Impact of Large-Scale Reclamation on Resources and Environment in West Liaodong Bay and Remediation and Restoration Suggestions—A Case Study of Xingcheng Coastal Industrial Area

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Abstract. Based on the case study of reclamation in west Liaodong Bay in Xingcheng City, this paper analyzes the construction background and implementation process of reclamation in the coastal industrial area, and assesses the major resource and environmental issues arising from reclamation. Since the reclamation of Xingcheng Coastal Industrial Area has caused the losses of lagoon coastal wetlands, coastline resources, hydrodynamic environment of islands and reefs and ecology as well as the changes of hydrodynamic and scouring and silting environment in local sea areas. The paper suggests that measures, such as watercourse and coast remediation and restoration, coastal wetland restoration, hydrodynamic recovery of islands and reefs, water system construction, reproduction and release, should be taken to mitigate the adverse impact of reclamation on resources and the environment to a certain extent.

Keywords. Reclamation; resources and environment; remediation and restoration; Liaodong Bay; Xingcheng City.

1. Overview
Xingcheng coastal industrial area is located in Caozhuang Town, Xingcheng City, Liaoning Province, and on the west side of Liaodong Bay, Bohai Sea. The coastal industrial area was once a vast marsh wetland-Caozhuang Lagoon. This lagoon was formed as parts of the sea have been gradually becoming semi-enclosed due to the development and continuous extension of sandbar into the sea caused by sediment transported from the south to the north. Factors, including the salinization or desalination of water medium caused by incomplete or periodical isolation of the seawater as well as the import of nutrients from rivers, have contributed to the abundant biological resources [1-3] in the lagoon, thus the lagoon has become the best place for the growth of benthic organisms such as shellfish and crustaceans, as well as a foraging habitat for birds [4, 5]. Due to the abundant underground brine resources, the Caozhuang Lagoon was developed into a salt field in the 1980s, and the original natural wetland was gradually replaced by artificial ponds. With the development of
coastal economic belt in the Liaodong Bay, the demand for land resources in coastal areas was increasing while the economic benefit of salt industry was deteriorating gradually, making the salt field a priority for sea reclamation.

Liaoning Province’s strategy of opening up the coastal economic belt was first proposed in late 2005, adopted as a national strategy and implemented in 2009. Under the general framework of coastal economic belt in Liaoning Province, Huludao City has proposed and realized the basic concept of “three points and one line” coastal development and opening up on the line starting from Tashan Town and Gaoqiao Town, Lianshan District in the east, passing through Caozhuang Town and Shahousuo Town in Xincheng City, and ending at Gaoling Town and Wanjia Town in Suizhong County in the west. To seize this great opportunity, Xingcheng City planned to build the coastal industrial area along the coast in Caozhuang Town. This area is to be built as a new ecological coastal urban district that integrates emerging industry and modern service industry and is compatible with multiple functions such as logistics, warehousing, finance, commerce, residence, etc. To make overall planning and reasonable layout of the construction project within Xingcheng Coastal Industrial Area and ensure the scientific development and effective utilization of sea resources, on the premise of comprehensively considering the natural environment, resource conditions and characteristics of sea area, Xingcheng City compiled the “Overall Plan for the Sea Area Used for Construction”. In October 2008, the project of Xingcheng Coastal Industrial Area was started by first carrying out the land area backfilling in the original salt field. By 2010, the 9,624 m long outer coastal dike had been built up. After that, sub-weir construction and reclamation construction have been successively carried out in the surrounding area. Up to now, the coastal industrial area has a total area of 1,080 hm². It consists of 700 hm² filled land area and 380 hm² reclamation area (Figure 1).

![Figure 1](image_url)

**Figure 1.** Reclamation location of Xingcheng Coastal industrial area and its surroundings.

2. Impact of Coastal Industrial Area Reclamation on Resources and Environment

2.1. Loss of Coastal Wetlands

The large-scale reclamation of coastal industrial area is completed on the original Caozhuang Lagoon and salt field, which results in the loss of large-scale coastal wetlands. With a water depth of 0-2 m and an average depth less than -6 m, the sea area occupied by the coastal industrial area belongs to the
area of coastal wetland. According to the measurement, the coastal industrial area caused a loss of 1,080 ha coastal wetland.

2.2. Loss of Coastline
The coastal industrial area occupies 4.12 km artificial coastline and 0.15 km natural coastline. The artificial coastline occupied was mainly the original seawall while the natural coastline occupied was the bedrock coastline. After the reclamation, a new artificial coastline of 12.8 km was formed. The newly formed artificial coastline is mainly composed of concrete structures that feature no ecological functions.

2.3. Loss of Hydrodynamic Environment of Islands and Reefs
Shiren Reef located in coastal waters of Xingcheng City was originally located in the natural open sea area. After the reclamation project in Xingcheng Coastal Industrial Area is implemented, Shiren Reef has been surrounded by the sea wall and isolated from the natural open sea area. Therefore, the hydrodynamic environment is basically lost and the reef ecosystem is also influenced.

