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A historical overview of coastal eutrophication in the China Seas

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ABSTRACT

China's rapid economic and social development has led to an acceleration in nutrient inputs to coastal waters, which, in turn, has resulted in severe coastal eutrophication. On the occasion of the 40th anniversary of China's reform and opening up, the evolution of the causative factors and the state as well as future prospects for coastal eutrophication in the China Seas are analyzed and summarized. Results showed that the coastal eutrophication situation was not so serious at the beginning of reform and opening up, but it worsened rapidly from the end of the 1980s to the mid-2000s. In the last decade, the worsening trend has been curbed but the status of coastal eutrophication has not been substantially improved. Much work is still needed to be able control the total amount of nutrients entering coastal waters and enable comprehensive treatment of coastal eutrophication in the China Seas.

1. Introduction

Eutrophication is the over-enrichment by nutrients in a water body causing an accelerated production of organic matter, particularly algae. In recent decades, various anthropogenic activities have substantially increased nutrient inputs to waters and changed the nutrient composition. This, in turn, has accelerated the accumulation of organic matter (especially algae) in waters and caused undesirable effects, such as harmful algal blooms, depleted dissolved oxygen, and loss of submerged aquatic vegetation and benthic fauna, thereby affecting seawater quality, ecosystem health, and human use (Bricker et al., 1999; Meyerreil and Köster, 2000). This phenomenon has been termed "cultural eutrophication" (Bricker et al., 1999). Coastal eutrophication has emerged as one of the major environmental problems that plague the coastal countries of the world, and it is also a focal point for scientific research on coastal ecosystems (Justic et al., 1995; Cloern, 1998; Scavia and Bricker, 2006; Andersen and Conley, 2009).

The coastal ecosystems of the China Seas provide important support for economic and social development. The four China Seas (the Bohai, Yellow, East China, and South China Seas) are adjacent to the edge of the continent of China, link to each other, and span the temperate, subtropical, and tropical zones, forming an arc from north to south (Fig. 1). They are marginal seas in the western North Pacific Ocean. The Bohai Sea is a shallow inland sea with an area of 77,000 km^2 and an average water depth of 18 m. Major rivers flowing into the Bohai Sea are the Yellow (Huanghe), Haihe, and Liaohe Rivers. The Yellow Sea is a semi-closed continental shelf sea between the Shandong Peninsula and the Korean Peninsula, which has an area of 380,000 km^2 and an average water depth of 44 m. The Yalu River and a small part of the Yangtze (Changjiang) River freshwater discharge into the Yellow Sea. The East China Sea has an area of 760,000 km^2 and mostly comprises continental shelves with depths less than 200 m. The main rivers discharging into the East China Sea include the Yangtze River and the Qiantang River. The South China Sea covers an area of approximately 3.5 million km^2, with an average water depth of 1212 m, and has an oceanic nature. The main river in mainland China discharging into the South China Sea is the Pearl (Zhujiang) River.

In 1978 China started to put into effect the policies of reform and opening up to the outside world, since then the whole of China has witnessed great changes in almost every field. For instance, China's GDP has grown by 75 times in 1978–2016, ranking it the second biggest economy in the world since 2010 (World Bank, 2018). However, like many other countries in the world, China's rapid economic and social development has also had consequences, namely environmental problems. In the last four decades, substantial changes have occurred in the coastal ecosystems of the China Seas as a result of multiple stresses. In particular, coastal eutrophication has become one of the major problems encountered in the coastal ecosystem of the China Seas (Wang, 2006), which severely restricts the sustainable economic and social development of coastal areas. Therefore, on the occasion of the 40th anniversary of China's reform and opening up, the authors decided that it was necessary to systematically analyze the cause of coastal

