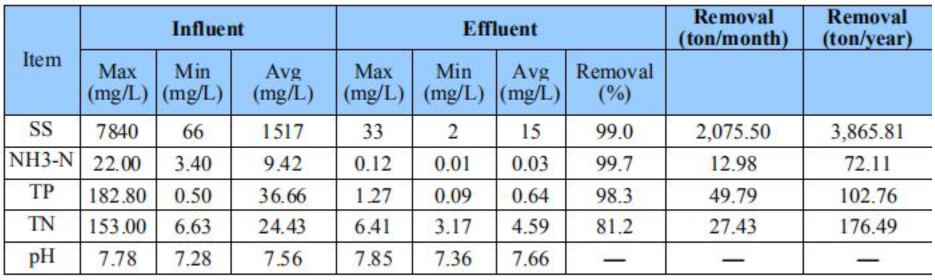
Output Description	At Appraisal	Actual Completed
Constructed Wetland (m^3/d)	Specifics not defined at appraisal	50,000

Treated Effluent Quality Achieved in North and East WWTPs (GB18918-2002). The following tables illustrate the concentrations of parameters that indicate the degree of pollutant removal. Table 4 indicates that the average effluent achieved meets class 1B and in some cases, even Class 1A discharge standards.

Table 4: Performance of North WWTP – October 2010

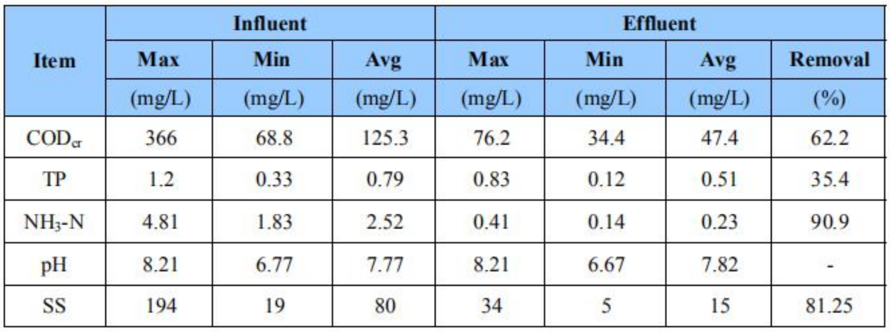


Item	Influent			Effluent				Removal (ton/month)	Removal (ton/year)
	Max (mg/L)	Min (mg/L)	Avg (mg/L)	Max (mg/L)	Min (mg/L)	Avg (mg/L)	Removal (%)		
CODcr	2094	89	483	41	21	32	93.3	623.25	2,134.01
BOD5	144	23	62.29	18	3.3	11.81	81.0	69.78	581.76

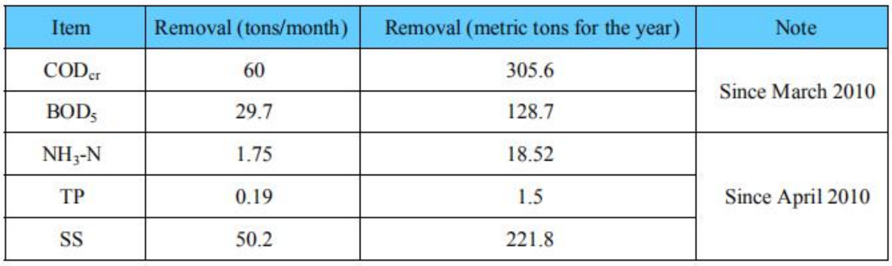


Item	Influent			Effluent				Removal (ton/month)	Removal (ton/year)
	Max (mg/L)	Min (mg/L)	Avg (mg/L)	Max (mg/L)	Min (mg/L)	Avg (mg/L)	Removal (%)		
SS	7840	66	1517	33	2	15	99.0	2,075.50	3,865.81
NH3-N	22.00	3.40	9.42	0.12	0.01	0.03	99.7	12.98	72.11
TP	182.80	0.50	36.66	1.27	0.09	0.64	98.3	49.79	102.76
TN	153.00	6.63	24.43	6.41	3.17	4.59	81.2	27.43	176.49
pH	7.78	7.28	7.56	7.85	7.36	7.66	—	—	—

Table 5: Performance of East WWTP – October 2010

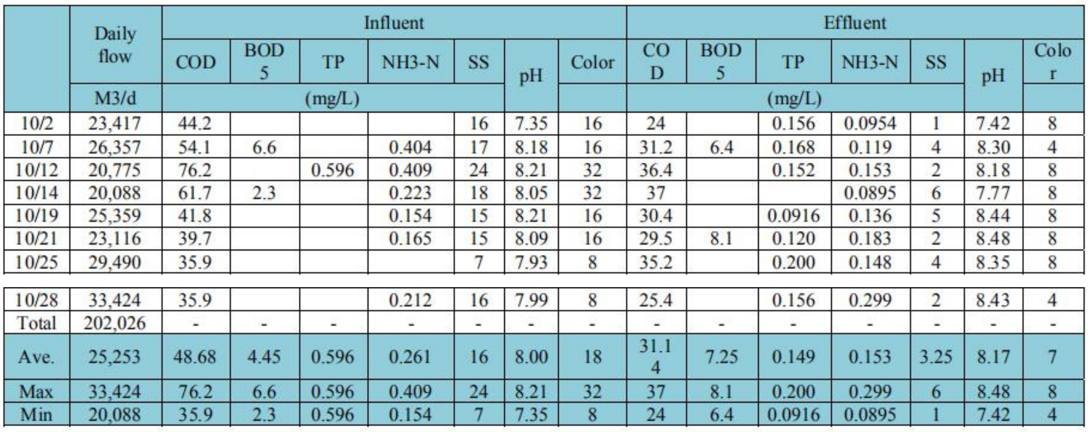


Item	Influent			Effluent			
	Max	Min	Avg	Max	Min	Avg	Removal
	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(%)
COD_{cr}	366	68.8	125.3	76.2	34.4	47.4	62.2
TP	1.2	0.33	0.79	0.83	0.12	0.51	35.4
NH_3-N	4.81	1.83	2.52	0.41	0.14	0.23	90.9
pH	8.21	6.77	7.77	8.21	6.67	7.82	-
SS	194	19	80	34	5	15	81.25



Item	Removal (tons/month)	Removal (metric tons for the year)	Note
COD_{cr}	60	305.6	Since March 2010
BOD_5	29.7	128.7	
NH_3-N	1.75	18.52	Since April 2010
TP	0.19	1.5	
SS	50.2	221.8	

Table 6: Performance of Constructed Wetlands in the Eastern WWTP – October 2010



	Daily flow	Influent							Effluent						
		COD	BOD 5	TP	NH3-N	SS	pH	Color	CO D	BOD 5	TP	NH3-N	SS	pH	Colo r
	M3/d	(mg/L)							(mg/L)						
10/2	23,417	44.2				16	7.35	16	24		0.156	0.0954	1	7.42	8
10/7	26,357	54.1	6.6		0.404	17	8.18	16	31.2	6.4	0.168	0.119	4	8.30	4
10/12	20,775	76.2		0.596	0.409	24	8.21	32	36.4		0.152	0.153	2	8.18	8
10/14	20,088	61.7	2.3		0.223	18	8.05	32	37			0.0895	6	7.77	8
10/19	25,359	41.8			0.154	15	8.21	16	30.4		0.0916	0.136	5	8.44	8
10/21	23,116	39.7			0.165	15	8.09	16	29.5	8.1	0.120	0.183	2	8.48	8
10/25	29,490	35.9				7	7.93	8	35.2		0.200	0.148	4	8.35	8
10/28	33,424	35.9			0.212	16	7.99	8	25.4		0.156	0.299	2	8.43	4
Total	202,026	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ave.	25,253	48.68	4.45	0.596	0.261	16	8.00	18	31.1 4	7.25	0.149	0.153	3.25	8.17	7
Max	33,424	76.2	6.6	0.596	0.409	24	8.21	32	37	8.1	0.200	0.299	6	8.48	8
Min	20,088	35.9	2.3	0.596	0.154	7	7.35	8	24	6.4	0.0916	0.0895	1	7.42	4

2.4.2 Economic Analysis

The development objective of the Ningbo Water Environment Project (NWEP) was to facilitate the expansion and quality of water and wastewater services in Ningbo City and Cixi City in an economically efficient and environmentally sustainable manner, thereby protecting public health, improving the environment, and supporting economic growth. There were no changes in the PDOs. With the successful construction and operation of Ningbo water supply and Cixi wastewater treatment facilities, as appraised, the project development objectives have been successfully achieved, although without the full benefit of the desired financial sustainability. Benefits accrued to residents, industrial, commercial and institutional organizations in

Ningbo and Cixi, in terms of a higher quality of water supply, protection of local water resources, and improved environmental conditions in the Hangzhou Bay. The key monitoring indicators associated with economic benefits were: (i) increase in the percentage of water supplied from high quality and reliable water sources and treatment plants in Ningbo City from 10% to 75%; and (ii) increase in the percentage of wastewater collected and treated in Cixi City from 10% to 65%.

Ningbo Water Supply Component. Ningbo water supply was greatly improved through this project. With high-quality raw water supply, the expanded water treatment capacity, NWSC provided high-quality water supply to all of Ningbo city and a large number of townships as well, thereby offering an essential element in protecting public health and living conditions. The percentage of residents with high-quality water supply increased from 1.2 million (23%) in 2006 to 2.5 million (almost 90%) at project completion, while the water supply capacity increased from 820,000 m^3/d to 1,300,000 m^3/d. The operation of the Bank-financed water supply system including Maojiaping WTP began in 2009 (instead of in 2008 as projected in PAD. The project component provided the incremental water consumption of 194,000 m^3/d in 2010. It is estimated that the incremental water consumption will reach 380,000 m^3/d from 2016 onward. With the completion of the new water supply network, which provides improved water quality and service reliability, the component also helped improve the quality of non-incremental water consumption. The volume of improved non-incremental water consumption due to the project was reported as 669,000 m^3/d in 2009 and is projected to reach 880,000 m^3/d in 2016 onwards.

Cixi Wastewater Treatment Component. The percentage of wastewater collected and treated in Cixi City increased from 10% to 65.43% for the one million residents, slightly above the project target of 65%. Cixi's economy grew by 102% throughout project implementation from 2005 to 2010. The average per capita GDP grew by 97% over the same period. Particularly noteworthy is the growth in tourism, which increased by 223% from 2005 to 2010. The net income per capita for urban and township residents increased by 62% and 84%, respectively, over the same period. With the completion of the Cixi wastewater component, the Cixi Municipality achieved a wastewater treatment capacity/coverage of 80% for the urban districts, 60% for the rural townships and 100% for industrial discharges located within industrial parks. This achievement will greatly reduce pollution loads discharged to the Hangzhou Bay.

