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Nutrient characteristics in the Yangtze River Estuary and the adjacent East China Sea before and after impoundment of the Three Gorges Dam

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ABSTRACT

From November 2002 to 2006, five cruises were undertaken in the Yangtze River Estuary and the adjacent East China Sea to compare the nutrient concentrations, ratios and potential nutrient limitation of phytoplankton growth before and after impoundment (June 2003) of the Three Gorges Dam (TGD). Concentrations of dissolved inorganic nitrogen (DIN), soluble reactive phosphorus (SRP) and total nitrogen (TN) exhibited an increasing trend from 2002 to 2006. In contrast, total phosphorus (TP) concentration exhibited a decreasing trend. The mean concentrations of DIN, SRP, and TN in the total study area increased from 21.4 μM, 0.9 μM, and 41.8 μM in 2002 to 37.5 μM, 1.3 μM, and 82.2 μM in 2006, respectively, while TP decreased from 2.1 μM to 1.7 μM. The concentration of dissolved reactive silica (DRSi) had no major fluctuations and the differences were not significant. The mean concentration of DRSi in the total study area ranged from 52.5 to 92.3 μM. The Si:N ratio decreased significantly from 2.7 in 2002 to 1.3 in 2006, while TN:TP ratio increased from 22.1 to 80.3. The area of potential P limitation of phytoplankton growth expanded after 2003 and potential Si limitation appeared in 2005 and 2006. Potential P limitation mainly occurred in an area of salinity less than 30 after 2003, while potential Si limitation occurred where the salinity was greater than 30. By comparison with historical data, the concentrations of nitrate and SRP in this upper estuary during November 1980–2006 increased obviously after impoundment of TGD but DRSi decreased. Meanwhile, the ratios of N:P, Si:N and Si:P decreased obviously.

1. Introduction

Damming of rivers has a global impact on natural water resources. Impoundments change the characteristics of a water body, affecting not only the hydrology but also physical, chemical, and biological characteristics. Reservoirs disrupt the natural biogeochemical cycles of carbon, nutrients and metals and possibly affect the whole catchment including downstream ecosystems such as wetlands, estuaries, deltas and adjacent sea areas (Friedl and Wüest, 2002).

The Yangtze River (Changjiang River) ranks the third in length (6300 km), the fifth in fresh water discharge (9.8×10^{11} m^3/year) and the fourth in solid discharge (4.86×10^8 t/year) in the world (Bearsdley et al., 1985). It discharges into the East China Sea (ECS) and plays a fundamental role in the terrigenous inputs to the ECS and the Pacific Ocean.

The Three Gorges Dam (TGD) is the largest hydroelectric project ever built in China, as well as in the world. The dam site is 27 miles upstream from Yichang City proper, at Sandouping Town, 38 km upstream from the Gezhouba Dam Lock, inside the third of the Three Gorges. The construction of the TGD began in 1993 and is expected to be completed in 2009. By the time of completion, the reservoir is capable of containing 39.3 billion m^3 of water and will lift the water surface 175 m above sea level. An initial TGD water storage of 12.4 billion m^3 began on June 1, 2003, with the water level reaching 135 m 10 days later. The annual runoff downstream of the dam will remain unchanged after the operation of the reservoir; however, the dam will cause changes in discharge pattern of the Yangtze River. The flow downstream of the dam will decrease because of impoundment in October and increase from January to May, while the rest of the time the monthly flow will remain relatively unchanged.

The response of coastal area to upstream damming of the Yangtze River has raised considerable interest and debate. Before the construction of TGD, the effect of TGD on the hydrodynamics, nutrients concentration and distribution, productivity in this estuary and the adjacent sea were predicted (Shen et al., 1992; Chen, 2000). In recent years, researchers studied the influence of TGD on river's sediment discharge, microbial community structure and primary production in the ECS (Chen et al., 2008; Xu and Milliman, 2008; Gong et al., 2006; Yuan et al., 2007; Jiao et al., 2007). Since the Yangtze River is a major source of nutrients, it is of great importance to study the nutrient characteristics in the Yangtze River Estuary before and after impoundment of TGD in order to further understand the effect of the Three Gorges Project on the coastal ecosystem. The change in nutrients in the

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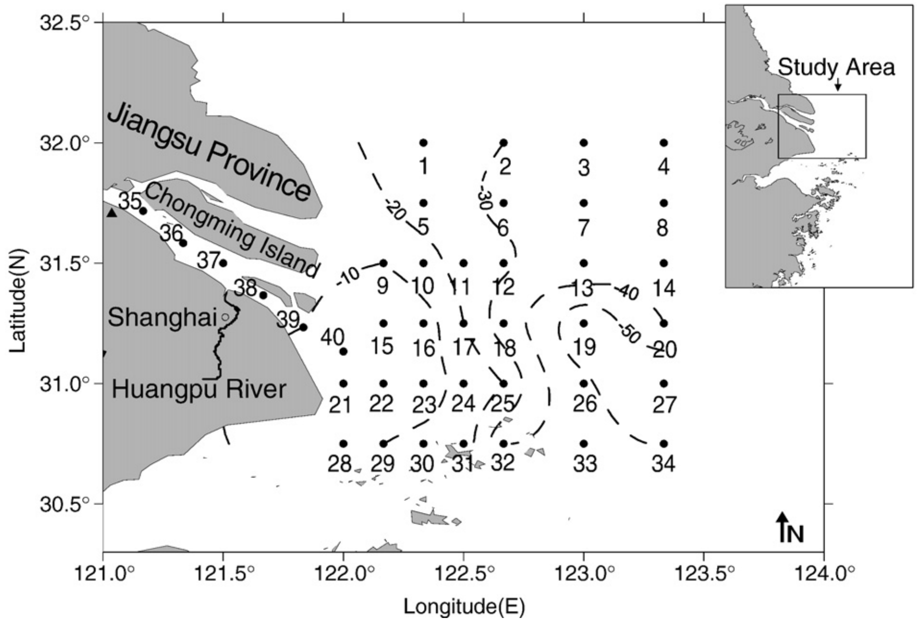

