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Relationship between nutrients and plankton biomass in the turbidity maximum zone of the Pearl River Estuary

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ABSTRACT

Nutrients, dissolved and particulate organic carbon and plankton (bacterio-, phyto- and zoo-) were compared in the turbidity maximum zone (TMZ) and adjacent areas (non-TMZ) in the Pearl River estuary. Our results showed that high levels of suspended substances had marked effect on dynamics of nutrients and plankton in the TMZ. Based on the cluster analysis of total suspended solids (TSS) concentrations, all stations were divided into two groups, TMZ with average TSS of 171 mg/L and non-TMZ of 45 mg/L. Suspended substances adsorbed PO_4^{3-} and dissolved organic carbon, resulting in higher particulate phosphorus and organic carbon (POC) and lower PO_4^{3-} and DOC in the TMZ, compared to the non-TMZ. However, suspended substances had limited effect on nitrogenous nutrients. Phytoplankton growth was light-limited due to high concentrations of suspended substances in the TMZ and a peak of phytoplankton abundance appeared in the non-TMZ. In contrast, the highest bacterial abundance occurred in the TMZ, which was likely partly responsible for low DOC levels. Two peaks of zooplankton abundance observed in the TMZ and non-TMZ in the Pearl River estuary were primarily supported by bacteria and phytoplankton, respectively. Our finding implied that high levels of suspended solids in the TMZ affect the trophic balance.

Introduction

Turbidity maximum zone (TMZ) is the dynamic region in an estuary, characterized by higher concentration of suspended matter than upstream and downstream of the estuary. The formation of the TMZ is generally attributed to gravitational circulation, tidal trapping, and sediment resuspension (Wai et al., 2004). TMZ has been observed and studied in many estuaries, including Gironde Estuary in France (Allen et al., 1977), Chesapeake Bay in USA (Sanford et al., 2001), St. Lawrence Estuary in Canada (Hamblin, 1989), Fly River Estuary in Papua New Guinea (Wolanski et al., 1995), Tamar Estuary in England (Uncles and Stephens, 1993), and Changjiang Estuary in China (Shen et al., 2008). However, the formation mechanism of TMZ varies between different estuaries, the location and intensity of TMZ are sensitive to changes in tidal range and freshwater flow within one estuary (Mitchell, 2013).

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The high concentrations of suspended matter play an important role in regulating physical, chemical and biological reactions between dissolved and particulate species as well as interactions among particulate species (Gebhardt et al., 2005). The tidal current causes periodic deposition and resuspension of particles during tidal cycles and increases residence times of particle and dissolved material (Herman and Heip, 1999), which affects important physical and biological processes such as the flocculation, solubilization, sorption/desorption, redox and mineralization (Goni et al., 2005). For example, the periodic resuspension of particles at the TMZ may facilitate the oxidation of recalcitrant particulate organic matter by recharging the metal-oxide phases due to repeated exposure to oxygenated water (Aller, 1994, 1998). Several studies (Crump and Baross, 1996; Ploug et al., 2002; Servais and Garnier, 2006) have shown that bacteria attached to particles dominated the total bacterial activity in TMZ, and bacterial mineralization of the organic carbon was enhanced by the high suspended substances concentration in the TMZ. In addition, the high concentrations of the suspended particles in the TMZ decrease the light penetration which restricts phytoplankton growth (Garnier et al., 2001). However, the particulate organic matter in the TMZ can be considered as the basis of a detrital food chain which can be consumed by zooplankton and hyperbenthos directly (Islam et al., 2006; Mitchell, 2013). Furthermore, TMZ could create a predation refuge in high turbidity water (Islam et al., 2006).

The Pearl River Estuary (PRE) is a very complicated large-scale estuarine system in China. Pearl River has three main tributaries, West, North and East Rivers, which pass through a complex river network and flow into the South China Sea through eight entrances. The total annual runoff reaches 3.33×10^{11} m^3 and has an annual suspended sediment load of 8.87×10^7 tons (Zhao, 1990; Xia et al., 2004). The PRE has a high loading of anthropogenic nutrients from activities in agriculture, fish dike farming and sewage effluents due to the high population and economic development in Pearl River delta region (Yin et al., 2001; Huang et al., 2003) The TMZ in the PRE is well developed and is primarily characterized by a high TSS compared with adjacent waters. Previous studies on TMZ in the PRE only focus on their dynamic mechanism (Wai et al., 2004). However, little attention has been paid to biogeochemical processes in the TMZ. In this study, nutrients, organic carbon and plankton (bacterio-, phyto- and zoo-) were compared between TMZ and non-TMZ, in order to examine effect of turbidity maximum on patterns of nutrients and plankton in the PRE.