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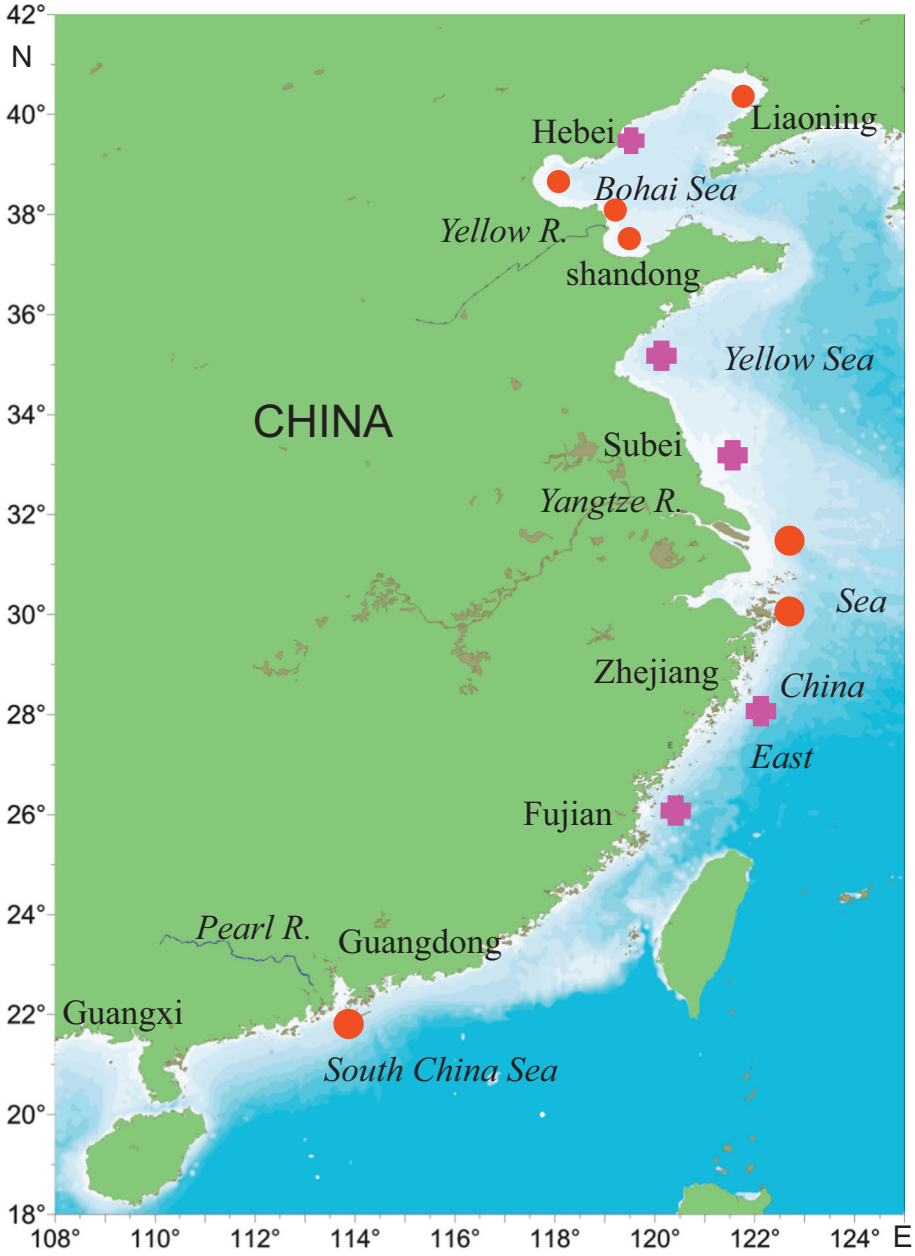

Fig. 1. Map of the China Seas and coastal eutrophication hotspots. The sites indicated by dots were coastal eutrophication hotspots before 2000, the sites indicated by dots and crosses were hotspots after 2000.

eutrophication, and to elucidate the historical evolution and future trends of its ecological and environmental effects in the China Seas. The purpose on the analysis was to identify controlling factors of coastal eutrophication as well as the relevant experience and lessons in marine environmental management over the past 40 years, so as to enable appropriate control and governance measures to be adopted in order to achieve and maintain a healthy marine environment in the China Seas, just like the "OSPAR Strategy to Combat Eutrophication" adopted by the European union (OSPAR Commission, 2010).

In this paper, we review the history of coastal eutrophication in the China Seas in the past 40 years with regard to the causes (i.e. stress, including terrestrial nutrient inputs and the levels and structure of nutrients in coastal waters), and ecological and environmental effects (i.e. state, including phytoplankton composition and biomass, harmful algal blooms, and depleted dissolved oxygen etc.). The likely future trends for coastal eutrophication are also investigated.

2. Long-term changes in the flux and composition of land-sourced nutrients input to coastal waters

Anthropogenic activities (e.g. industrial and agricultural production, urban living, and aquaculture) result in nutrient inputs to coastal waters directly or indirectly, accelerating the external inputs of nutrients to coastal waters. Terrestrial inputs, especially river inputs, are the most important external source of nutrients in coastal waters of the China Seas (Qu and Kroeze, 2010).

In the last four decades, changes in the flux and composition of nutrients from major rivers in China varied according to the different rivers and the different nutrients. The variation trend of various nutrients differed in the same river, while there were also differences in the trend of the same nutrient among different rivers. The sum of freshwater discharge from the three largest Chinese rivers, namely the Yellow River, Yangtze River, and Pearl River, represents 73% of the total freshwater discharge from Chinese rivers into the China Seas