Fig. 1. Sampling stations in the Yangtze River Estuary and the adjacent ECS. Each dot represents a survey station. The dashed lines are isobaths and depth is given in meters.

coastal zone in 2003 and 2004 due to the TGD has been reported (Yu et al., 2006; Gong et al., 2006; Chai et al., 2007). However, the effect of fresh input from the Yangtze River on this estuary and the adjacent sea might be phase-lagged (Delcroix and Murtugudde, 2002) and it was difficult to discuss the influence of TGD on the coastal ecosystem just shortly after impoundment. From November 2002 to Novemeber 2006, oceanographic investigations were conducted in the Yangtze River Estuary and the adjacent ECS before and after impoundment (June 2003) of the TGD. Based on the investigation, the objectives of this study were: (1) to compare nutrient concentrations and ratios before and after impoundment of TGD; (2) to compare potential nutrient limitation of phytoplankton growth before and after impoundment of TGD. The data were examined to check for possible causes of the change in nutrients before and after impoundment in the Yangtze River Estuary and the adjacent sea.

1.1. Description of the study area

The length of the Yangtze River Estuary from Xuliujing to the mouth is about 110 km and the width of estuary mouth is about 90 km. It is a mesotidal, partially mixed estuary characterized by semidiural tides, with a mean tidal amplitude of 2.8 m (Shi, 2004) and tidal currents of 1.0–2.0 m/s. The Yangtze River Estuary is a complex system, which is separated into North and South Branch, North and South Channel by Chongming, Changxing and Hengsha islands. Water mixing is very forceful in these long channels, which leads to strong sediment resuspension processes, with a turbidity maximum at the estuary mouth (Li and Zhang, 1998). The discharge of the Yangtze River varies seasonally. From May to October, in the wet seasons, the water delivery accounts for 71.7% of the annual total discharge. In the dry seasons, from November to April, the riverine outflow is 28.3% of the annual total discharge.

The Yangtze River's basin is characterized by many industrial and urban centers, especially along its lower reaches and the estuary. With the influence of the dense population, the extensive use of chemical fertilizers and domestic waste, the Yangtze River Estuary is facing the challenge of environmental deterioration. In recent decades, the Yangtze River Estuary has received a high loading of anthropogenic nutrients from more and more activities in agriculture, sewage due to massive economic growth and urban development. Investigations revealed that the nutrient load in the Yangtze River Estuary has increased approximately seven- to eight-fold since 1960 (Shen, 2001). As a result, eutrophication has become increasingly serious and noxious algal blooms have been of more frequent occurrence in the Yangtze River Estuary (Han et al., 2003).

2. Sampling and methods

2.1. Field sampling

Five cruises were carried out from 17th to 28th of November 2002, 30th of October to 2nd of November 2003, from 3rd to 8th of November 2004, from 18th to 26th of November 2005, from 17th to 27th of November 2006 in the Yangtze River Estuary and in the adjacent ESC, where 40 sampling stations were located (Fig. 1). The five surveys, covering periods before impoundment (November 2002) and after impoundment (November 2003–2006), were conducted from the upper estuary to the ECS, covering a salinity range of 0.1 to 35.

Water samples were collected from surface (depth of 0.5 m) and were analyzed for nitrate (NO_3-N), ammonium (NH_4-N), nitrite (NO_2-N), soluble reactive phosphorus (SRP), dissolved reactive silica (DRSi), total nitrogen (TN), total phosphorus (TP), phytoplankton chlorophyll *a* (Chl *a*) and suspended particulate matter (SPM). An aliquot of water was filtered on board through pre-ignited Whatman GF/F filters for

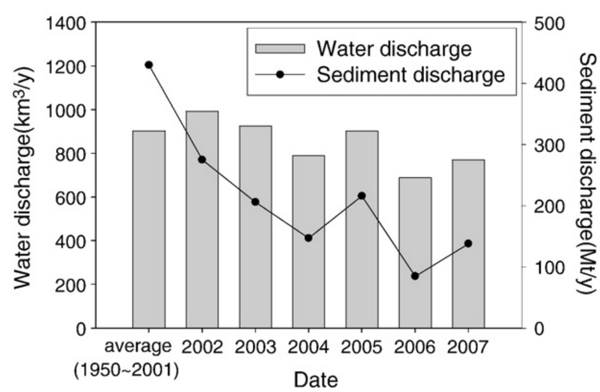

Fig. 2. Temporal variations of annual water and sediment discharge in Datong Hydrographic Station of the Yangtze River. Data are from the Yangtze River Water Resources Commission.