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Editor

Studies of the Biogeochemistry of Typical Estuaries and Bays in China

Springer

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ISSN 2197-9596 ISSN 2197-960X (electronic)
Springer Earth System Sciences
ISBN 978-3-662-58167-4 ISBN 978-3-662-58169-8 (eBook)
https://doi.org/10.1007/978-3-662-58169-8

Library of Congress Control Number: 2018962388

This Springer imprint is published by the registered company Springer-Verlag GmbH, DE part of Springer Nature
The registered company address is: Heidelberger Platz 3, 14197 Berlin, Germany

Foreword

Estuaries and Gulf regions are among the most heavily populated areas on earth with the most intensive human activities. It is roughly estimated that the riverine inputs lead to an annual freshwater discharge of 4.7×10^{13} m^3 into the ocean, with the transportation of $\sim 1.83 \times 10^{10}$ tons of particulate matter and $\sim 0.42 \times 10^{10}$ tons of dissolved material. Influenced by the complex hydrodynamics such as tide, wind, diluted water, and ocean currents, the estuaries and bay areas experience a series of significant physical and chemical changes, making the estuarine ecosystems unique from other marine waters. Due to the considerable nutrient input, estuaries, bays, and coastal waters represent one of the most productive areas in the world, where also harbor more than 90% of the marine fish and other economic biological resources. Therefore, the coastal zone including estuaries and bays plays an essential role in the survival and evolution of human society. However, rapid economic development and increasing human activities also cause the degradation of the estuarine and coastal systems, and the resultant eutrophication has become a global problem. Thus, studies on estuary and bay have received much attention from the oceanographers, among which estuarine biogeochemistry is one of the major focuses.

Marine biogeochemistry is an interdisciplinary research that mainly focuses on the source, distribution, transport, sink, and cycling of the compounds related to the marine biota and biological processes. In particular, the biogeochemical cycling of biogenic elements including carbon, nitrogen, phosphorus, silicon is among one of the most important and fundamental studies. As one of the key topics in the research of global change, marine biogeochemistry involves many subjects including oceanography, chemistry, biology, geology, ecology, and environmental sciences.

This book is devoted to the studies of the biogeochemistry of typical estuaries and bays in China, with the focus on biogeochemical cycling of the biogenic elements. The study areas include the Changjiang River, the largest river in China; the estuaries of the two largest rivers, the Changjiang estuary and the Yellow River estuary; and a semi-enclosed bay that is significantly impacted by human activities, the Jiaozhou Bay. These areas involve an important inland economic belt and two

coastal integrated economic belts in China, the Changjiang basin, the Changjiang River delta, and the Shandong Peninsula. To some extent, they are representative of typical rivers, estuaries, and bays environments and also have extensive research interests for oceanographers.

This study investigated Changjiang and its estuarine area as an integrated ecosystem, from the Changjiang upper reaches (Jinshajiang River) to the downstream estuary and the marine waters and from the atmosphere, land, to the ocean. The authors systematically studied the concentration distributions, variations, and removals as well as the molar ratios of various forms of nitrogen, phosphorus, and silicate in the Changjiang mainstream and tributaries in the dry and flood seasons. They provided a new perspective for the nutrient budget in the large watershed and quantitatively constrained the budget and control mechanisms of nitrogen and phosphorus in the Changjiang basin for the first time. They also investigated the behaviors and removals of various forms of phosphorus and silicon during estuarine mixing. Furthermore, they made the first measurements for the sedimentation fluxes of suspended particulate matter, phosphorus, and silicon and calculations for the mass balances of phosphorus and silicon in the turbidity maximum zone of the Changjiang estuary. A novel method was also established to estimate the ratio of resuspension of sediment. They are among the first to study nutrient structure, nutrient balance, and the ecological responses of phytoplankton in Jiaozhou Bay. They monitored the long-term changes in nutrients and their structure, documented the influences on phytoplankton community in the Changjiang estuary and Jiaozhou Bay, and explored the mechanism that triggers the occurrence of red tide. In this study, carbon, nitrogen, phosphorus, and silicon composition and their mole ratios of various size fractions of phytoplankton were reported; the silicon limitation on the growth of phytoplankton was illustrated in Jiaozhou Bay; a new concept was proposed for the nutrient structures in seawater and phytoplankton, and the balance between them. For the first time, they successfully isolated a large diatom of *Coscinodiscus asteromphalus* from natural seawater, determined its carbon, nitrogen, phosphorus, silicon, and chlorophyll *a* contents, and further estimated its contribution to the phytoplankton biomass in Jiaozhou Bay. Collectively, those studies are among the research frontier of the marine sciences, the findings of which will open a window and provide references to further studies.

