

Comprehensive Coastal Waters Management in Xiamen and Its Effects

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Abstract. Over the past 50 years, the burgeoning socioeconomic development in Xiamen has led to a significant decrease in the area and the tidal influx of its coastal waters, resulting in the degradation of its marine ecosystem. Nonetheless, through the implementation of comprehensive management measures such as causeway openings and coastal dredging, Xiamen Bay has seen marked improvements in the water quality of various local waters: dissolved oxygen (DO) levels have stabilized, inorganic nitrogen and reactive phosphate levels have decreased, and the diversity index of large benthic organism communities has increased. These results well demonstrate the effectiveness of Xiamen's comprehensive coastal waters management in improving its marine ecosystem and environment.

Keywords. Comprehensive coastal waters management, effects analysis, Xiamen coastal waters

1. Introduction

As a coastal city of important status in China, Xiamen's economic growth is closely tied to its marine environment and coastal resources. However, over the past 50 years, the burgeoning socioeconomic development in Xiamen has led to a significant decrease in the area and the tidal influx of its coastal waters, resulting in the degradation of its marine ecosystem and environment. The comprehensive coastal waters management program kicked off by Xiamen has played a crucial role in improving its marine ecosystem and environment [1-5]. Through measures such as dredging, expanding water areas, opening causeways, and creating wetlands, Xiamen Bay has seen an increase in tidal influx and improved hydrodynamic conditions, leading to the gradual restoration of its coastal waters.

The preliminary research on Xiamen's coastal dredging efforts began as early as 2000, with results indicating that causeway openings and tidal flat dredging increased flow velocity in the main channel areas of both eastern and western waters, thereby enhancing hydrodynamics and seawater exchange capacity while reducing sediment deposition, particularly in the western waterway and Dongdu Port Area [6, 7]. These findings provided a strong technical basis for Xiamen's follow-up implementation of

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comprehensive coastal waters management from 2002 to 2018.

2. Overview of Comprehensive Coastal Waters Management in Xiamen

Xiamen's comprehensive coastal waters management encompassed causeway opening renovation and comprehensive coastal waters environmental management.

2.1. Causeway Opening Renovation Projects

These projects mainly involved the renovation of the Gaoji, Jixing, and Maluan Causeways. The 2,212 meter-long Gaoji Causeway had previously cut off the connection between the eastern and western waters, turning them into semi-enclosed bays with severe sedimentation on both sides. In 2014, an 800 m opening was created in the causeway using a 16-span (each being 50 m) continuous beam bridge structure, thus facilitating free water exchange between Tong'an Bay and the western waters.

The Jixing Causeway, measuring 2,890 m in length, underwent renovation in 2010 with the construction of a new 335 v sluice at its opening, employing a sluice-culvert combined structure. This allowed for free water exchange between Xinglin Bay and the western waters.

The Maluan Causeway, located at the mouth of Maluan Bay in southern Xinglin and measuring 1.67 km in length, underwent renovation in September 2005 with the construction of a new sluice with a net width of 228 m at its opening. This allowed for free water exchange between Maluan Bay and the western waters.

2.2. Comprehensive Coastal Waters Management Projects

These projects mainly involved the comprehensive management of Xiamen's western waters and Tong'an Bay. The comprehensive management of western waters encompassed aquaculture withdrawal, shoreline management, dredging on the western side of the Gaoji Causeway, and Haicang Bay dredging. The comprehensive management of Tong'an Bay included aquaculture withdrawal, eastern shoreline management, implementation of artificial beach and mangrove projects, and dredging on the Tong'an Bay side of the Gaoji Causeway.

By 2018, aquaculture withdrawal in both the western waters and Tong'an Bay had been completed, with a total dredging volume of 111 million m³, representing 54% of the planned volume. Table 1 shows the dredging completion status in each area. In regard to the remaining dredging volume, the vicinity of Dadeng accounts for the largest proportion at 35%, followed by the causeway opening impact area at 31%, and the eastern waters dredging area at 20%.

3. Effects of Comprehensive Coastal Waters Management in Xiamen

3.1. Changes in Water Quality

According to the "Reports on the State of Marine Ecosystem and Environment in Xiamen" from 2014 to 2018 [8-12], dissolved oxygen (DO), inorganic nitrogen, and

reactive phosphate were selected as evaluation indicators to analyze trends in Xiamen's marine environment quality following the implementation of comprehensive coastal waters management program from 2014 to 2018. Figures 1-3 show these trends. As can be seen from the figures, during the five-year period from 2014 to 2018, DO levels in various local waters of Xiamen Bay remained stable, while inorganic nitrogen and reactive phosphate levels had decreased on the whole, suggesting that the program had a positive impact on environmental management.

