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Decadal changes in nutrient fluxes and environmental effects in the Jiulong River Estuary

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ABSTRACT

Estuaries are areas of both freshwater and seawater that are partially enclosed with contact to the open sea and a flow of fresh water. Although the Jiulong River Estuary has a relatively small catchment, this area was found to exhibit high nutrient fluxes. The nutrient fluxes showed obvious fluctuations for different years. The Jiulong River Estuary was predominantly P-limited, and was slowly moving towards higher DIN:DIP and DSi:DIP ratios as the nitrate concentrations increased. The high nutrient fluxes into the estuary may affect estuarine ecosystems by the alteration of DO concentrations in bottom waters, causing harm to benthic fauna due to a lack of oxygen, triggering algal blooms. Additionally, the Jiulong River Estuary was slowly moving towards lower DSi:DIN and DSi:DIP ratios along with the change of time scales, which caused nutrient limitation of phytoplankton growth as P and Si levels decreased and became more limiting.

1. Introduction

An estuary is a mixed zone of freshwater and seawater and this ecosystem exhibits high productivity. Estuaries may play an important role in interactions between land and the oceans, serving as a main channel for marine terrigenous material transport. Globally, terrestrial matter is delivered to the ocean at a rate of about 2.5×10^{10} $t \cdot yr^{-1}$, and about 90% of this material enters the ocean via estuary. Rivers of nutrient input can stimulate the primary productivity of marine ecosystems, especially estuary and coastal regions (Turner and Cope, 1998; Turner and Rabalais, 1994). After decades of rapid economic growth, there have been significant increases in human activities, population growth, municipal and industrial sewage discharge, more extensive application of agricultural chemical fertilizers, expanded poultry/livestock culture, and dam construction (Cao et al., 2014; Li et al., 2011; Strokal et al., 2014). The effects of these activities coupled with global climate change have led to the Jiulong River Estuary receiving a high loading of anthropogenic nutrients that have affected the environmental quality in estuarine and coastal waters (Cao et al., 2005; Yan et al., 2012). The environmental quality of estuaries can influence the global geochemical cycle.

Eutrophication is a widespread concern and has become increasingly serious as noxious algal blooms have started to occur more frequently in estuary zones (Chai et al., 2006). Estuaries generally receive a significant amount of nutrients, especially nitrogen and phosphorus, which seriously affect phytoplankton community composition and production (Cao et al., 2015; Rosenberg, 1985). Red tide is the common name for an algal bloom that is caused by a few species of dinoflagellates producing a red or brown colour. Red tides are events in which estuarine, marine, or fresh water algae accumulate rapidly in the water column, resulting in coloration of the surface water. Eutrophication is now recognized as a major factor contributing to habitat change and to the geographical and temporal expansion of some harmful algal bloom species (Anderson et al., 2002; Glibert et al., 2005b).

In this paper we analyzed extensive nutrient data sets from the Jiulong River Estuary. This analysis was performed with two major objectives: (1) to analyze change trends in the levels of nutrients, nutrient fluxes, and input sources in the Jiulong River Estuary over recent decades; and (2) to evaluate the role of nutrient proportions in the eutrophication of coastal marine ecosystems.

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2. Materials and methods

2.1. Study area

The Jiulong River Estuary is located on the southeast coast of Fujian, China, and is a shallow estuary that connects Xiamen Bay and the Taiwan Strait (Fig. 1). Its length is about 21 km from east to west and the width is about 6.5 km from north to south, for a total water area of 100 km^2. The Xiamen western waters and Xiamen eastern waters form an inverted "T" shape, and the mouth width of estuary is about 4.5 km. This estuary receives freshwater from the Jiulong River, the second largest river in Fujian Province, with a total drainage basin area of 14,741 km^2 with an average annual runoff of 1.49×10^{10} m^3 (Chen et al., 2015). The Jiulong River Estuary is mainly formed by the confluence of three major tributaries, and receives the total discharge from two of the major tributaries for an average annual runoff of 8.22×10^9 m^3 and 3.68×10^9 m^3 from the North Jiulong tributary and West Jiulong tributary, respectively.

The Jiulong River Catchment has a population of 6.52 million residents. The river catchment is politically administrated by six counties and two cities (Longyan and Zhangzhou) (Cao et al., 2005). The estuary is adjacent to Xiamen, a special economic zone in China that had an annual gross domestic product (GDP) growth rate of 7.2%, reaching 346.6 billion RMB with a population of 3.85 million in 2015. The Jiulong River Catchment and Xiamen area covers only 13.4% of the land area of this region, but contributes >13% of the GDP of Fujian Province. Many dam reservoirs have been constructed in the catchment for hydropower generation and irrigation. Of the land in the catchment, 78% is forest, 16% arable land, 3% urban and residential land, 2% water, and 1% is bare or grass land (Chen et al., 2012). Due to a number of factors, the Jiulong River Estuary receives nutrient fluxes from both the Jiulong River Catchment and its adjacent coastal areas.

