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Particulate nitrogen and phosphorus in the East China Sea and its adjacent Kuroshio waters and evaluation of budgets for the East China Sea Shelf

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ABSTRACT

Nitrogen (N) and phosphorus (P) in suspended particles are important to the cycles of N and P in marine ecosystem. Suspended particles were collected from the East China Sea (ECS) and its adjacent Kuroshio waters to investigate the composing and distribution characteristics of particulate inorganic and organic nitrogen and phosphorus (PIN, PIP, PON and POP, respectively). The particulate N and P concentrations were fairly low in the Kuroshio water but much higher in the ECS water, especially in nearshore waters. PON and PIP were the dominant forms of particulate N and P, with an exception that POP was the major form of particulate P in the Kuroshio upper water. The regime of particulate N and P in the ECS was strongly influenced by riverine input, oceanic input, ocean current and photosynthesis. Among them, PON and POP were mainly from biogenic source, while PIN and PIP were originated from biogenic and external sources. And sedimentation, remineralization and resuspension were important influencing factors for the vertical distributions of particulate N and P.

The budgets of particulate N and P for the ECS Shelf during rainy season (May–October) were also evaluated. The total particulate N and P (TPN and TPP) fluxes from oceanic input are respectively 10.99 and 2.49 times of those from riverine input. And oceanic input contains more POP, which is liable to be decomposed into phosphate, than riverine input. Furthermore, particulate nutrients fluxes from photosynthesis are the overriding source of total influxes for the ECS Shelf, accounting for 90.93% of TPN and 89.37% of TPP influxes. As for the photosynthetic fixed N and P, only 6.17% and 7.60% of them can reach the seafloor, while up to 87.73% and 60.06% of them are likely to be remineralized. The POP-rich oceanic input and the intensive photosynthesis and remineralization processes play important roles in the biogeochemical cycles of N and P in the ECS.

1. Introduction

Suspended particulate matter (SPM), a complex mixture of inorganic and organic solid substances including living organisms and detritus, plays an important role in the cycling of biogenic elements in aquatic ecosystems (Hung et al., 2007; Noe et al., 2007; Pettersson, 2001). In particular, dissolved nitrogen (N) and phosphorus (P) in seawater can be converted to particulate forms of N and P through photosynthesis, while particulate N and P also can be returned to seawater through remineralization process (Van Mooy et al., 2015; Voss and Hietanen, 2013; Weber and Deutsch, 2010). That is, particulate N and P account for a large proportion of N and P pools and are potential sources of dissolved nutrients (Lipizer et al., 2012; Loh and Bauer, 2000). What is more, particulate inorganic N and P (PIN and PIP) occur in mineral phase and mainly exist as adsorbed to particles as well as intracellular contents (Ruttenberg and Goñi, 1997; Yu et al., 2012), whereas particulate organic N and P (PON and POP) comprise N and P incorporated in living and detrital organic compounds (Loh and Bauer, 2000; Yoshimura et al., 2007). And different forms of particulate nutrients vary in their bioavailability and turnover times (Singh et al., 2015; Yoshimura et al., 2007). Therefore, all forms of particulate N and P are important to the biogeochemical cycles of N and P in marine ecosystem.

The East China Sea (ECS) is one of the largest marginal seas in the world, noted for its complex hydrogeologic condition, abundant substance, great primary productivity, rich biodiversity, active biogeochemical processes and thriving aquatic ecosystem (Chen, 2009; Zhou et al., 2015). But in recent years, the ECS coastal area has experienced

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severe environmental deterioration, such as considerably eutrophication and increasingly frequent outbreak of harmful algal blooms (HABs) in spring (Song, 2009; Strokal et al., 2014). Numerous studies and surveys show that the deterioration appears under the combined effects of a dramatically increased riverine input with relatively excessive nitrate and a sustained current input with relatively high concentration of phosphate (Chen and Wang, 1999; Li et al., 2014; Umezawa et al., 2014). However, SPM in the ECS also contains massive amount of N and P and acts as a potential support for outbreak of HABs once it is decomposed (Fang, 2004; Liu et al., 2016; Mayer et al., 1998). Therefore, without taking particulate forms of N and P into account, study on the eutrophication in ECS ecosystem would be incomplete.

Several sources have been reported to contribute to the particulate N and P in the ECS: (1) Song, 2009 external, mainly inorganic terrestrial SPM from rivers (Liu et al., 2016; Meng et al., 2015); (2) internal, primarily organic biogenous SPM related to primary production (Yu et al., 2012; Zhang et al., 2007b); (3) the contribution from ocean currents such as the Kuroshio (Chen and Wang, 1999; Fang, 2004); (4) resuspended particles from the bottom sediments (Liu et al., 2015; Yu et al., 2012). Even so, studies concerning particulate N and P are relatively sparse in comparison to the more comprehensive studies of dissolved nutrients or particulate organic carbon in the ECS (Yu et al., 2012). And the budgets of particulate nutrients for the ECS shelf are still undetermined.

Therefore, we investigated the concentrations of different forms of particulate N and P in the ECS and its adjacent Kuroshio waters during spring 2014, summarized their composing and distribution characteristics and systematically discussed the corresponding influencing factors. Furthermore, we calculated the budgets of particulate nutrients for the ECS Shelf in rainy season (May–October), the period when the HABs and hypoxia frequently occurred, and discussed the significance of different sources for the ECS ecosystem. This study will also provide data of particulate N and P for further research on N and P cycles in the ECS.