2.5 Cost-benefits

The main beneficiaries of the water supply investments were the 1.2 million people of Ningbo City and the population in surrounding townships. The main beneficiaries of the wastewater investments in Cixi were about one million people in the urban areas of Cixi City and townships within the Cixi City administrative area.

(1)Advanced Technical Design. The adoption of the main ring concept for balancing water pressure throughout the system is an innovation worth replicating in other cities. Many water supply systems in developed cities, including London, rely on the main ring design for its efficiency and balancing pressures. Computer-Aided network design was adopted for Ningbo's trunk water supply network, which is also long overdue in China. Optimization software provides a modern tool for design of economically efficient distribution networks, which makes computations simple, and provides optimal pipe sizes to accommodate varying site conditions. This approach is a good example of efficiencies that can be achieved with the use of a large diameter ring main and can be replicated in other cities in China.

(2)Wetlands for Natural Treatment of Wastewater. With the increasing requirements for wastewater companies to provide Class 1A treatment standards, the potentially costly tertiary treatment is now imperative. Available data from other projects in China indicate that tertiary treatment would add about RMB 0.30/m^3 to the cost of treatment. The use of engineered wetlands provides a lower cost alternative to achieve the mandated discharge standard. The prevailing understanding of ‘wetlands’ is to provide large water surfaces with some plants along the edges, that may be aesthetically pleasing but have minimal treatment functions. However, properly designed wetlands are comprised of shallow water depth, adequate retention periods, and most importantly, the correct vegetation that will absorb the pollutants. The Ningbo Water and Environment Project has demonstrated the feasibility of using constructed wetlands for wastewater treatment at lower costs.

(3) Advantages of Regional Planning and Implementation. The prevailing practice in China is for each local government jurisdiction to construct its facility for water supply and wastewater treatment. This approach increases unit costs; requires the levy of higher tariffs; and does not realize economies of scale that could be achieved through regional planning, rationalization, and consolidation of services. The stated policy of Ningbo Municipality – to integrate the 25 water supply companies under NWSC – is a fine example for the rest of China. Municipal Government leadership and commitment are required to fully achieve this objective; NWSC by itself, had no power to make it happen because townships were generally unwilling to merge and give up their independence. Water sales agreements must be considered as an interim step, but they do not capture the full benefits that can be achieved. The upgrading of distribution networks in the townships is essential to reduce leakages in the network that increase with higher pressures available with the new supply.

(4) Effective Project Design. This project was successful and was completed on time without restructuring because its design was straight-forward and well within the capacity of the implementing agencies. The project involved only two geographical areas within the same municipality, and the two second-level borrowers (NWSC and

CMSC) had the strong technical capacity, particularly NWSC, and were well funded; and the design of the project was built around high priority policies and objectives.

(5) Utility Financial Performance Covenants. The project included financial performance covenants for both NWSC and CMSC, and compliance by the utility companies was possible only through the provision in the legal agreements for ‘non operating income’ (subsidies). Under prevailing practice in China, a higher priority is given to service quality over tariff increases, which are introduced over a longer period. In projects where this provision was not made, the implementing agencies remained in a state of noncompliance throughout the project period.

Chapter 3. Case Study III: use species and aquaculture to achieve the co-benefits of sustainable harvest and environmental performance in China

The present case study chapter takes Yuzhenzhou farmland in Longhai, Fujian as the research area as an example, which applies the established coastal wetland ecological restoration effect evaluation and evaluation method system to the practice of ecological restoration effectiveness evaluation. This chapter firstly outlines the background of Longhai ecological restoration, including the status of the aquaculture history, the ecological environment problems before the restoration, and then we will brief introduce the main engineering measurement implemented in the restoration activities, after that we will elaborate the detail results and service improvement after coastal wetland restoration. Based on the results and the benefits, we can put forward a brief cost-benefits measurement during the coastal wetland measurements, which will be adapted to the ecological restoration or coastal wetland management or protection in the future.

3.1 Background

With the decline of marine fishery resources and the continuous growth of human society's demand for aquatic products, the scale of marine aquaculture has expanded year by year, and the aquaculture area and density have exceeded the environmental carrying capacity (Hall et al., 1992; Holby and Hall, 1991). High population density, intensive agriculture, and industrial activities have led to a huge increase in nutrient inputs to coastal waters, which receive some the world’s highest riverine and atmospheric inputs of nutrients to the coastal ocean. Nutrient inputs to coastal waters are dominated by non-point sources, largely derived from excessive fertilizer application, while pointing sources, easier to control, represent less than 15% of nutrient inputs. Moreover, the nutrient inputs identified atmospheric deposition to the coastal ocean, supplying twice the nutrient inputs delivered by rivers. The consequences are widespread eutrophication, manifested in an increased frequency of harmful algal blooms and widespread hypoxia across coastal waters. Hence, nutrient pollution leading to coastal eutrophication is recognized as one of the most significant environmental problems, posing a great challenge to the coastal wetland. It has been confirmed that marine fish and shrimp farming is causing eutrophication of marine coastal waters，which were the most important sources of pollution. The annual losses caused by pollution in China's fisheries amount to billions of dollars, giving fishermen production declined (Cao et al., 2007). At the same time, due to the lack of scientific planning and unreasonable layout, various serious ecological and environmental problems have emerged(Qin et al., 2005).

In addition, due to the large discharge of industrial and domestic sewage, the coastal, estuary and inner bay had polluted to some extent. Such pollution accidents have increased sharply, and engineering construction projects have seriously damaged fish habitats. The ecological environment of the waters is suffering from serious pollution, such as the quality of the bottom is deteriorated, the environmental quality is deteriorating, the frequency and area of occurrence of red tides continue to expand, and natural fishery resources and aquaculture are threatened, causing the traditional fish and shrimp spawning grounds no longer exist.

The problem of breeding self-polluting is still outstanding. The main sources of pollution are cage culture, high-level pond culture, and factory farming. At present, cage culture is set up with traditional rows and rows of fishing rafts. The layout is unscientific, the water circulation is poor, the water exchange rate is low, and the bottom of the aquaculture waste is deposited. The high-level pool and the greenhouse are laid through the mulch and a large number. Microbial live bacterial preparations are used to regulate water quality. Although the amount of water exchange is reduced, the generated sewage still needs to be discharged from the central sewage system. The pond dredging is also a manual flushing method, which directly discharges sediment pollutants into the adjacent sea area; most of the feed used in factory fish farming is still chilled or frozen small fish, which destroys fishery resources and seriously pollutes the cultured waters. The breeding diseases frequently occur; the aquatic nursery farms are scattered, but most of them are individual or family-owned enterprises. The scale is small and the infrastructure construction is backward. The nursery wastewater is discharged without treatment. The impact of aquaculture production on the environment has become increasingly serious and has become an important factor restricting the sustainable development of marine aquaculture.

Aquaculture has been a fast-growing industry because of significant increases in demand for fish and seafood throughout the world. It is growing more rapidly than any other segment of the animal culture industry (Qin et al., 2005). China has a long history in aquaculture back to 2000 years ago. Since the 1970s, under the reform policies and driven by the economic benefits, the rapid development of China's aquaculture both in freshwaters and marine waters has been the focus of the world's attention. China is now the world's largest fishery nation in terms of total seafood production volume, a position it has maintained continuously after the 1990s. According to the Fishery Bureau, Chinese Ministry of Agriculture (MOA), the total production in 2005 amounted to 51.0 million metric tons, making up one-quarter of the world total (NaturalBureauofStatisticsofChina, 2005). Aquaculture contributes to 65% of the total fishery production, among which freshwater aquaculture is a major part. Without a doubt, China's aquaculture will continue to play an important role in the global supply of fish in the future (Cao et al., 2007).

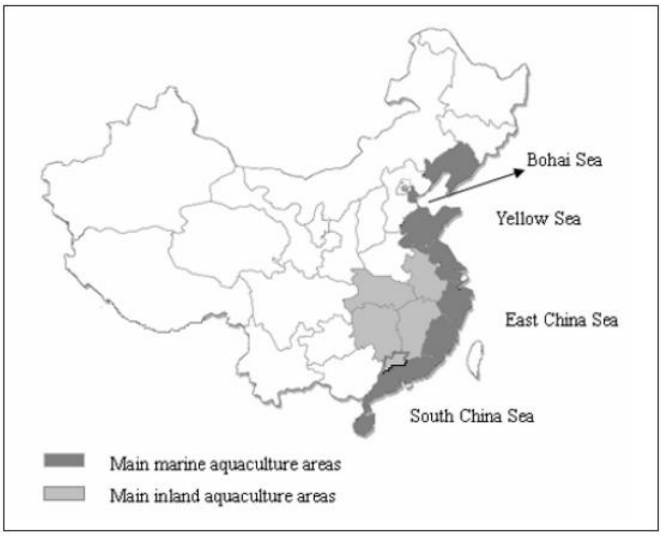


Figure 3.1 Illustration of aquaculture concentration areas in China (aquaculture pollution hot spots) (adapted from Cao et al., 2007)

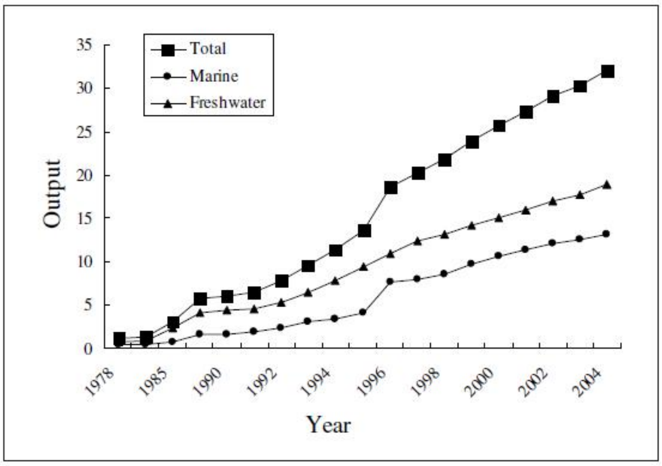


Fig. 2: China aquaculture production by year (unit: million metric tons)

Figure 3.2 China aquaculture production by year (unit: million metric tons) (adapted from Cao et al., 2007)

3.2 Project Description

The restoration area is located in the Dachengping Farm of Yujiaozhou, the estuary of Jiulong River in Longhai City, Fujian Province. Since Fujian province is adjacent to Taiwan, the aquatic technology and variety exchanges between the two places are frequent, Zhangzhou had become the aquaculture base area with the most varieties of the province, with the species can reach up to 156 and the annual economic output can reach up to the value of 6 billion RMB. The current output of four aquatic products such as abalone, grouper, oyster and blue crab ranks first in the country. The marine aquaculture area of Zhangzhou City is nearly 6 million mu. However, these aquaculture wastewaters are discharged directly into the sea without any treatment, bringing a lot of organic pollution to the Jiulong River. The area of mangroves in the Jiulong River estuary has dropped rapidly from 4,800 mu in the 1950s to less than 200 mu now. The massive loss of mangroves has reduced biodiversity, and the wetland ecosystem has become fragile, which limited the sustainable development of the Jiulong River (Fig. 3.3).