Table 1. Summary of dredging status in each area by 2018.

Name of the dredging area		Design dredging volume (10,000 m ³)	Actual dredging volume (10,000 m ³)	Completed dredging volume (10,000 m ³)	Unfinished dredging volume (10,000 m ³)
Causeway opening impact area	Zone A and Zone C	1618	1618	1618	0
	Zone B and Zone D	1194	1194	638	556
	First power supply channel to Xiamen Island	300	300	0	300
	Newly added area in Zone D	750	750	0	750
	Vicinity of Baozhu Isle	1225	1225	0	1225
	Other dredging areas	92	92	92	0
Eastern waters	West side of eastern waters	1814	1990	1990	0
	Vicinity of Eyu Isle	1850	1850	0	1850
Haicang Bay		2213	2119	2119	0
Maluan Bay		1458	1458	0	1458
Vicinity of Dadeng	North of Dadeng Bridge	2062	1692	1558	134
	South of Dadeng Bridge	5862	5646	2580	3066
Others		550	550	550	0
Total		20988	20484	11145	

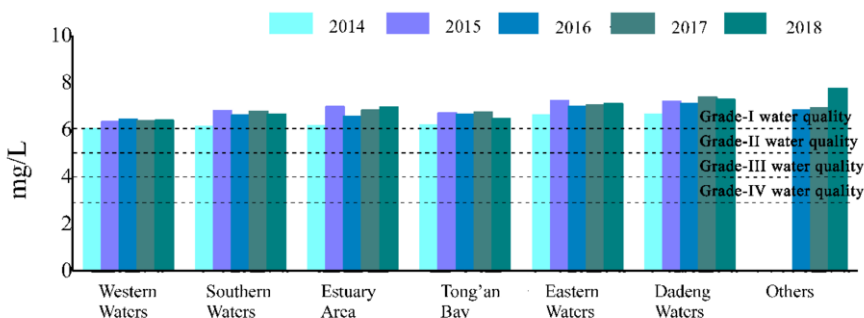


Figure 1. Changes in dissolved oxygen concentration in local waters of Xiamen Bay from 2014 to 2018.

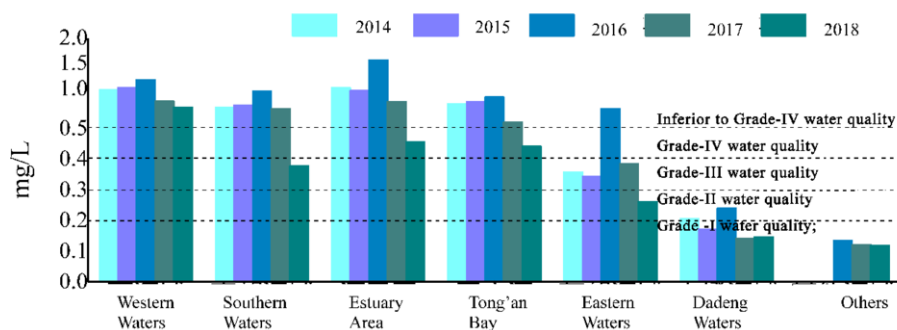


Figure 2. Changes in Inorganic nitrogen concentration in local waters of Xiamen Bay from 2014 to 2018.

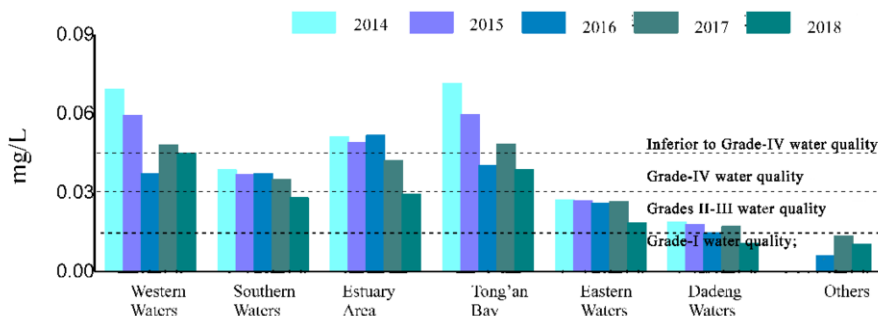


Figure 3. Changes in reactive phosphate concentration in local waters of Xiamen Bay from 2014 to 2018.