2. Materials and methods

2.1. Sampling

Field expedition was conducted aboard the R/V *Kexue I* in the ECS and its adjacent Kuroshio during the spring cruise (18 May–13 June 2014), and 58 stations along 11 transects were occupied in consideration of the current system in the study area (Fig. 1). Although we expected a thorough investigation in the open ECS and Kuroshio waters, we failed to set more sampling stations for sensitive factors. However, according to previous studies, the spatial variation ranges of physical and chemical properties in the Kuroshio current were relatively small (Chen et al., 1995; Liu et al., 2000; Umezawa et al., 2014; Zhang et al., 2007b) and the sampling stations in this study were representative.

At each station, hydrographic data including temperature (T) and salinity (S) were acquired by a conductivity-temperature-depth (CTD) profiler (Sea-bird SBE 9/11 plus). Water samples were collected at various depths with 10-liter Niskin bottles which were mounted onto a Rosette sampling attached to the CTD. As for each water sample, a certain amount of seawater (800–2000 ml for the ECS waters and 10000 ml for the Kuroshio waters) was filtered through a pre-combusted (450 °C for 4 h, acid-cleaned, dried at 60 °C and then weighted), 47 mm diameter glass-fiber filter (Whatman GF/F, nominal pore size around 0.7 μm). After filtration, the filter was rinsed with ultrapure water (Milli-Q) to remove dissolved nutrients and salts before stored. And 200–500 ml of seawater was filtered through an acid-cleaned (10% HCl and ultrapure water), 47 mm diameter cellulose-acetate membrane (Advantec, nominal pore size around 0.45 μm) for analysis of Chlorophyll *a* (Chl *a*). All of these filters and membranes were stored at −20 °C until further analysis could be conducted.

2.2. Analysis

In the laboratory, the glass-fiber filters were dried at 60 °C and reweighted to determine the concentrations of SPM. Then, these filters and blank filters were shaken with 25 ml 0.1 M HCl for 2 h and centrifuged at 4000 rpm for 5 min to extract particulate inorganic fractions, and the supernatants were diluted and analyzed by a nutrient automatic analyzer (Skalar SAN^{++}) to determine the PIN and PIP contents (Ruttenberg, 1992; Yu et al., 2012). The residues were digested with 25 ml 0.15 M alkaline $K_2S_2O_8$ at 124 °C for 1 h to determine the contents of PON and POP (Bronk et al., 2000; Yu et al., 2012). The relative standard deviations (RSD) for triplicate extractions and measurements were less than 10% for PIN, and less than 5% for PIP, PON and POP. In addition, total particulate N or P (TPN or TPP) was the sum of particulate inorganic and organic N or P. The Chl *a* on the cellulose-acetate membranes were extracted by 10 ml N,N-dimethylformamide at 4 °C in darkness for 0.5 h and then measured on a fluorescence spectrophotometer (Hitachi F-4600), with RSD less than 5% (Suzuki and Ishimaru, 1990).

3. Results

3.1. Hydrography

The hydrologic condition in the ECS is complicated, with the Changjiang Diluted Water (CDW) flows offshore, the Zhe-Min

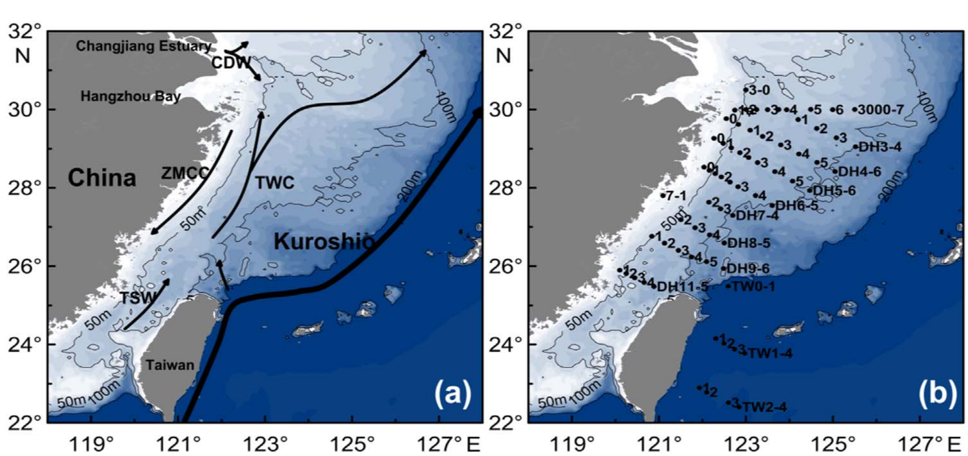

Fig. 1. Schematic diagrams showing circulation regimes (a) (Chen, 2009; Zhou et al., 2015) and sampling station locations (b) in the study area. The arrows indicate the Changjiang Diluted Water (CDW), the Zhe-Min Coastal Current (ZMCC), the Taiwan Strait Water (TSW), the Taiwan Warm Current (TWC) and the Kuroshio, respectively.