Figure 3.3 The location of the restoration area

The pollution problem of marine aquaculture environment has arisen the attention of scientists from all over the world, and its treatment methods are discussed from different angles. The single water treatment technology or several water treatment technologies are simply combined and no longer meet the needs of ecological restoration of a polluted environment, bio-ecology comprehensive management technology is a new technology developed rapidly in recent years at home and abroad. It has the advantages of ecological, green, high efficiency, no secondary pollution, and low cost. The project combines ecological farming, biological purification and recycling, and wetland ecological restoration technology to form an efficient composite purification system, and constructs an ecological restoration model of coastal wetlands under the influence of aquaculture wastewater integrated into the shallow sea, tidal flat and high-level pond culture.

The rational layout and optimal combination of marine aquaculture rely mainly on a variety of biological and ecological methods to use the organism's functions to eliminate pollutants or change the presence of pollutants to reduce their toxicity and restore or rebuild degraded ecosystems. To achieve the biological regulation of water quality and self-recovery of a polluted environment, the key technology is to screen plants that are salt-tolerant, anti-pollution and have efficient ecological restoration functions (large seaweed and tidal flat repair plants), animals (filter feeders and detritus food animals). In the restoration project, the wastewater from seawater industrialized culture was used for breeding *Perinereis aibuhitensis*, *Ruditapes philippinarum*, *Crassostrea gigas,* and *Gracilaria tenuistipitata*. Sewage resistance and absorption rate were preliminary discussions on the recycling of industrial aquaculture wastewater, to provide a scientific basis for the reuse of aquaculture wastewater and three-dimensional ecological breeding (Lin et al., 2009).

3.3 Implementation modalities

3.3.1 Screening of salt-tolerant and anti-fouling organisms with a comparison of various biological stain resistance

The test vessel is a 50 cm × 40 cm × 50 cm aquarium equipped with an aeration device, the light irradiance is about 3,000 to 5,000 lx, the seawater salinity is 20, and the seawater temperature is 20 to 23 °C. The stocking density of the double-toothed silkworm, the Philippine clam and the long oyster, the Philippine clam and the long oyster were 500/m^2, and the silkworm was 1000/m^2 (size 2.20g/ind). The sediment formed during the shrimp breeding process was mixed with 10% of the bottom of the sediment, and the wastewater discharged from the seedling was introduced to a depth of 40 cm. The result shows that the survival rate of the double-toothed silkworm is still 98% in the environment where the COD and the substrate organic matter content are 5.6 mg/L and 4.2%, respectively. The survival rates of the Philippine clam and the long oyster are respectively 76% and 46%, indicating that the stain resistance of the double-toothed silkworm is stronger than the other two shellfish.

The aquarium mentioned above was used to stock the fine-grained carp and the double-toothed silkworm, and the purification rate of the seedling wastewater was analyzed. The stocking density of the fine-grained carp was 500g/m^2, and the density of the double-toothed silkworm was also 1,000 m^2. Take water samples at 17:00 every afternoon to determine the chemical parameters such as nutrient salt and chemical oxygen demand, and drain the water to check the survival. At the same time, let the double-toothed silkworms dry for 1 hour, take the sediment to determine the organic content, and then the discharge water is returned to the original aquarium.

The recycling of aquaculture wastewater can not only reduce the pollution of itself and the offshore environment but also achieve energy conservation and emission reduction and waste resource utilization. It has obvious economic and ecological benefits, and develops marine recycling economy and promotes sustainable development of marine aquaculture. It has great practical significance. Shellfish are considered to be the preferred species in the treatment of aquaculture wastewater and pond polyculture, but have limited tolerance to pollutants and are also limited by the production season. Besides, pathogens and residual drugs may be enriched in shellfish. The hairy species are the most tolerant of the benthic organisms. Kaspar et al. (1985) surveyed a mussel farm in New Zealand and found that the polychaetes of benthic organisms were dominant (Kaspar et al., 1985). The silkworm is a genus of benthic polychaetes. The feeding principle is that a large number of swallowed sediments are obtained, from which organic matter is obtained to obtain energy and converted into self-protein. The polychaetes process the amount of sediment equivalent to at least the body weight (dry weight) through feeding activities. (Lopez and Levinton, 1987), the average feeding rate of sediments by Japanese silkworm was 5.71±2.76mg/(mg/d)(Wang and Zhang, 1998). The silkworm can be used as a bait for leisure fishery and good bait for economic fish and shrimp. Gyangze is a high-quality feed for agar and abalone. Therefore, the use of hairy silkworms and large algae for aquaculture wastewater treatment methods is simple and easy, and does not cause secondary pollution to the environment, and can also realize the recycling of aquaculture wastewater. It can be used for concentrated sedimentation of discharged wastewater in areas where industrial aquaculture is concentrated. An artificial wetland treatment system based on sandworms and large-scale economic algae are established, and silkworms and large-scale economic algae are cultivated in ponds to establish three-dimensional bioremediation of different niches mode.

3.3.2 Ecological farming model construction

The principle of multi-eco-aquaculture is mainly based on ecological theory such as ecological balance, species symbiosis and multi-level utilization of materials, and a production form in which a variety of mutually beneficial breeding species are integrated into the same pond for breeding. Appropriate aquaculture objects in each niche and trophic level correspond to each other, which can enhance the spatial structure and hierarchy of aquaculture bio-communities, optimize ecological structure, and enhance biodiversity; The food chains of the grades are connected to each other, which can make full use of various natural bait resources or artificial feeds in the aquaculture water body, thereby improving the utilization efficiency of materials and energy, thereby making up for the simple disadvantages of the single cultured food web; At the same time, the animal's metabolites are decomposed by bacteria and absorbed by photosynthetic organisms, which not only improves the primary productivity, but also promotes the self-purification of the water environment, prevents self-contamination, and is conducive to improving the growth rate and disease resistance of the cultured organisms; The components maintain a relative dynamic balance between energy and material metabolism through mutual restraint, transformation, feedback, and other mechanisms, and have strong self-regulation ability and ability to resist external interference. In this way, the ecosystem can be kept stable without a lot of water production measures, such as semi-enclosed or fully enclosed farming, which can block the exchange of water between the pond and the offshore waters, protect the coastal ecosystem environment, and prevent the introduction of disease sources in the sea area. Controlling the large-scale occurrence and rapid spread of epidemic diseases is of positive significance.

From the ecological principle of polyculture, it can be seen that through the different kinds of polyculture, it can not only improve the water quality but also significantly improve the material utilization rate of the ecosystem. Therefore, polyculture can be used as a bioremediation technology to repair the aquaculture environment. A variety of biological combined repair systems have greater performance ratios, better stability, and higher efficiency in terms of energy and resource utilization compared to single biological restoration systems, enabling aquaculture and pollution control, farming and planting. Reciprocal and aquaculture species are diversified, and a whole aquaculture ecological structure with a large number of biological populations, a sound food chain structure, a fast energy flow and a fast circulation of logistics is established, and the aquaculture ecological structure is integrated, so that aquaculture develops from a single type to an ecological type.

The aquaculture water body is a small-scale ecosystem. Its structure and function are relatively perfect. From the ecological point of view, ecological principles should be used to solve the water pollution problem of the aquaculture ecosystem, and ecological compensation and environmental compensation technology should be used to repair and improve the aquatic ecosystem. Structure and function, gradually adjust and transform in the cultured species, pond structure, water intake and drainage system, appropriate increase of herbivorous, rot-eaten fish and autotrophic large-scale economic seaweed, using the metabolic complementarity between cultured organisms Consumption of harmful metabolites, reducing the nutrient load of water bodies, forming a good ecological environment, in order to make full use of the production potential of aquaculture waters, and improve the economic and ecological benefits of aquaculture. Based on the experiments in 2008, this study explored the multi-dimensional ecological farming model of the pond in Dacheng Farm, Haicheng Town, Longhai City, Fujian Province, and applied the research on the ecological breeding of the shrimp and pond in the pond. R & D pond transformation process and supporting breeding facilities, rational allocation of main cultured species and cultivars, construction of ecologically complementary *Litopenaeus vannamei*, *Sparus latus*, *Mugil cephalus*, glandular thorn Ecological farming model of *Neonthes glandicincta* and *Gracilaria tenuistipitata* (Lin et al., 2011).

3.3.3 Water quality regulation

Ecological floating beds or ecological floating islands plant aquatic plants can remove nitrogen, phosphorus and other pollutants from polluted water bodies, inhibit excessive algae growth in water bodies, purify water quality and inhibit red tides, and also beautify water bodies and landscapes. However, some ecological floating beds currently use high-molecular polymer materials. Although they are convenient to use, they are difficult to promote and apply in large areas because of the high cost. Some ecological floating beds use foam plastics, although the cost is low, it may cause secondary pollution. Therefore, an ecological floating bed with convenient materials, economical and practical, and no secondary pollution is prepared. According to the needs of seawater pond culture, the soil-free ecological saline bed is used to soil the salt-tolerant plants, and the pollutants generated during the breeding process are stabilized. The ecological environment of the pond is of great significance. Establish a water-saving plant double-spotted locust ecological floating bed in a marine aquaculture pond to absorb the inorganic nutrient salt produced during the breeding process, improve the pond ecological environment, inhibit the eutrophication and red tide of the aquaculture water, and provide clean and comfortable habitat and shelter for the growth of the fish and shrimp.