1. Materials and methods

In the present study, 16 stations were visited in the main channel of the PRE during 6 to 10 January 2011 (during high tide) (Fig. 1). Vertical profiles of salinity were measured *in situ* with a multi-parameter sensor YSI6600 (YSI, Yellow Springs, Ohio). Water samples were collected at the surface (in 0.5 m) and bottom layers (1 m above the seabed) at all stations using a 5-L Niskin bottle.

Each water sample was immediately filtered through Whatman GF/F filters (0.7 μm pore size), nutrient (NO_3^-, NO_2^-, NH_4^+, and PO_4^{3-}) were preserved in polyethylene bottle. Total dissolved phosphorus (TDP) and dissolved organic carbon (DOC) were preserved in glass bottle and immediately frozen (−20°C) until analyzed. Nutrient concentrations were determined colorimetrically following the protocols described by Grasshoff et al. (2009). TDP was measured using the approach described by Valderrama (1981). The concentrations of dissolved organic phosphorus (DOP) were determined by subtracting the dissolved inorganic phosphorus (PO_4^{3-}) concentrations from the TDP. Samples for DOC concentrations were analyzed with a high temperature combustion method using a Liquid TOC II analyzer (Knap et al., 1996). The analytical precision of nutrient, DOC and TDP was <5%.

Total suspended solids (TSS) samples were all filtered on to pre-weighed Whatman GF/F fiber filters (0.7 μm pore size), and the filters were dried at 45°C and weighed to determine the amount in mg/L of sample. Samples for particulate organic matter analysis were filtered on to precombusted Whatman GF/F filters and stored at −20°C. The concentrations of particulate organic carbon (POC) and particulate organic nitrogen (PON) were determined with a CHN Elemental Analyzer (Elementar, Vario EL-III, Germany). The analytical precision of POC and DOP was 6% and 7%, respectively. Total particulate phosphorus (TPP) was extracted with 1 mol/L hydrochloric acid (GR, Sigma) after ignition at a high temperature (550°C) then determined by using the ammonium molybdate method with ascorbic acid reduction (Aspila et al., 1976). For particulate inorganic phosphorus (PIP) measurements, samples were digested with 1 mol/L hydrochloric acid for 16 hr at room temperature, including 2 hr of vibration, and then analyzed according to Aspila et al. (1976). Particulate organic phosphorus (POP) was defined by subtracting the PIP from TPP. The analytical precision of PIP and TPP was <5%.

Water for bacteria enumeration was collected at the surface and prefiltered through a 20 μm mesh netting. Triplicate samples were fixed with formaldehyde (2% final concentration) for 15 min in 2 mL cryotubes, quick-frozen in liquid nitrogen. The bacteria abundance were counted with an epifluorescence microscope (OLYMPUS BX51, Japan) with a 100 W high-pressure mercury burner for epifluorescence illumination after staining with DAPI (4,6-diamidino-2-phenylindole dihydrochloride, Sigma) for at least 5 min in the dark (Porter and Feig, 1980). Stained bacterial cells were counted at 1000× magnification under UV excitation, and at least 10–20 random fields (minimum of 400 cells) were counted.

Water for phytoplankton enumeration was collected at the surface and preserved with 1% acidified Lugol's iodine solution. Phytoplankton were concentrated by settling 5–25 mL aliquots by sedimentation for 48 hr and then identified with a microscope (>2 μm were counted) according to the method described by Utermöhl (1958).

Zooplankton was sampled using a shallow-water type I net (the mouth area, 0.2 m^2; the mesh pore size, 505 μm) by towing vertically from 1 m above the bottom to the surface and the volume of the filtered water was determined with a flow-meter (Hydro-Bios) attached to the net. The zooplankton samples were preserved immediately in 5% formaldehyde, and then identified and counted with a microscope.

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