2.4. Change of Hydrodynamic and Scouring and Silting Environment
The reclamation changes the hydrodynamic environment by changing the submarine topography and the trend of coast, thus leading to the change of the scouring and silting environment in the local sea area [6]. The distribution of annual average scouring and silting intensity from 2009 to 2019 is shown in figure 2. In most areas, the scouring and silting intensity is between 0 - 5 cm/a; and as a certain degree of siltation occurred in the coastal area on the northeast side of the project, the average annual sedimentation is 5-23 cm/a; as the erosion occurred on the southeast side of the project due to the uplift flow, the average annual erosion is 5-25 cm/a; as the coastal area adjacent to the southwest side of the project has siltation, the average annual sedimentation is about 8 cm/a; as the erosion occurred outside the bedrock cape in the west of the survey area, the average annual erosion is about 18 cm/a, which may be related to other local projects; and as the belt-like siltation occurred on the west side of Juehua Island and extended to the southwest, the average annual sedimentation is about 6-24 cm/a.

Figure 2. Distribution of annual average scouring and silting intensity from 2009 to 2019.
2.5. Loss of Marine Biological Resources and Ecosystem Service Function

The reclamation caused the loss of marine biological resources. For one thing, there is the loss of marine biological resources in the occupied sea areas. The reclamation takes up marine space resources by permanently taking up the living space for marine creatures living in the area in addition to burying some marine creatures during construction [7]. For another, the loss of marine biological resources is caused by suspended matter spreading. The pollutants such as suspended matter produced during the riprapping for reclamation cofferdam may cause the seawater quality pollution, which will cause harmful effect to marine organisms [8, 9]. Fortunately, this effect can be gradually eliminated after a period of time. According to calculation, the loss value of marine biological resources caused by the reclamation in Xingcheng Coastal Industrial Area is about RMB 9.66 million.

The ecosystem service function refers to the natural environment conditions and utility for human survival developed and maintained by ecosystem and ecological process [10, 11]. It not only provides human beings with food, medicine and other production materials, but also creates and sustains the Earth’s life system as well as develops the environmental conditions necessary for human survival. The connotation of ecosystem service function may include the production and synthesis of organic matter, the generation, maintenance and regulation of biodiversity, regulation, the climate, the storage and circulation of nutrients, the environmental purification and harmful and toxic substance degradation, the pest control system, the mitigation of natural disasters, etc. The loss of ecosystem service value from reclamation is summarized into 4 categories in terms of marine supply services, marine regulation services, marine culture services and marine support services. Marine supply services include aquaculture fishing and oxygen production; marine regulation services include climate regulation and waste disposal; marine culture services include recreation and entertainment as well as scientific research and education; and marine support services are primarily biodiversity maintenance. According to calculation, the loss value of marine ecosystem service function caused by reclamation in Xingcheng Coastal Industrial Area is about RMB 5.4658 million per year.

3. Suggestions for Sea Area Remediation and Restoration

3.1. Watercourse and Coast Remediation and Restoration

Liuhe River, located on the west side of the reclamation area, is a seasonal river with almost no surface runoff except in the rainy season. Structures, such as breeding plants, aquaculture ponds, etc., in the watercourse of Liuhe River, have occupied the natural bedrock coast on the west bank of Liuhe River and affected the safety for flood discharge at the river mouth. It is suggested that unreasonable facilities in the watercourse should be removed.

3.2. Restoration of Coastal Wetlands

Since the mudflat on the sea side northeast of the seawall features good cover conditions, less effect from waves and flat terrain, it formed a tidal flat wetland. To create a three-dimensional habitat environment for inter-tidal creatures, improve the biodiversity of the sea area, and enhance the ecosystem service function of the mudflat wetland, it is suggested that the suaeda heteroptera should be selected as a species for planting in the mudflat for ecological restoration. Meanwhile, due to the large number of industrial aquaculture around, the aquaculture sewage causes pollution to the nearby sea area. By planting suaeda heteroptera community, its components may also purify the seawater and improve the environment. This area has been sporadically grown with patchy suaeda heteroptera, which is suitable for the restoration of coastal wetland.

3.3. Hydrodynamic Recovery of Islands and Reefs and Water System Construction

It is suggested that the overall layout of water system in the reclamation area should be designed. For the hydrodynamic recovery of Shiren Reef, It is suggested that dikes and dams in the reclamation area should be demolished partially and modified as permeable structures such as bridges and culverts; and gates should be set up at two positions of the seawall to connect Shiren Reef with the natural open sea.
area. These measures can promote the circulation of water system in the reclamation area and recover the hydrodynamic environment of Shiren Reef. Meanwhile, the construction for water system circulation will also promote the increase of sea area and the positive development of marine ecology in the reclamation area.

3.4. Recovery of Biological Resources

Fishery release is an effective measure to supplement the population and quantity of fishery resources, improve and recover the ecological environment damaged by overfishing or water conservancy projects, as well as maintain biodiversity [12]. The reclamation occupied the sea area, resulting in the loss of bentonic organism, intertidal organisms, phytoplankton and zooplankton in the reclamation area. Reproduction and release can be adopted to recover the marine biological ecology, promote the recovery of marine biological resources and the sustainable use of fishery resources.

4. Conclusions

Taking Xingcheng Coastal Industrial Zone as an example, this paper analyzed the construction background and implementation process of reclamation on the west bank of Liaodong Bay, and evaluated the main impact of reclamation on resources and the environment. The results show that the reclamation had caused the loss of lagoon wetlands and coastline resources, the loss of the hydrodynamic environment of islands and reefs, and changes in the hydrodynamic and sedimentary environment of local sea areas. It is recommended to take measures such as shoreline restoration, coastal wetland restoration, hydrodynamic restoration of islands and reefs, construction of artificial water systems, and fishery release to reduce the adverse impact of reclamation on resources and the environment.

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