Figure 3.4 Ecological floating beds used in the aquaculture restoration

The pollutants produced by the aquaculture industry mainly include three types: organic matter such as residual baits and feces, nutrient salts such as nitrogen and phosphorus, pesticides for clearing ponds and disinfection, and drugs for controlling water-borne diseases. These pollutants enter the water body in the form of dissolving, suspending or precipitating, which deteriorates the water quality of the local aquaculture waters, causes eutrophication, inhibits the growth of the cultured organisms, and even morbidity and death. The proportion of pollutant sources in the breeding process is: excess bait accounts for 35%, excreta accounts for 50%, domestic garbage accounts for 5%, and other pollutants account for 10%, that is, 85% of pollutants in the breeding process come from the breeding itself. For each 1t fish cultured in sea cage culture, the nitrogen and phosphorus loads discharged into the environment are 161 kg and 32 kg respectively. Funge et al. (1998) studied the material balance in intensive shrimp ponds and found that only 10% of nitrogen and 7% of phosphorus were used in the culture process, and others entered the environment in various forms (Funge-Smith and Briggs, 1998). Therefore, the pollution generated by the aquaculture process can be ecologically restored and recycled, and energy conservation and emission reduction and waste resource recycling can not only reduce the pollution to the offshore environment, but also have obvious economic and ecological benefits, and develop the marine recycling economy and promoting the sustainable development of marine aquaculture has great practical significance.

The multi-culture mode refers to a culture area with different functions. The materials and energy (bait) in the system are circulated with water in different culture areas so that they can be used by various culture objects at different trophic levels and niches. A certain proportion of the area is planned in the shrimp culture area, and the filter-feeding shellfish is stocked in February-March, and the optimized combination of shrimp and alfalfa is implemented. The suitable temperature range of strontium is 8-30 °C, the optimum temperature is 15-20 °C, and the specific gravity of seawater is 1.005-1.020. The feeding habit is single-cell algae and organic debris in seawater, which has no strict selectivity to food. As long as the particle size is appropriate. In this way, the wastewater discharged from the shrimp culture flows through the shellfish culture area, and the organic waste and microalgae in the culture discharge water can be used as bait to realize the reuse of the culture waste (Fig. 3.3).

Figure 3.5 The multi-culture mode

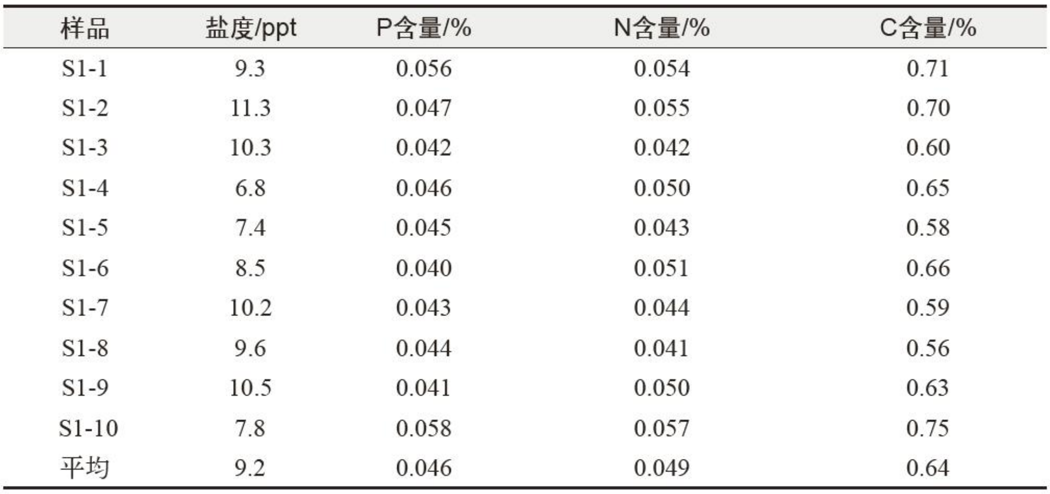
The aquaculture pond should have a circular ditch and a certain area of the central beach. The ring groove is about 1 m deep and not less than 2 m wide. The wide annular groove has a buffering effect on the influent water and can protect the stability of the central beach ridge. The central beach has to be turned flat beforehand and divided into several rafts, namely ridges. The width of the raft is 3 to 5 m, and the length of the raft is determined by the length of the beach surface, generally 10 to 20 m, which is advantageous for management. The gap is 0.3 to 0.4 m, and the depth is about 0.5 m. The area of aquaculture pond is controlled at about 1/5 of the whole pond area. The seedlings are selected to be larger and higher quality seedlings. The seedlings are clean and uniform, and the size is uniform. At present, more than 1cm seedlings are selected, more than 12,000 per kilogram, or 1.5cm size, about 5,000 seeds per kilogram is more appropriate. The stocking density is 200,000 to 300,000 per mu, which is almost half the density of stocking. The seedlings with a specification of 12,000 pieces/kg are raised from 16 to 26 kg per mu; the specifications are about 5,000 pieces/kg, and 40 to 60 kg per mu. Because the tidal flat is affected by the tidal movement, there are two dry dews in one day, so that the cockroaches cannot get the food all day, almost half of the time to rest in the cave, no food, affecting the growth, thus extending the breeding cycle, affecting the output. Nowadays, the seedlings are transplanted into shrimp ponds or ponds for water storage, so that they can obtain bait 24 hours a day, thus accelerating growth, shortening the breeding cycle, and correspondingly increasing the yield and quality.

In addition, in November, the earthen ponds of the cockroaches can be artificially cultivated, and the phytoplankton and organic granules in the water discharged from the nearby prawn ponds are used as bait. The earthen pond is rectangular, and the pool seat is long to the east and west, and short to the north and south to prevent larvae from accumulating in the southeast wind or the northeast wind. This method is simple in equipment and low in cost and is a method for raising seedlings.

3.3.4 Ecological restoration technology for aquaculture pollution

***Restoration of shrimp pond bottom environment*:** The rapid development of the aquaculture industry has led to the growing problem of pollution of residual bait and excrement and enrichment of sediment pollution. Due to the high salt content of the aquaculture wastewater, effective wastewater treatment measurement have been lacking so far, resulting in a deterioration of the water environment, disease prevalence and yield of the culture area. Therefore, screening plant resources that are resistant to salt and alkali and efficiently degrading pollutants has become a key factor for effectively controlling coastal wetland pollution in aquaculture areas. *Tetiagonia expanpa Murr*, commonly known as New Zealand spinach, is an annual half-small succulent herb of the genus Apricot. It is an evolutionary species of common spinach, native to Australia, New Zealand, Chile, and Southeast Asia. China has a long history of large-scale cultivation and cultivation. It has only been introduced from Europe in recent years, and it is now being promoted in parts of North China. Apricot has high nutritional value, rich in minerals, vitamins, and amino acids, especially rich in folic acid. It contains 2.29 g of protein, 2.06 g of cellulose, 46.4 mg of vitamin C and 10.4 mg of vitamin B per 100 g edible part. The apricot has strong adaptability, heat resistance, and cold resistance. It can withstand the low temperature of 2~3°C in a short time. The seeds can germinate in the range of 8 ～ 30°C. The germination temperature is 25～28°C, and the seedling growth is moderate. It is 20 to 25 ° C. The vegetable grows fertile sand or sandy loam, is salt-tolerant, suitable for various soil cultivation, and has a long growing period. It is a multi-harvest vegetable, and the yield of vegetables can reach 4.5-7.5 kg/hm^2, which is a high yield. Efficient and easy to manage vegetables with good economic benefits and market development potential. A large amount of organic matter was deposited in the sediment of the shrimp pond. The phosphorus content was 0.046%, the nitrogen content was 0.049%, and the organic carbon content was 0.64%. However, the salinity was as high as 9.2 ppt.

Table 3.1 Element analysis for the pond sediment.



样品	盐度/ppt	P含量/%	N含量/%	C含量/%
S1-1	9.3	0.056	0.054	0.71
S1-2	11.3	0.047	0.055	0.70
S1-3	10.3	0.042	0.042	0.60
S1-4	6.8	0.046	0.050	0.65
S1-5	7.4	0.045	0.043	0.58
S1-6	8.5	0.040	0.051	0.66
S1-7	10.2	0.043	0.044	0.59
S1-8	9.6	0.044	0.041	0.56
S1-9	10.5	0.041	0.050	0.63
S1-10	7.8	0.058	0.057	0.75
平均	9.2	0.046	0.049	0.64

Figure 3.6 the restoration activity for the aquaculture pond by spinach plantation

In this restoration, the cultivation techniques of salt-tolerant plant resources and anti-fouling ability were screened in coastal wetlands in aquaculture areas, and the cultivation techniques for planting apricots in winter-vacuum shrimp ponds were developed. The apricot fruit has a horny shape and a light brown color. The single fruit weighs about 67g. Each fruit contains 6-10 seeds. The seeds are dark brown and have a ribbed surface. The apex of the rib has a fine thorn. The 1000-grain weight is 80-100g. The shrimp pond in southern China has been completed in November, and the shrimp pond can be drained, and the soil is turned over 30-35 cm deep, and the sputum is fine and smooth. The width of the kneading surface is 1 to 1.2 m wide, 5 cm high, and 30 cm wide, which is convenient for management and irrigation. First, soak the apricot seeds in warm water at 45 ° C for one hour, pay attention to keep the water temperature, then wrap it with wet gauze and place it under 25 to 28 ° C to moisturize and germination.

When 80% of the seeds are swelled and swelled, they can be sown. Before sowing, the seedbed should be poured with water, and after sowing, cover the soil with a thickness of about 1 cm. Due to the high temperature in autumn and winter in the southern region, it is not necessary to cover the plastic film in the north, and the sediments at the bottom of the shrimp pond are rich in organic matter, and no fertilization is required. It takes about one week from seed to sprouting. When the seedlings have 5 to 6 true leaves, 1 to 2 strong seedlings are retained in each hole, and the density is generally 50 cm, and the plant spacing is 40 cm. Due to the strong germination ability of the lateral branches of the plant, the growth is strong when the fertilizer is sufficient, and the germination is more after harvesting the young shoots. When the plants grow to a height of 20 to 30 cm, they can be harvested with tender tips, and the lateral branches can grow for 10 to 15 days. When harvesting, the flower buds should be removed, and the weak branches should be cut off, and the strong new branches should be preserved to ensure the vegetative growth, the plants are thick, and the leaves are young and fat. It can be seen that the apricot can absorb the organic matter deposited in the sediment, thereby improving the bottom quality of the shrimp pond, reducing the manpower and material resources of the mud and the pollution of the adjacent sea area, and increasing the additional economic income of the farmers.