Data of this book come directly from Prof. Shen's substantial research surveys and seagoing cruises. This book summarizes findings and discoveries in his long-term studies on biogeochemistry of the estuaries and bays and presents a number of innovations and creativity in this field. Some of the research outcomes mark pioneering discoveries in estuary/bay studies, which have aroused international influence and been frequently cited by researchers of home and abroad. This recounting of these research findings represents China's research excellence in estuarine biogeochemistry and is of essential theoretical significance and academic values, so as to provide scientific support for coastal management and ecological–environmental protection.

The publishing of this book is dedicated to the 50th anniversary of Prof. Zhiliang Shen's research in marine sciences. It is with great pleasure I am writing this forward and I would like to express congratulations on this publication, which contributes to the development of China's marine research and greatly advances biogeochemical studies on estuaries and bays.

Qingdao, China
August 2018

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Preface

The special natural geographical environments and the processes of mixing of freshwater–saltwater, tide, terrigenous matter input, etc., of estuaries and bays make them to be unique ecological systems with complex structure different from other waters of the ocean. On the other hand, the important function of estuaries and bays in the global economy and social development also makes them strongly affected by human activities, and thus their ecological structure and function are sometimes vulnerable and unstable. There are three major problems for human at present: population, resources, and environment, all which become more serious in the areas of estuary and bay. In the long term, the impact of human activities on the marine ecosystem is consistent, and human impact on the biogenic elements is fundamental and significant. Nitrogen, phosphorus, and silicon are essential nutrients for marine phytoplankton, which run through every link of the food chain and marine biological processes, and directly affect the primary productivity of the ocean. However, excessive nutrient is a kind of pollutant, harmful for water area and endangering marine ecological environment. For nearly half of a century, a global eutrophication has been caused by the input of excessive nutrients into estuaries, bays, and coastal waters. In China's Changjiang estuary, Bohai Bay, and Jiaozhou Bay waters, nitrogen and phosphorus have increased several times, and as a result the original nutrient structure was changed, which led to abnormal reproduction of phytoplankton, destroyed the ecological balance, and did harm to biological resources. The pollution caused by the increase of nitrogen and phosphorus in coastal waters is the most common problem in the world. Red tide is an inevitable result of eutrophication in waters. Before the 1970s, the red tide occurred only in a few coastal countries, but now more than 30 countries in the world were threatened by the red tide. These problems have restricted the development of human beings and brought us to a hot topic: How to protect the marine ecological environment? How to maintain the sustainable use of marine biological resources?

Marine biogeochemistry was developed after the 1980s with the implementation of major international cooperation programs such as International Global Change Study. The biogeochemical study on marine biogenic elements has been incorporated into many major international cooperative research projects and has become

one of the hot spots in the frontier of international marine research. For example, the plan of Land Ocean Interaction in Coastal Zone (LOICZ) organized by the International Geosphere-Biosphere Programme (IGBP) has taken the biogenic element transport in rivers and estuaries as a fundamental goal of its first action. The Joint Global Ocean Flux Study (JGOFS), Global Ocean Ecosystem Dynamics (GLOBEC) research, and Global Ocean Euphotic Zone Study (GOEZS) include the biogeochemical study of biogenic elements as its important research contents. In China, the biogeochemical study of biogenic elements in estuaries and bays can be dated back to the 1960s. Professor Li faxi et al. studied the geochemistry of silicon in Jiulongjiang estuary, and Prof. Gu Hongkan et al. carried out researches on "geochemistry of nitrogen in Jiaozhou Bay" and "geochemistry of nitrogen in the Changjiang estuary." After the 1980s, the related studies were more popular in China, such as "the study of fishery resources, ecological environment, and its proliferation potential in the Bohai Sea waters," "the investigation of marine environment and resources in Jiaozhou Bay," and "the investigation and study of impacts of the three gorge projects on ecology and environment of the Changjiang estuary." Some international cooperative studies had also been carried out, such as "study on sedimentary dynamics of the Changjiang estuary and its adjacent waters of China and the USA," "studies on the biochemical processes of pollutants and nutrients in the Changjiang estuary and its adjacent waters of China and France," and "study on biogeochemistry in the Yellow River estuary of China and France." In these projects, the biogeochemical studies of biogenic elements were important topics. Since the 1990s, in order to follow the development of the frontier field of international marine science, National Natural Science Foundation of China organized and implemented part of national key funds on the biogeochemical studies of biogenic elements in estuaries and bays, such as "study on key processes of ocean flux in the East China Sea," "study on fluxes of the Changjiang River estuary," "study on biogeochemical cycle of biogenic elements in Taiwan Strait," "study on carbon flux in the north China Sea," "study on dynamic process and sustainable development of typical bay ecosystem," and the national fund of "study on the controlling mechanism of inorganic nitrogen content in the Changjiang mouth." During the "Ninth Five-Year Plan" of the Chinese Academy of Sciences, a major project was set up to "study on the optimization model and productivity sustainability of typical bay ecosystems." And a key project "study on the budget dynamics of inorganic nitrogen in the Changjiang mouth" and the knowledge innovation projects "study on degradation mechanism of ecosystem in the eutrophication process of typical bays" and "study on the dynamic change of typical bay ecosystems in China under the influence of human activities" were carried out as well. In addition, the Chinese National Basic Research Priority Program (973) funded the project of "Ecology and Oceanography of Harmful Algal Blooms in China," and National Natural Science Foundation of China funded the key project of "study of eutrophication characteristics and countermeasures in the Changjiang estuary waters" and the national fund "stoichiometric nutrient balance and its ecological responses in Jiaozhou Bay," etc. The implementation of these projects has promoted our country to a new level in the biogeochemical study of

