Estuarine, Coastal and Shelf Science 198 (2017) 92–105

Contents lists available at ScienceDirect

Estuarine, Coastal and Shelf Science

journal homepage: www.elsevier.com/locate/ecss

Impact of Water-Sediment Regulation Scheme on seasonal and spatial variations of biogeochemical factors in the Yellow River estuary

Yujue Wang [a], Dongyan Liu [b,*], Kenneth Lee [c], Zhijun Dong [a], Baoping Di [a], Yueqi Wang [a], Jingjing Zhang [a]

[a] Key Laboratory of Coastal Environmental Processes and Ecological Remediation, Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences, Yantai, Shandong 264003, PR China
[b] State Key Laboratory of Estuarine and Coastal Research, East China Normal University, Shanghai 200062, PR China
[c] Oceans and Atmosphere, Commonwealth Scientific Industrial Research Organisation (CSIRO), Australian Resources Research Centre, Kensington, WA 6151, Australia

ARTICLE INFO

Article history:
Received 11 November 2016
Received in revised form
21 July 2017
Accepted 7 September 2017
Available online 8 September 2017

Keywords:
Yellow river estuary
Water and sediment regulation scheme (WSRS)
Nutrients
Chl-*a*
Seasonal and spatial variation

ABSTRACT

Seasonal and spatial distributions of nutrients and chlorophyll-*a* (Chl-*a*), together with temperature, salinity and total suspended matter (TSM), were investigated in the Yellow River estuary (China) to examine the biogeochemical influence of the "Water and Sediment Regulation Scheme (WSRS)" that is used to manage outflows from the river. Four cruises in April, June (early phase of WSRS), July (late phase of WSRS) and September were conducted in 2013 (WSRS from 19th June to 12th July). The results showed that nutrient species could be divided into two major groups according to their seasonal and spatial distributions. One group included NO_3^-, dissolved organic nitrogen (DON) and $Si(OH)_4$, primarily from freshwater discharge. NO_3^- and DON related to anthropogenic sources were also separated from $Si(OH)_4$, which was related to weather. The other group included dissolved inorganic phosphorus (DIP), dissolved organic phosphorus (DOP), NO_2^-, and NH_4^+. Along with freshwater inputs, sediment absorption/desorption showed impacts on DIP and DOP concentration and distribution. Nitrification was a dominant factor controlling NO_2^- concentrations. NH_4^+ was influenced by both sediment absorption/desorption and nitrification. The WSRS not only shifted the seasonal patterns of nutrients in the estuary, with high concentrations moved from autumn to June and July, but also promoted the nutrient spread to the south central part of the Bohai Sea. Spatial distribution of Chlorophyll-*a* (Chl-*a*) was influenced by the WSRS, with high concentrations being found in the river mouth in June and September, flanking the river mouth in July, and in the south central part of the Bohai Sea in September. Although Chl-*a* concentrations increased in June and July, the seasonal patterns did not change. The highest concentrations were found in September. Nutrient loadings during the WSRS relieved DIP and $Si(OH)_4$ limitation in the estuary and south central Bohai Sea, causing an excess of DIN and disrupting the balance of DIN/DIP in the estuary and Bohai Sea. High turbidity and freshwater flushing depressed the growth of phytoplankton during the WSRS. The growth of phytoplankton was nutrient limited in June (DIP) when the WSRS started and in September after DIP and $Si(OH)_4$ had been consumed by phytoplankton.