Ecological restoration of coastal wetlands in aquaculture areas: A good ecological environment in aquaculture waters is a prerequisite for the survival and development of aquaculture. Improper production activities will inevitably lead to environmental degradation, disease ravages, proliferation and increased mortality of cultured organisms, and decreased production. Therefore, we must rationally plan the breeding area and scale, vigorously develop clean production, block its sources of pollution, control it from the source, and establish measures such as vegetation buffers along the coast to implement land and sea management and management of aquaculture pollution. Biological treatment is an important trend in the current aquaculture pollution control. Because of its low cost and low energy consumption, it does not cause secondary pollution to the environment. It is suitable for various variable water conditions and is a promising future. "Green" marine aquaculture pollution control technology. According to the source, distribution, and transportation mechanism of aquaculture pollution, explore the optimal combination of planting and spatial allocation techniques, plant mangroves, shoal culture shoals, shallow sea hoisting tendon tendons and large seaweeds in coastal wetlands in the aquaculture area, and establish sea and land pooling and breeding. In the present project, the detail measurement included the following aspects.

1) Mangroves plantation: Coastal vegetation not only protects the wind from sand, protects the coast, but also purifies the seawater, eliminates pollution, and maintains the ecological balance of the system. Mangroves are woody plants that grow in the intertidal zone of tropical and subtropical coasts. There are abundant species in the mangrove growth area, providing habitat, feeding and breeding ground for about 2,000 species of fish, invertebrates, and epiphytes. The mangrove has a strong ability to absorb nitrogen, which can weaken the eutrophication caused by over-culture of fish and shrimp and play a biological purification role. Also, mangrove plants can absorb heavy metal elements from the soil and concentrate in the plants to avoid the recycling of these heavy metal elements into the food chain, reducing the degree of water and metal pollution of the water, thereby reducing pollution and purifying the environment. The total amount of N, P, K, Na, Ca, and Mg absorbed by the canola community per hectare per year in Fujian Province is 248.9 kg, which are 46.8, 5.6, 26.6, 105.0, 38.6, and 26.3 kg, respectively (Lin, 1989). Hainan Island Dongzhai Port Sea mulberry and Kandelia mixed plantation, only the aboveground part of the annual absorption of 10 elements per hectare from forest land and seawater (N, P, K, Ca, Mg, Mn, Zn, Cu, B, S) The total amount is 555.1 kg (Liao et al., 1999). The Jiulong River

Estuary in Longhai City, Yinzhou City, is a mangrove provincial nature reserve, and the area of the dominant species “Kumquat” accounts for 90% of the existing forest area. In April-May, the mature hypocotyls that are falling near are used, and they are directly entangled after soaking for 1 hour in seawater. The depth is 1/3 to 1/2 of the length of the hypocotyl, and the plant line is generally 0.5 m. Planting mangroves in the coastal wetlands of the aquaculture area, strengthening the role of plants in the ecosystem, and constructing a system of seawater planting and breeding recycling, not only increasing the biodiversity of the waters and enhancing the self-purification of the water bodies, but also taking into account the effects of wetland landscapes and the invasive alien species. The biological control of rice grass, the realization of the natural maintenance of water bodies and landscape construction.

Figure 3.7 The mangroves planted in the restoration area from aquaculture pond.

2) Convex hull aquaculture: The shellfish filter system is very developed, with a very high water filtration rate, and the amount and composition of suspended particulate organic matter in water bodies by large-scale shellfish culture activities through the filtration and ingestion of phytoplankton and particulate organic debris in water bodies. There is a certain degree of control (Dong et al., 1999; Nakamura and Kerciku, 2000; Prins et al., 1995). Ding et al. studied the purification ability of alfalfa on aquaculture water. The results showed that alfalfa had certain purification ability for DO, COD and ammonia nitrogen in aquaculture water. After 96 h purification, the pH value of polluted seawater increased by 7.79. %, DO value increased by 47.25%, while COD value decreased by 23.60%, and ammonia nitrogen decreased by 15.94%

(Ding and Xu, 2006).

Musculu senhousia is a warm-temperate and widely distributed shellfish, which often inhabits the bottom of the muddy strait in the estuary and the intertidal zone to the subtidal zone. Its vertical distribution generally ranges from the middle and lower zones of the intertidal zone to the shallow seabed of about 20 m in the subtidal zone. The breeding season is from the end of May to the middle of October, and the breeding season is from July to September. Generally, the fertilized egg needs to develop for about 20 days in the condition of water temperature of 19.8-25 ° C and a specific gravity of 1.018 21 to 1.024 0. Although the shellfish is small in size, it has a wide distribution, large yield, and the shell is extremely thin, the meat is plump, the taste is delicious, and the nutrition is rich. It is a relatively important small economic shellfish. The culture method is suspended by a floating table. The cylindrical floating raft made of granular foamed polyethylene is 0.5m in diameter and 0.6m in length. The function of the pontoon is to provide buoyancy so that the floating raft can be lifted and lowered with the tide. The polyethylene rope is pulled into a rope frame and fixed with bamboo, and the thick rope is used as the attachment base of the convex tendon. The length of the rope is 1.5 to 2.0 m. Of course, the number of strands of the rope is large, and the surface roughness is favorable for the adhesion of the convex tendon. The breeding area is located in the salty and fresh water junction area of the Jiulong River estuary. It is very suitable for the growth and reproduction of this kind of shellfish. It is used to filter the particulate organic matter in the cultured discharge water, and then as a high-quality natural bait for shrimp and crab to realize the recycling and recycling of wastewater.

3) Large seaweed plantation: Large-scale algae as a biological filtration technology was developed in the 1970s. They have a niche complementarity with farmed animals. They can absorb the excess nutrients released by the cultured animals into the water, generate oxygen, and regulate the pH of the water. Achieve bioremediation and ecological regulation of the culture environment. Swedish scientists Haglund, Pedersen and Chilean scientist Troell have reduced the concentrations of N and P in cultured waters by using the waste produced in the fish farming process as a nutrient source for algae growth. Studies have shown that the 1ha sea area can produce 258 t of *G. glabrata* per year, and 1 020 kg of nitrogen and 374 kg of phosphorus can be removed through the harvest of *G. sinensis* (Haglund and Pedersén, 1993; Troell et al., 1997). Therefore, large-scale cultivation of seaweed can not only effectively reduce the concentration of nutrients such as N and P, but also constitute the basis of the primary productivity of waters through the photosynthetic carbon fixation of large seaweeds, and plays an important role in the carbon cycle of aquatic ecosystems.

3.4 Results and service improve and cost-benefit analysis

The traditional shrimp culture in Dachengping Farm is dominated by a single species. In this project, the ecologically complementary glandular thorns, the prawn, the carp, the yellowfin, and the fine carp are cultured in the same pool. Carnivorous fish can remove sick shrimps in time and optimize the shrimp population, thus effectively controlling disease transmission and reducing the production cost of using probiotics. The fine base Jiangyan not only plays a role in purifying water quality but also provides a clean and comfortable habitat and shelter for the molting and growth of shrimp. It also provides a protective barrier for the silkworm to avoid the feeding of shrimp and fish and creates and maintains good growth of shrimp surroundings. The omnivorous and filter-feeding squid can effectively utilize plankton in the pool, inhibit the overgrowth of large algae such as *Prorocentrum* spp. And maintain the algal phase of beneficial algae. The glandular silkworm can ingest excess residue and organic matter in the substrate to improve the ecological environment of the shrimp and reduce water pollution. At the same time, it is converted into its protein, which is used as a high-quality natural bait for shrimp, which enhances the disease resistance of shrimp and reduces the cost of bait. The breeding model was extended to 500 mu in Dachengping Farm, Yukangzhou, Longhai City, Zhangzhou City, and achieved obvious economic benefits. The cultured aquatic products reached the quality standard of pollution-free products, and the comprehensive aquaculture production value increased by more than 20%.

3.4.1 Comparison of ecological benefits

As the breeding time prolongs, the mineralization and decomposition of organic matter in the sediments gradually increase the nutrients produced by the bio-metabolism. The ammonia nitrogen content of the experimental pool was 0.077mg/L, the range was 0.026～0.126mg/L, the ammonia nitrogen content of the control pool was 0.159mg/L, the range was 0.067～0.320mg/L, and the experimental pool was 51.57% lower than the control pool. The total nitrogen content in the experimental pool was 1.399mg/L, the range was 0.271~2.725mg/L, and the total nitrogen content in the control pool was 2.048mg/L, the range was 0.280～3.926mg/L. The experimental pool was compared with the control pool. The average active phosphate content in the experimental pool is 0.017 mg / L, the variation range is 0.009 ~ 0.027 mg / L, the active phosphate content in the control pool is 0.030 mg / L on average, the range is 0.016 ~ 0.056 mg / L, The experimental pool is 43.33% lower than the control pool. The various nutrient content of the experimental pool is significantly reduced, and the nutrient salt of the nested pond is absorbed in large quantities and is removed from the aquaculture water by mining.

As the breeding time prolonged, a large amount of organic matter such as residual baits and metabolites were deposited at the bottom of the pond or suspended in water. The COD value in the pond gradually increased, but the experimental pool increased slowly. The COD value of the experimental pool was 3.72 mg/L on average, ranging from 1.06 to 6.24 mg/L, and the COD value of the control pool was 4.41 mg/L on average, ranging from 0.86 to 7.22 mg/L. The experimental pool was 15.65% lower than the control pool. The difference between the two was significant ($P<0.01$), which was related to the feeding of sedimentary organic matter at the bottom of the pool. The silkworm can feed excess residue, and particulate organic matter deposited in the substrate and convert it into its protein. At the same time, the silkworms living in the burrowing area increased the dissolved oxygen at the bottom of the pool due to the continuous stroke of the bristles and promoted the oxidation of organic matter and the release of inorganic salts in the sediment.

3.4.2 Comparison of economic benefits

Because the water quality of the experimental pool is relatively stable, the silkworm can provide high-quality natural bait. The disease resistance of the shrimp is enhanced, the growth rate is fast, and the survival rate is high (74.7%). The water exchange in the control pool causes the culture environment to change drastically, resulting in shrimp production. Stress response, some weak shrimps die hard and die; the survival rate is low (72.2%). It can be seen from Table 7.2 that the growth of shrimp in the pre-culture experimental pool and the control pond is not much different, but the length and body quality of the shrimp in the experimental pool in the middle and late stages are significantly better than those in the control pool, and the individual differences of the shrimp are small.