biogenic elements in the estuaries and bays. The publication of this book is based on the implementation of some of above projects.

This book focuses on the Changjiang estuary and Jiaozhou Bay as the main research areas, including nutrients, suspended particulate matter, phytoplankton, and heavy metals, involving biogeochemistry, marine chemistry, ecology, environmental science, oceanography, and biology.

This book consists of four parts. Part I systematically studies the distributions, variations, and removals of concentrations and molar ratios of various forms of nitrogen, phosphorus, and silicate in the Changjiang mainstream and tributaries in the dry and flood seasons, estimates the nutrient fluxes transported from tributaries to mainstream and the nutrients output fluxes of the Changjiang mouth, and illuminates the relationships of seasonal distributions and variations of nutrients in the estuary and the Changjiang runoff. For the first time, it quantitatively reveals the budgets and controlling mechanisms of nitrogen and phosphorus in the Changjiang catchment, suggests nitrogen coming mainly from precipitation, fertilizer nitrogen losses from gaseousness and agricultural nonpoint sources, the key factor in controlling high-content inorganic N in the Changjiang mouth, and suggests that the phosphorus in the Changjiang catchment comes mainly from agricultural nonpoint source fertilizer and soil phosphorus losses, and most of them are transferred to freshwater wetlands during transportation. Part II studies the behaviors and transfers of various forms of phosphorus and silicon during the Changjiang estuarine mixing, for the first time, measures the sedimentation fluxes of suspended particulate matter, phosphorus, and silicon, estimates the mass balances of phosphorus and silicon in the turbidity maximum zone, and establishes a new method for estimating the ratio of resuspension of estuary sediment. In this part, the distributions and variations of nutrient concentrations and structure and their effect on chlorophyll *a* in the upwelling area of the Changjiang estuary were studied, and the sources and transport fluxes of nutrients were estimated. In addition, this part also studies the removals and changes of heavy metals in the Changjiang estuary and studies the distributions and removals of nutrients in seawater and interstitial water of surface sediments in the Huanghe River estuary, nutrient transports in the Yellow River mouth, and phosphorus cycle in the estuary. Part III studies the long-term changes of nutrient concentrations and structure and its influences on phytoplankton community in the Changjiang estuary and Jiaozhou Bay, and discusses the succession of phytoplankton community and the occurrence mechanism of large-scale red tide in the Changjiang estuary. It is the first time to study nutrient structure, nutrient balance, and the ecological responses of phytoplankton in Jiaozhou Bay, measures the contents of carbon, nitrogen, phosphorus, silicon, and chlorophyll *a* in different-sized suspended particulates, studies the compositions of carbon, nitrogen, phosphorus, silicon, and molar ratios of different-sized fractions of phytoplankton and their ecological response to the nutrient structure of seawater, and reveals silica limitation of phytoplankton growth. A new concept of nutrient structure including the nutrient structures in seawater and in particulate, and the nutrient balance in between is proposed. This part also discusses the primary cause of the increased algal blooms in recent years in Jiaozhou Bay. Part IV studies the spatial and

temporal distributions and composition of particulate organic carbon in Jiaozhou Bay. It also studies the nutrient structure of laboratory-cultured dominant phytoplankton species, explores the differences of nutrient structures of cultured different-sized fractions of dominant phytoplankton species in different sea areas and seasons, and studies their relationship with the nutrient structure of seawater. In this part, in addition, the large diatom *Coscinodiscus asteromphalus* was separated from natural seawater for the first time, its chemical composition of carbon, nitrogen, phosphorus, and silicon combined with chlorophyll *a* was measured, and its contribution to phytoplankton biomass was estimated in Jiaozhou Bay. These studies are the hot spots in the forefront of international marine science.