1. Introduction

An estuary is an important transitional zone of interaction between river and ocean. The incoming freshwater delivers materials and energy to the sea, which influences the regulation of biogeochemical cycles and the magnitude of hydrodynamic processes that support the high primary production rates often observed in coastal ecosystems (Meybeck, 2004; Seitzinger et al., 2010). Nitrogen and phosphorus inputs from rivers to the coasts are estimated to have doubled over the past 50 years (Mackenzie et al., 2002). These high nutrient loadings, especially the overloading of nitrogen from anthropogenic sources, have been linked to observed variations in primary production and phytoplankton succession in many

* Corresponding author. Postal address: State Key Laboratory of Estuarine and Coastal Research, East China Normal University, No.3663 Northern Road of Zhongshan, Shanghai 200062, PR China.
E-mail address: dyliu@sklec.ecnu.edu.cn (D. Liu).

http://dx.doi.org/10.1016/j.ecss.2017.09.005
0272-7714/

of the world's estuaries (Rabalais et al., 1996; Lopes et al., 2007; Roubeix et al., 2008; Pearl et al., 2010). For example, increased inputs of nitrogen and phosphate together with a corresponding decrease of silicate within the Changjiang (Yangtze) estuary resulted in a decrease in diatoms and an increase in dinoflagellates (Jiang et al., 2010). Increasing numbers of cyanobacteria and dinoflagellates in Patos Lagoon Estuary (Brazil) were shown to be coincident with an increase in the N:P ratio (Haraguchi et al., 2015).

The impoundment of freshwater in artificial lakes and reservoirs (e.g., Nile River, Niger River, Colorado River and Yangtze River) for irrigation, drinking water, and hydroelectric power has greatly increased over the last century (Abam, 1999; Carriquiry et al., 2001; Tockner and Stanford, 2002; Walling, 2006). There is now growing concern that reduced freshwater inflow as a result of impoundment may cause environmental consequences for estuarine and near shore habitats, due to changes in multiple factors including increased salinity, alteration of hydrological and biogeochemical processes, and impacts on ecosystem function (Gillanders and Kingsford, 2002).

The Yellow River (Huanghe), P.R. China, provides an ideal case for environmental studies on variations in freshwater inputs associated with human activities. The river flows 5464 km eastward to the Bohai Sea through northwestern China from its headwaters in the east Qinghai–Tibet Plateau (Fig. 1). It is regarded as the second largest river in the world in terms of freshwater and sediment discharge. Freshwater discharge from the Yellow River contributes more than 75% of the total freshwater discharge to the Bohai Sea (Liu, 2015), and the sediment discharge represents 6% of the estimated global river sediment flux to the ocean (Milliman and Meade, 1983). These contributions of freshwater and sediment have changed dramatically, in three phases, due to human intervention. The first phase was the pre-regulated period from 1950 to 1968, when freshwater and sediment discharge was maintained at relatively consistent levels (Chen et al., 2005; Wang et al., 2007; Liu et al., 2012). The second phase was the highly regulated period during 1969–2001, when significant decreases in sediment and water discharge from the main channel of the Yellow River were caused mainly by regulation of reservoirs and increased river water use. For example, the average inflow of freshwater to the Bohai Sea between 1990 and 1999 (13.2×10^9 m^3/year) was reduced to 28.7% of the inflow observed in the 1950s, with a corresponding reduction in sediment load to 389.9×10^6 t/year, only 29.5% of the 1950's value (Milliman and Meade, 1983; Yang et al., 2004). The Water-Sediment Regulation Scheme (WSRS), started in 2002 and continuing to the present, is the third phase: discharge of freshwater and sediment has increased again.

The Yellow River Conservancy Committee initiated the WSRS with the aim of regulating water flow and reducing sediment deposition in the lower reaches of the river by the controlled release of large amounts of water over a short period (Bi et al., 2014; Wang et al., 2005, 2011). The WSRS involves two stages: (1) floodwater is released from the Xiaolangdi Reservoir (*XLD* in Fig. 1a) to control the sediment level and to improve the reservoir storage capacity, and (2) sediment-containing floods are delivered to the sea to decrease the riverbed sediment deposited in the lower reaches from Huayuankou to Lijin (Ma et al., 2011; Hu et al., 2015). The WSRS increased the annual freshwater discharge in the lower reaches of the river from less than 5×10^8 m^3 in 2000 to more than 2×10^9 m^3 after 2002 (Liu et al., 2012), and dramatically altered the seasonal patterns of water discharge and sediment load. WSRS discharge currently represents 14–55% of the annual water discharge and 26–66% of the annual sediment load. Its peak water flow occurs at least 2 months prior to the normal high flow season (Liu et al., 2012; Liu, 2015).