The multi-ecological polyculture of ponds is to mix a variety of economic animals and plants with complementary niches in a reasonable proportion with the pool. Due to the complementarity of space and diet in various polyculture organisms and the coupling in energy and material circulation. The utilization efficiency of the bait is improved, thereby reducing the breeding cost and improving the comprehensive economic benefit of the pond. The silkworm and *G. sinensis* screened in this study can not only purify the water quality of the shrimp pond but also serve as a natural, high-quality bait for shrimp and fish. At the same time, Jiangyan increased the dissolved oxygen content of water by photosynthesis, stabilized the ecological environment of the pond, reduced the use of water quality improvers and aerators in the aquaculture process, reduced the cost of breeding, and gained additional economic benefits from harvesting. As can be seen from Table 7.3, although the yield of shrimp and fish in the experimental pool is not much different from that of the control pool, the feed coefficient (calculated by the increased quality of shrimp and fish) and the ratio of input to output (by annual statistics) are significantly lower in the control pool.

3.4.3 Summary and prospect

The sustainable development of marine aquaculture is facing major ecological and technical problems. At present, in the research of bioremediation of aquaculture water, the ecological structure and function of the whole water environment are not deep enough, especially the application of ecological principles to study biology. The repair has yet to be strengthened. Furthermore, for aquaculture water bodies with more serious pollution or combined pollution, single bioremediation technology is often difficult to achieve the desired effect, and different bioremediation technologies can be effectively combined to form a joint bioremediation technology to achieve the purpose of degrading and removing pollutants more effectively. Only by making reasonable planning before breeding, scientific management during breeding, rational management after breeding, and standardizing the marine aquaculture industry, implementing energy-saving, environmentally-friendly and efficient production methods can ensure the sustainable development of marine aquaculture.

In the future, when we focused on the ecological restoration on the aquaculture pond, two things should be focused. First, we must change the farming methods and vigorously develop carbon sink fisheries. It is necessary to innovate traditional farming methods and technologies, promote the concept of low-carbon farming, and vigorously promote clean and environmentally friendly production methods. According to the reasonable layout of the culture capacity and the control of the density of the culture, the breeding area and scale should be rationally planned to adapt the development of the aquaculture industry to the environmental carrying capacity; promote standardized ponds and multi-ecological farming, optimize the culture structure from the perspective of ecological farming, and implement varieties. Reasonable matching and complementary advantages, an appropriate increase of shellfish and large-scale economic seaweed culture, while speeding up the development of anti-wind cages, and vigorously promote deep-water and floating cage culture; carbon sink fishery is a new concept of a fishery development strategy that is emerging recently and is expected to become seawater. The new growth point of the aquaculture industry and the driving force of a new round of development are of great significance and great industrial potential for the development of a low-carbon economy. The 21st century is a new era in the world of large-scale development and utilization of marine resources, expansion of the marine industry, and development of the marine economy. As a major maritime country, China should actively develop carbon sink fisheries with marine aquaculture as the mainstay and seize the technological highlands of the blue low-carbon economy. Second, we must adhere to the concept of sea and land pooling and circular economy, and develop sustainable aquaculture. Afforestation pollution control must proceed from the perspective of sea and land pooling, change the farming mode, and control it from the source, which can achieve twice the result with half the effort. Relying on various biological and ecological methods, implementing multi-eco-aquaculture and multi-level comprehensive management measures, organic combination of biological purification of aquaculture wastewater, three-dimensional ecological farming of ponds, and ecological restoration of adjacent waters will become an efficient purification system and establish a biological population. More, the food chain structure is sound, the overall ecological structure of energy flow and logistics circulation is faster, the aquaculture ecological structure is integrated, and the aquaculture is developed from a single type to an ecological type. The combination of aquaculture and pollution control, breeding and planting reciprocal, and breeding species diversification measures to achieve the recycling and recycling of aquaculture waste.

Chapter 4. Case Study IV: Nutrient bio-extraction in coastal areas of China through restoration

The present case study chapter takes Yellow River Delta as the research area as an example, which applies the established coastal wetland ecological restoration effect evaluation and evaluation method system to the practice of ecological restoration effectiveness evaluation. This chapter firstly outlines the background of the Yellow River Delta ecological restoration, including the historical changes of Yellow River Delta, the ecological environment problems before the restoration, and then we will brief introduce the main engineering measurement implemented in the restoration activities, after that we will elaborate the detail results and service improvement after coastal wetland restoration. Based on the results and the benefits, we can put forward a brief cost-benefits measurement during the coastal wetland measurements, which will be adapted to the ecological restoration or coastal wetland management or protection in the future.

4.1 Background

Yellow River Delta Wetland is the youngest coastal wetland ecosystem in China, which formed by the continuous oscillating movement of the Yellow River Delta. It is an important transit station and wintering habitat for the migration of birds in the inland and East Asia-Australia. It is located between the land and the sea, and the storm surges or land salinization was common here. The salinized land area of the whole area is about 44.29×10^4 hm^2, accounting for more than half of the total area. Among them, the area with heavily salinized soil and the saline-alkali are 23.63×10^4 hm^2, accounting for 28.4% of the land area. The salt content in this area was generally above 0.4%, with the most highly saline-alkali can reach up to 2-3%. The average salt content from 0-100 cm is 0.58%. The composition is mainly chloride, accounting for more than 80% of the soluble salt solution, the groundwater depth is generally 2-3 m, the groundwater salinity is 10-40 g/L, and some are as high as 200 g/L.

The wide distribution of primary salinized soil in the region of Yellow River Delta was determined by the sedimentary environment, climatic conditions and soil parent material, accompanied by the shortage of freshwater resources and the rapid development of coastal economy, resulting in the intensification of coastal wetland fragmentation. The salinization soils in the Yellow River Delta account for more than 50% of the total area, which was the most important factor of the bare mudflat (Guan et al., 2001). The regional ecological environment is deteriorating and seriously threatening, and the ecological reconstruction of coastal saline soils had been widely concerned by ecologists.

The soil parent material of the Yellow River Delta is the Yellow River alluvial deposit, and the bottom is made up by marine sediment, which is mainly composed of fluvo-aquic soil and saline soil. In general, the salinization situation is gradually increasing from high elevation to low elevation. From the perspective of micro-geomorphology, the edge of depression and the local elevation of the low-lying land can easily accumulate salt due to the evaporation. Liu (2006) and other studies have shown that the soil salinization degree in the modern Yellow River Delta is serious, and the whole belongs to the type of coastal chloride-type saline soil, the organic matter is relatively lacking, and the soil is alkaline. With the increase of soil depth, the degree of salinization is gradually reduced; there are differences in soil salinization characteristics among different geomorphological area (Liu et al., 2006).

There are two vegetation succession of wetland in the Yellow River Delta: one is the pathway from the bare tidal flat to the succession of the halophyte community; the other is the succession from the secondary bare land to the desalination of the reed community. Coastal wetland vegetation is natural shrub vegetation and salty coastal vegetation, and its distribution is affected by habitats. The vast tidal flats with low terrain and affected by the tides have high salinity in the soil, mainly distributed with salt-tolerant plants such as 1-year-old herbaceous *Suaeda* and perennial *Tamarix*. From the tidal flat to the inland, the salt-to-salt is gradually increasing, and at the same time, in the place where there is a provenance of *Tamarix chinensis*, it gradually develops into a shrub-dominated by *Tamarix chinensis*. With the increase of the terrain, when the altitude is above 3 m, the salt content on the surface is reduced, forming a 1-year or perennial meadow vegetation with certain salt-tolerant characteristics. The plant community is simple in composition and few in the group.

4.2 Project description

The study area is located in the degraded saline area of the coastal wetland of the Yellow River estuary. The geographical coordinates of the center are (38°16'N, 118°18'E), which belongs to the warm temperate monsoon continental climate. The average annual precipitation of the Yellow River Delta is 537.4 mm, and the average annual evaporation is 1885.0 mm, the annual steaming ratio is about 3.5:1. Affected by the monsoon climate, rainfall is concentrated in the flood season from June to September, accounting for about 75.5% of the annual rainfall. The overall terrain of the Yellow River Delta is gentle, with an altitude of 1 to 6 m, and the terrain ratio is about 1/8 000 to 1/12 000. The freshwater resource in the study area is a shortage, and the groundwater level is shallow. Every year from March to May and December to February of the next year is a period of low rainfall and drought, and the evaporation is strong, forming two returning periods of soil. On the one hand, the precipitation in the rainy season leaches the soil salt, on the other hand, the soil moisture is supplemented, and the surface soil of 0-5 cm is in the desalting stage. The seasonal variation of soil salinity has a great influence on the seasonal phase of the vegetation.

In April 2010, the field soil sampling was carried out, and the coastal wetland of the Yellow River estuary was used as the research area. The degraded alkali plaques and the wetlands with different reed coverage were selected as research plots, respectively representing the reed wetland restoration, which illustrated as follows: Area 1 (JLD) has a higher micro-topography and is in a salinized state; Area 2 (LWD1) has a high micro-topography, which is naturally infiltrated by the Yellow River diversion, and has a natural recovery state; Area 3 (LWD2) has a good inflow and drainage system. For six consecutive years, the Yellow River water was flooded, and the reed wetland developed well. The surface layer of 0-20 cm in depth and the two layers of soil samples of 20-40 cm were collected separately, and 5 points of soil were collected and mixed into a sampling bag for soil chemical factor measurement.