3.2. Changes in Benthic Organism Communities

According to the “*Reports on the State of Marine Ecosystem and Environment in Xiamen*” from 2014 to 2018, the Margalef species richness index (d), Shannon-Wiener diversity index (H'), and Pielou evenness index (J) were selected to analyze the changes in the large benthic organism communities in Tong'an Bay and western waters. Figures 4-6 show these trends. As can be seen from the figures, from 2015 to 2018, the diversity index of large benthic organism communities in Tong'an Bay and the western waters increased significantly, suggesting that the program had a positive impact on the overall health of large benthic organism communities.

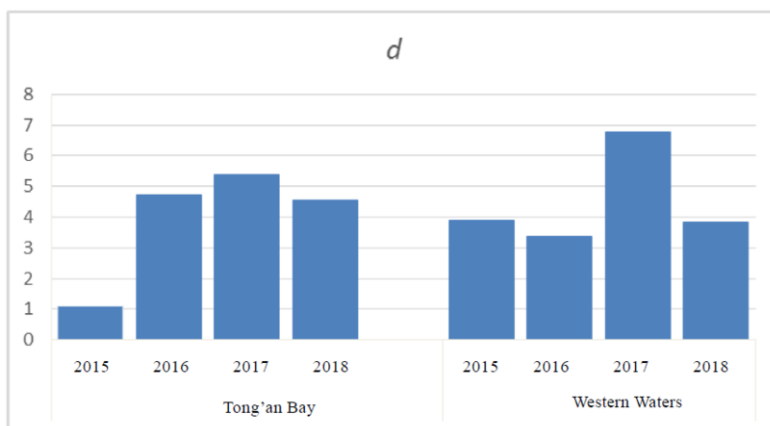


Figure 4. Changes in large benthic organism species richness index (d) in Xiamen's coastal waters from 2015 to 2018.

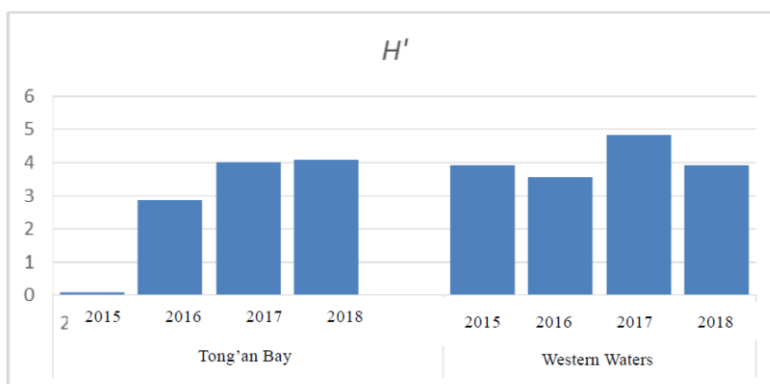


Figure 5. Changes in large benthic organism diversity index (h') in Xiamen's coastal waters from 2015 to 2018.

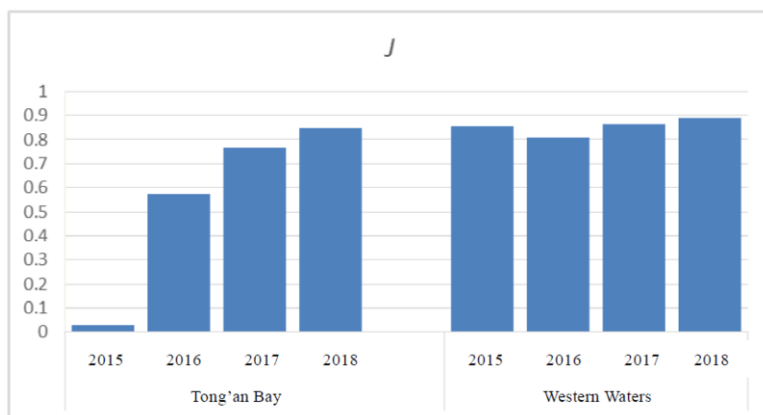


Figure 6. Changes in large benthic organism evenness index (j) in Xiamen's coastal waters from 2015 to 2018.

4. Conclusions

For many years, Xiamen's coastal waters were shrinking in area and tidal influx due to a variety of reasons, leading to the siltation of tidal flats on both sides of the causeways, disordered beach surfaces, and a deteriorating landscape. Through the implementation of comprehensive management measures such as causeway openings and coastal dredging, Xiamen Bay has seen marked improvements in the water quality of various local waters: dissolved oxygen (DO) levels have stabilized, inorganic nitrogen and reactive phosphate levels have decreased, and the diversity index of large benthic organism communities has increased. These results well demonstrate the effectiveness of Xiamen's comprehensive coastal waters management in improving its marine ecosystem, maintaining ecological balance, and restoring marine resources.

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