Variations in freshwater and sediment discharge from the Yellow River have altered environmental conditions in the Bohai Sea over the last 40 years of the 20th century. For example, mean sea surface salinity (SSS) increased by 0.074 psμ yr^{-1} during the highly regulated period as a result of decreased freshwater discharge (Liu et al., 2011). The increase in freshwater since the WSRS not only

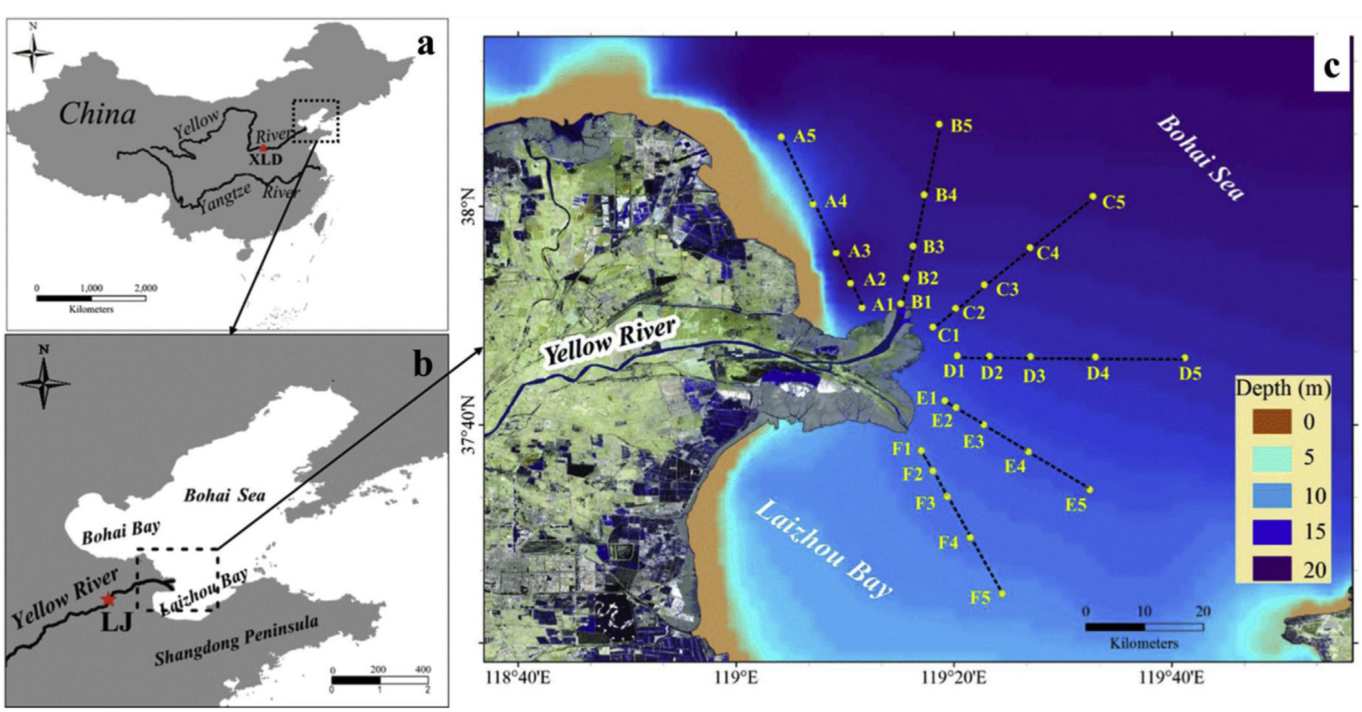

Fig. 1. Sampling stations and water depth in the Yellow River estuary, (a) location of the Yellow River and Xiaolangdi Reservoir (*XLD*); (b) location of study area and Station Lijin (*LJ*); (c) study transects at the mouth of the river.