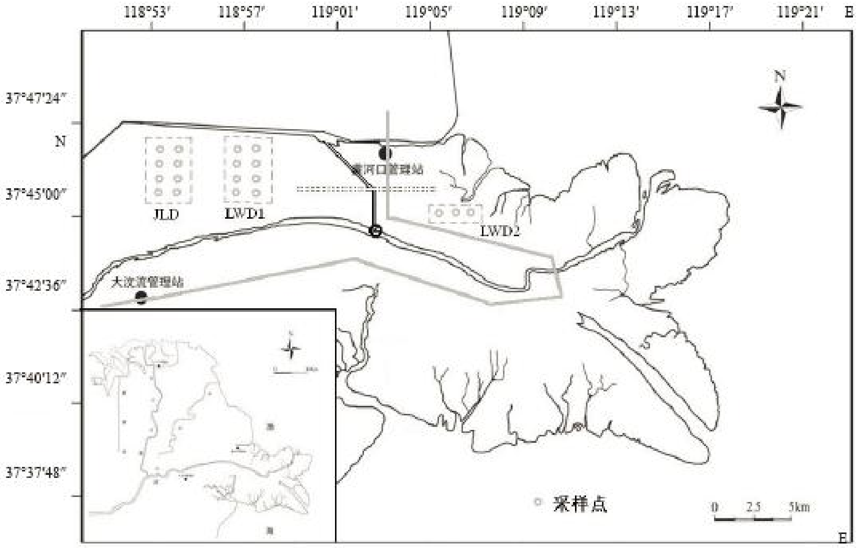


Fig. 4.1 Sampling plot in the restoration area of Yellow River Delta

4.3 Implementation modalities

According to the composition of the wetland and the characteristics of the coastal wetland ecosystem, the ecological restoration process of the wetland can be summarized as wetland habitat restoration, recovery of wetland organisms and restoration of wetland ecosystem structure and function. Correspondingly, the ecological restoration techniques of wetlands can also be divided into three categories, which described in detailed as below: 1) Wetland habitat restoration technology. The goal of wetland habitat restoration is to improve the heterogeneity and stability of habitats by adopting various technical measures. Wetland habitat restoration includes wetland base restoration, wetland hydrological recovery, and wetland soil restoration. The restoration of the wetland is to maintain the stability of the substrate by engineering measures, stabilize the wetland area, and transform the topography and landform of the wetland. Wetland hydrological recovery technologies mainly include wetland hydrological connectivity technology and ecological water replenishment technology; soil restoration technologies include soil salinization control technology and soil fertility restoration technology; 2) Wetland biological recovery technology. It mainly includes species selection and cultivation techniques, species introduction and protection techniques, population dynamic regulation techniques, community structure optimization configuration and formation techniques, community succession control, and restoration techniques; 3) Ecosystem structure and function recovery technology. It mainly includes the overall design technology of ecosystems, ecosystem construction, and integration technologies. According to different types of degraded wetland ecosystems, the optimal allocation and reconstruction of wetland ecosystem structure and function and its regulation, and the restoration and maintenance of species diversity are carried out. In the present restoration project, we mostly use reed wetland to restore the coastal saline area of the Yellow River Delta, which included the following three aspects.

4.3.1 ***Rapid desalination technology for the soil in the saline area***

In generally, the coastal saline-alkali soil is generally distributed mainly in the coastal area, and the improvement of saline-alkali soil is limited by the following factor. 1) Due to the influence of seawater irrigation, the groundwater level is difficult to control; 2) the land age is very young, and soil salinity is serious; 3) Re-salt and re-alkalization is serious for this region; 4) the flushing freshwater is insufficient; 5) the physical properties of the water are degraded, and 6) the organic fertilizer source is insufficient. At present, the technology using for soil improvement of saline-alkali was usually included water conservancy projects, chemical improvements treatment, halophyte transplantation, *etc*. The goal of these measurements is to control the level of groundwater preventing the groundwater pumping into the surface layer. For the saline-alkali soil, engineering methods and soil transformation such as storage of salt, irrigation and salt washing, and underground salt discharge are used to improve the quality of the soil. In common, three measurements were used in the procedure of a typical project:

(1) Project preparing: In the early stage of the project, the following two aspects of project construction were carried out. Firstly, the hydraulic connection of the Yellow River was restored to connect the linkage between wetland and river. Secondly, the micro-topography should be renovated to increasing the water storage capacity, ensuring smooth drainage during the drainage of the reed wetland, which will not

affect the normal survival of fish, shrim, and crab during the drainage period, and promoting the recovery of aquatic animal populations.

(2) Flushing the salinized soil by freshwater: According to the basic rules of saline soil water and salt operation, restoring the hydraulic connection between wetland and river, restoring surface runoff, implementing large water pressure salt, and then washing salt. The infiltrated soil salt is drained by underground drainage method. Generally, the smaller and deeper the groove distance, the faster the soil desalination rate, the better the groundwater level is controlled, and the better the desalination effect.

(3) Water management technology: Moisture is the dominant ecological factor affecting the restoration of reed vegetation in saline areas, so the recovery process focuses on basic water. The water level will affect the structural composition of the vegetation community in the wetland ecosystem. Under the condition of meeting the water demand in the saline area, according to the water demand of different growth stages of the reed, a reasonable irrigation system was established to promote the good development and distribution of the underground rhizomes of the reed, making it a colony of plants in the saline area. In addition, ploughing can accelerate soil desalination, increase soil porosity, and reduce soil bulk density. As the physicochemical properties of the soil are improved after ploughing, the development of rhizome of reeds is promoted, the density of reeds is increased, the plants are increased, and the stems are thickened.

4.3.2 Natural restoration technology of reed wetland in saline mudflat

Constrained by the soluble salt and water in the soil, the coastal wetland showed the characteristics of salinization which showed that the increase of the percentage of an annual halophyte, dwarfing of reed plants and reduction of vegetation coverage, etc. The reed community is one of the main plant communities in the coastal wetland of the Yellow River Delta, which had high ecological and economic value and played an important role in maintaining the structural and functional stability of the wetland ecosystem. The prerequisite condition should be required if the reed can grow well, the first and most important is the water resource requirement; the second one was whether there are enough rhizomes in the soil. Only the rhizomes that have been bred are rapidly developed into ponds after being induced by water. The general rule is that under the conditions of proper irrigation and drainage, the reed can emerge in one year, and the reed can get economic benefit in three years, and after 7 to 9 years, the reed ecosystem can reach up to the peak of production, the average yield per mu is 600-700 kg.

In the present research study area, there are still a large number of available rhizomes in the topsoil of 20 ~ 60 cm. By adopting habitat modification, irrigation of water conservancy projects is carried out. After 3 to 5 years of wetland ecological tending, reeds can develop into dominant populations. The transplanting technique is used for artificial planting of alkali plaques; the reed plants excavated in the project are transplanted through the rip piers to a place with low density for natural reproduction.

During the project implication, the following measurements were taken in the procedure: 1) Investigation on background characteristics of vegetation community and soil salinization in coastal saline-alkali area; 2) Renovate the wetland habitat, restore the hydraulic connection, and washing the salt; 3) Water environment induces growth and development of reed rhizomes; 4) Implement a reasonable irrigation and drainage system, and the reed community will continue to expand.

4.3.3 Breeding and cultivation techniques of reed in the saline area

The reed wetland restoration mainly relies on the seeds or components (rhizome) of the reeds. The main method is habitat restoration, seed, and transplant methods. The habitat recovery act has low investment and low cost but has a long cycle. Transplantation of restored reed mainly including the greening transplantation, the piercing transferred and the rhizome plantation.

1) Seedling transplanting

This project was implicated from mid-May to early July when the height of the reed seedlings was more than 30 cm. The stalks with thick stems and 2~4 tillers are selected from the healthy reed wetland. The seedlings are cut and excavated with the length and depth of 20-25 cm and then transplanted to the mudflat with the 1 to 1.5 m in the beach. Then make sure the mudflat had 10~15 cm shallow water, and the maximum is no more than 33 cm, to facilitate roots survive.

2) Rhizome reproduction

Healthy rhizomes were selected for propagation when the buds on the rhizomes begin to germinate after the soil is thawed in spring. The healthy standard rhizomes were always dark yellow to brown, with the thicker stem wall, and the stems on the ground are thick and firm. The roots are 30~50 cm long, always more than 5 knots, each section has obvious lateral buds, and there are many branches of branches. The healthy rhizomes were selected based on the above criteria and then cut the branches of 30~50 cm thick with tillers make about 1 m each, and insert them into the soft mud on the beach. In the layer above the mudflat, the upper part leaves about 7 cm, to ensure the emergence of seedlings. The soil surface of the seedlings should be kept moist or kept shallow water before and after the seedlings are unearthed.

3) Reproduction by the adult plants

In the rainy season such as July and August, healthy green reed plant was cut off from the surface and removed the young shoot which was about 50 cm. Then, the mudflat was plowed and inserted the tipped green stalks into the soil one by one. What should be emphasized is the part below the soil should have a knot at least to make sure the cultivated plants can sprout and grow. The cultivated plants are 30-50 cm apart, and the planting density is 5000-6000 plants per mu. The survival rate can reach up to as high as 98% when incorporating proper management.

4.4 Results and service improve

The present study was implemented at the coastal saline area of the Yellow River estuary. The field vegetation structure survey and soil sampling analysis were used to compare the ecological environment characteristics of wetland in different restoration stages, and the restoration project was discussed by the method of space generation time. The changes of vegetation characteristics before and after were designed to grasp the changes of vegetation growth, composition, and soil physical and chemical properties during the freshwater restoration of reed wetland in the degraded coastal saline area of the Yellow River Delta, and provide basic data and basis for the smooth follow-up work.

Reed wetland is one of the main vegetation types in the coastal wetlands of the Yellow River Delta. Due to the low vegetation coverage of reeds, the monotonous composition, low biodiversity, poor soil improvement, and the insufficient freshwater supply, the vegetation was degradation gradually. The degree of soil salinization in the reeds is generally light salinized or medium salinized soil, but the salt content in the reeds is very high. The pH value is 7.29～8.92, the average value is 8.28; the organic matter content is 2.07～78.62g/kg, the average value is 22.46g/kg; the (K^+ +Na^+) / (Ca^{2+}+Mg^{2+}) ratio is 0.06～18.14, the average value is 5.88; Cl-/SO42- the vast majority are greater than 1, which implied that the type of sulfate-chloride or chloride-type saline soil. However, the Yellow River estuary wetland has good ecological water replenishment measures, and the reed population has been expanding in size in recent years. There are already 200,000 mu of artificially restored reed wetland systems.

4.4.1 Vegetation community characteristics changed due to the restoration

After the restoration project was implemented, the wetland environment in the recovery area has undergone major changes, not only the water area with a certain area and depth, but also the aquatic plant community with reeds as the dominant species. It is accompanied by a large number of aquatic and wet plants such as leeches, bulrush, and alfalfa. The species and quantity are abundant and vigorous, the density and coverage are large, and the biodiversity is rich. There are many aquatic animals and rare birds. The vegetation community characteristics in the saline area after restoration are shown in Table 6.6. According to the important value, the dominant species were reed and apocynum, and the coverage reached 70% or more. Population dominance was more significant. After restoration, the density of reed plants was higher, the plants were taller and thicker, the leaves were longer and wider, and the ears were larger. The aboveground and underground biomass was significantly higher than the biomass of reeds in the unrecovered area, reflecting that their growth was better and they were in good habitat. Field investigations have found that the vegetation with high micro-landscapes is still the most important for salt-tolerant salt and alkali.

盐地碱蓬—芦苇群落

光板地与盐地碱蓬群落

芦苇*Phragmites communis*

盐地碱蓬*Suaeda heteroptera*

Figure 4.2 The vegetation characters of the restoration vegetation.