2.2. Sampling and analysis

In our study we used nutrient concentration data from 2008 to 2011 that were obtained from previously published literature (Yan et al., 2012). Additionally, we collected nutrient concentration data from the years 1982–1983 and 1987–1988 (Chen, 1985; Chen et al., 1993). The mean monthly runoff data were obtained from published literature (Huang, 2008). Red tide data were obtained from Xiamen's marine environment quality bulletin in the Oceans and Fisheries Bureau of Xiamen PR China (http://www.xmhyj.gov.cn/Ocean/Index.aspx).

Water samples were collected in the estuary from near-surface and near-bottom depths using 5 L Niskin bottles (model QCCC-5, National Ocean Technology Center, China). Water samples were filtered onboard with 0.45 μm cellulose acetate membranes, then filtered water samples were poisoned with 1‰–2‰ chloroform and preserved at −20 °C for NO_3^--N (nitrate), NO_2^--N (nitrite), NH_4^+-N (ammonium) and PO_4^{3-}-P (DIP, dissolved inorganic phosphate) and DSi (dissolved silicate) determination. DIN (dissolved inorganic nitrogen) is the sum of NO_3^--N, NO_2^--N, and NH_4^+-N. NO_3^--N and NO_2^--N were measured by reducing NO_3^--N to NO_2^--N with a Cd column, and then determining NO_2^--N using the standard pink azo dye spectrophotometric method (Dai et al., 2008a). PO_4^{3-}-P, DSi and NH_4^+-N were measured based on the standard phospho-molybdenum blue, silicon molybdenum blue, and indophenol blue spectrophotometric procedures (Pai et al., 2001), respectively. NO_3^--N, NO_2^--N, NH_4^+-N, PO_4^{3-}-P, and DSi were determined using an AA3 Auto-Analyzer (Bran + Luebbe Co., Germany). Detection limits of the AA3 Auto-Analyzer were 0.1, 0.04, 0.5, 0.08, and 0.08 $\mu mol \cdot L^{-1}$ for NO_3^--N, NO_2^--N, NH_4^+-N, PO_4^{3-}-P, and DSi, respectively. Samples with high nutrient concentrations were properly diluted before determination.

2.3. Data analyses

We conducted normalization processing for the compiled nutrient concentration data and then performed statistical analysis with SPSS18.0 software. Significantly different means were separated at the 0.05 probability level by the least significant difference (LSD or Dunnett) test. The correlation between variables was analyzed with the Pearson correlation. Statistical analyses were carried out at a significance level of $\alpha = 0.05$. The data was graphed using the Origin 9.1 software.

Estimates of nutrient fluxes were developed for each studied nutrient using available data for nutrient mean concentrations and annual average monthly runoff (Billen et al., 1999; Li et al., 2007). The Jiulong River Estuary nutrient fluxes were calculated using the following formula: $F = C \times Q$; where F is the nutrient flux in the area of interest ($mg \cdot s^{-1}$); C is the nutrient mean concentrations in the area of interest ($mg \cdot L^{-1}$); and Q is the average monthly runoff in the area of interest ($m^3 \cdot s^{-1}$).

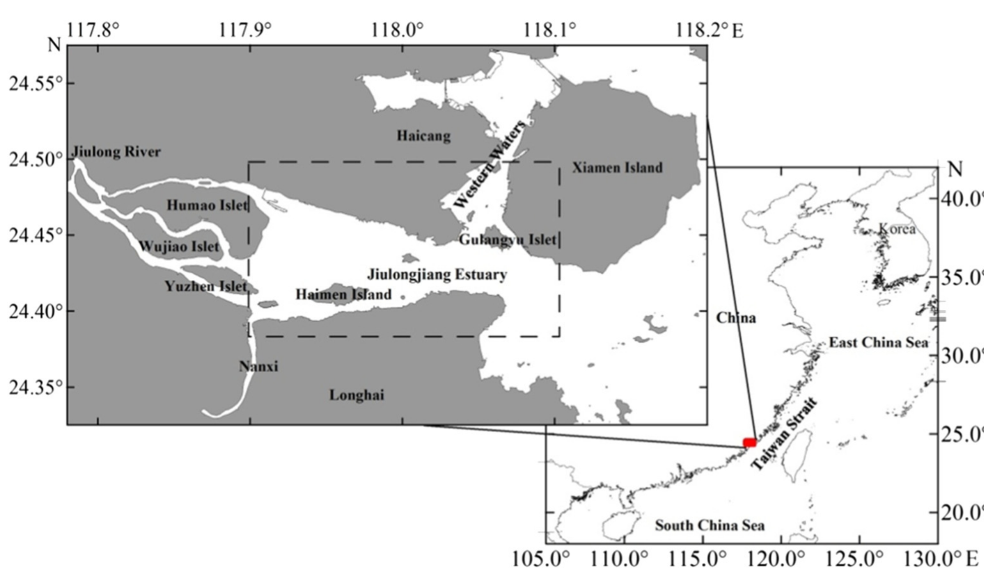

Fig. 1. Map of the Jiulong River Estuary showing the study area.