Based on a large number of field investigations, this book summarizes the partial results of the author's long-term study on the biogeochemistry of the estuaries and bays, and it reflects the research level and progress in this field in China. These achievements have been innovated and developed in academic thinking, and some achievements and discoveries are the first time. These results have been widely influenced and cited at home and abroad. The research achievements showed by this book not only have important theoretical and practical significances for further studying the biogeochemistry of estuaries and bays, but also will provide a scientific basis for ecological–environmental management and protection in China.

Should point out that the results showed by this book only involve the part of the subject, some results are still preliminary and also need to be verified and perfected, and the related research may also need to be further strengthened. Since the study involving multiple subjects, the unique natural geographical environment of estuaries and bays, and the strong influences of human activities, the ecological environment is fragile and changeable, and new problems emerge in endlessly. We should further strengthen the study of the long-term changes of the biogenic elements in estuaries and bays, and strengthen the study on the balance of nutrient structure between seawater and phytoplankton and their ecological responses. It is necessary to further explore the mechanism of the transfer and interfacial exchange of the biogenic elements, and the dynamics process model of each link in the biogeochemical cycle of the biogenic elements is still to be established. It is suggested to strengthen the long-term regular and fixed-point observation of the main river estuaries and bays in China, and conduct multi-disciplinary joint research. At present, a contradiction between the worsening environmental pollution in the coastal waters and the rapid development of national economy in the coastal areas is faced in China, which provides a new opportunity for the development of this subject. Looking to the future, the study of biogeochemistry of estuaries and bays will benefit mankind.

The achievements of this book is dependent on the long-term funding of the Chinese Academy of Sciences and the National Natural Science Fund Committee, and also cannot leave the support and help of the leaders and colleagues of Institute of Oceanology, Chinese Academy of Sciences. We are very grateful to Yaping Ao, M. Dagg, Minhan Dai, Yuanchao Gai, Shangwu Gao, Hongkan Gu, Yujie Guo, P. Harisorn, Minghou Ji, Chaolun Li, Pengcheng Li, Yan Li, Xinian Ma, Hui Miao, Shaofeng Pei, Guangfa Ren, Huijuan Tang, Xuchen Wang, Yunfeng Wang, Yulin

Wu, Weiwei Xian, Longyuan Yang, Yun Yao, Rencheng Yu, Fang Zhang, Minghan Zhang, Ping Zhang, Qilong Zhang, Shumei Zhang, Weihong Zhao, Jiaozhou Bay Marine Ecosystem Research Station, and the Marine Economy and Technology Branch, the China Senior Professor Association, which provided part of data, valuable suggestions, and some other helps. These studies were supported by NSFC No. 39630060, 40076021, 40776043, 41176138, 49876020, and 50339040; NSFC for Creative Research Groups No. 40821004 and 41121064; the National Basic Research Priority Program (2001CB409700), KZCX2-YW-208, KZCX3-SW-214, KZCX3-SW-232, KZ951-A1-301, KZ952-S1-421, and KZ95T-04 from Chinese Academy of Sciences; SX(97)-11-4 and SX2004-010 from Three Gorges Project Construction Committee of the State Council; and the Research Foundation of Chinese Ecosystem Research Network. This book is funded by the publishing fund of the Institute of Oceanology, Chinese Academy of Sciences. In particular, we would like to thank Prof. Guipeng Yang, a famous chemical oceanographer, and Director, Institute of Marine Chemistry, Ocean University of China. He is very interested in supporting the publication of this book and writes a foreword for this book amidst his busy schedule. Finally, we would also like to thank everyone from Springer for their help and assistance, whose work has enabled this book to be published at an early date.

Qingdao, China Zhiliang Shen
July 2018

Parts of this monograph have been published in the following journal articles:

1. Shen Z. L., Zhou S. Q., Pei S. F., 2008. Transfer and transport of phosphorus and silica in the turbidity maximum zone of the Changjiang estuary. ***Estuarine, Coastal and Shelf Science*** 78 (3), 481–492. (Reproduced with permission from Elsevier)
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Editor and Contributors

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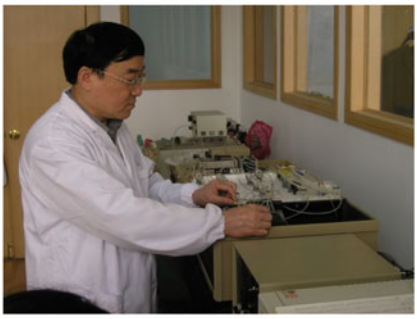

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1—In the office; 2—in the laboratory; 3—at the gate of Institute of Oceanology, Chinese Academy of Sciences; and 4—report at the fifth international symposium on the marine sciences of the Yellow Sea (Incheon, South Korea)

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