4.4.2 Dominant species succession and community vegetation area

Through the survey results of the native vegetation in the fall of 2009 and the type and distribution of vegetation in the fall of 2012, a raster image file was drawn, and then the vector map file of the vegetation distribution was obtained by using ArcView, and the spatial analysis ability of ArcView was used to calculate each The distribution space and area of the species. Using plant species as effective fields, different vegetation values were assigned to different colors in ArcView for comparative study.

Before the restoration, the Suaeda community dominated the land covered with vegetation. In the third year of artificial tending reeds, the reed community replaced the Suaeda community as a dominant community. The two survey data were compared and analyzed. The results showed that the plaque aggregation of vegetation increased significantly. In 2009, the distribution of reeds was scattered. By 2012, the reed community and the plant communities mixed with reeds tend to concentrate. In the early stage of artificial tending in 2010, the *Suaeda salsa* community was the dominant community on the experimental ground. By 2012, the reed community in the restoration area increased from 217.96 mu to 383.4 mu, and the reed coverage of the polder increased by 31.5% to 73.1%. The soil decreased by 1.6%, the coverage of Suaeda salsa decreased to 21.2%; the desalination rate of 0-20 cm soil in Putian land decreased by 10.6% on average; the soil organic matter content increased by 23.7%. During the study period, the vegetation of the control ground without artificial tending did not show any signs of benign transformation, and there was a sharp contrast on both sides.

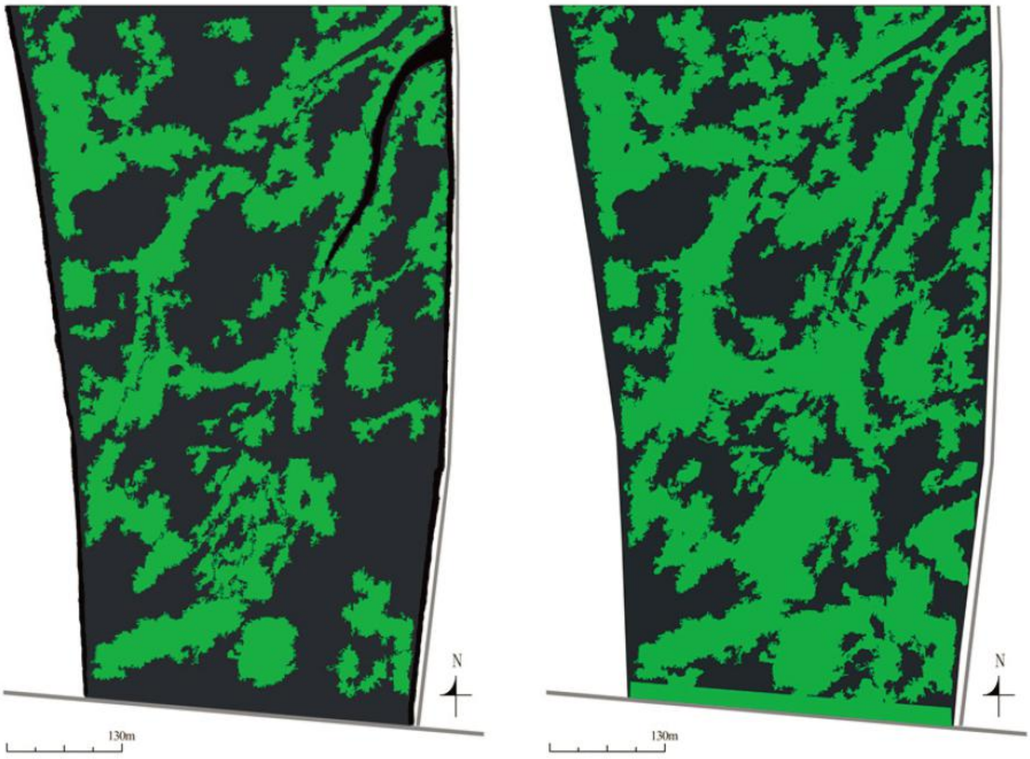


Figure 4.3 Changes in the reed distribution before and after the restoration.

4.4.3 Reed and river crab production

In 2011, Dongying City Yinhe Aquaculture Company promoted 2 000 hectares, the total benefit of reeds was 4.7 million RMB; the total output of river crab farming was 230t, the output value was 13.8 million RMB, the cost was 3 million RMB, the profit was 10.8 million RMB, and the average output was 115kg/hm^2. The average benefit is 5,400 RMB/hm^2; the total output of fish farming is 180t, the total output value is 9 million RMB, the cost is 2 million RMB, the profit is 7 million RMB, the average output is 90kg/hm^2, and the average benefit is 3,500 RMB/ha. The comprehensive benefit is 22.5 million RMB, and the average benefit is 11 250 RMB/hm^2. Among them, the aquaculture benefit was 17.8 million RMB, and the average benefit was 8 900 RMB/ha.

Based on the restoration technology of degraded reed wetland in coastal saline area, apply the relevant principles of restoration ecology. Through the connection of water system, deep groove pressure alkali washing salt, reed population rejuvenation and other engineering measures, combined with the ecological water demand guarantee of wetland reed, establish an ecological circulation economic model of "reed-fish-crab" compound breeding system, while promoting the normal growth of reed Using the abundant biodiversity resources of the reed wetland, artificially stocking fish and crabs, enabling the organic integration of energy flow and logistics, and constructing a recycling network of food nets, which has become a small input, low consumption, high efficiency, and no pollution. The artificial ecological recycling economic system has significantly improved the economic, social and ecological benefits of the reed wetland.

References

Cao, L. et al., 2007. Environmental impact of aquaculture and countermeasures to aquaculture pollution in China. Environmental Science and Pollution Research-International, 14(7): 452-462.

Chen, B., Yu, W., Liu, W. and Liu, Z., 2012. An assessment on restoration of typical marine ecosystems in china – Achievements and lessons. Ocean & Coastal Management, 57: 53-61.

Chen, J., Wang, J. and Chen, Y., 2011. Technology research and application of ecological restoration in urban landscape water--A case study of Xiamen Wuyuan Wetland Park water system's treatment. Guangdong Agricultural Science, 38(1): 168-170.

Ding, C. and Xu, G., 2006. Studies on the purification of aquaculture water with Sinonovacula constricta. Reservoir Fisheries, 26(2): 73-74.

Dong, S., Wang, F., Wang, J., Qi, Z. and Lu, J., 1999. Effects of bay scallop on plankton and water quality of mariculture pond. Acta Oceanologica Sinica, 21(6): 138-144.

Funge-Smith, S.J. and Briggs, M.R., 1998. Nutrient budgets in intensive shrimp ponds: implications for sustainability. Aquaculture, 164(1-4): 117-133.

Guan, Y., Liu, G., Liu, Q. and Ye, Q., 2001. The Study of Salt-affected Soils in the Yellow River Delta Based on Remote Sensing. Journal of Remote Sensing, 5(1).

Haglund, K. and Pedersén, M., 1993. Outdoor pond cultivation of the subtropical marine red algaGracilaria tenuistipitata in brackish water in Sweden. Growth, nutrient uptake, co-cultivation with rainbow trout and epiphyte control. Journal of Applied Phycology, 5(3): 271-284.

Hall, P.O., Holby, O., Kollberg, S. and Samuelsson, M.-O., 1992. Chemical fluxes and mass balances in a marine fish cage farm. IV. Nitrogen. Marine Ecology Progress Series: 81-91.

Holby, O. and Hall, P.O., 1991. Chemical fluxes and mass balances in a marine fish cage farm. II. Phosphorus. Marine Ecology Progress Series: 263-272.

Huang, H.P., 2012. Study on Assessment of Coastal Wetland Restoration: A Case Study of Wuyuan Bay in Xiamen, Third Institute of Oceanography, State Oceanic Administration, China, Xiamen.

Kaspar, H., Gillespie, P., Boyer, I. and MacKenzie, A., 1985. Effects of mussel aquaculture on the nitrogen cycle and benthic communities in Kenepuru Sound, Marlborough Sounds, New Zealand. Marine biology, 85(2): 127-136.

Liao, B. et al., 1999. Aboveground biomass and nutrient element accumulation and distribution in different types of mulberry - aubergine plantation. Journal of Applied Ecology, 10(1): 11-15.

Lin, G., Li, B., Xiang, P. and Yang, Q., 2009. Preliminary studies on cyclic utilization of wastewater from marine aquaculture plant. Marine Science, 33(5): 47-50.

Lin, P., 1989. Biomass and element cycle of Kandelia forest, China. Journal of Wuhan Botanical Research, 7(3): 251-257.

Liu, Q., Liu, G., Xue, K. and Song, H., 2006. Elementary Analysis on Characteristics of Soil Salinization of Geomorphology Units with Different Scales in the Neoteric and Modern Yellow River Delta. Chinese Agricultural Science Bulletin, 22(11).

Liu, Z. and Chen, B., 2004. Report of Environmental Impact Assessment on Projects of

Zhongzhai Bay Rehabilitation and Road Construction along the Bay., Third Institute of Oceanography, State Oceanic Administration, China.

Liu, Z., Shi, S. and Chen, B., 2009. Report of Strategic Studies and Practices on Ecological Rehabilitation in Wuyuan Bay, Third Institute of Oceanography, State Oceanic Administration, China.

Nakamura, Y. and Kerciku, F., 2000. Effects of filter-feeding bivalves on the distribution of water quality and nutrient cycling in a eutrophic coastal lagoon. Journal of Marine Systems, 26(2): 209-221.

NaturalBureauofStatisticsofChina, 2005. China Fishery Statistic Year book. Chinese Statistic Press.

Prins, T., Escaravage, V., Smaal, A. and Peeters, J., 1995. Functional and structural changes in the pelagic system induced by bivalve grazing in marine mesocosms. Water Science and Technology, 32(4): 183-185.

Qin, G., Liu, C.C., Richman, N.H. and Moncur, J.E., 2005. Aquaculture wastewater treatment and reuse by wind-driven reverse osmosis membrane technology: a pilot study on Coconut Island, Hawaii. Aquacultural Engineering, 32(3-4): 365-378.

Troell, M. et al., 1997. Integrated marine cultivation of Gracilaria chilensis (Gracilariales, Rhodophyta) and salmon cages for reduced environmental impact and increased economic output. Aquaculture, 156(1): 45-61.

Wang, S. and Zhang, Z., 1998. Study of Neanthes japonica Feeding on Natural Sediment. Journal of Ocean University of Qingdao, 28(4): 587-592.