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Changes in concentrations of oxygen, dissolved nitrogen, phosphate, and silicate in the southern Yellow Sea, 1980–2012: Sources and seaward gradients

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ABSTRACT

To investigate the influence of nutrients on the occurrence of the world's largest trans-regional green tide bloom along the coast of the southern Yellow Sea, spatial and temporal variation in dissolved inorganic nutrients, dissolved oxygen and the dissolved inorganic nitrogen/phosphorus (N/P ratio) in the southern Yellow Sea from the 1980s to 2012 were analyzed on the basis of our field data and historical data. The transport and concentration of nutrients and oxygen may be significantly affected by the complex hydrographic conditions that were found in the southern Yellow Sea year-round. The input from diverse nutrient sources, especially from the Yangtze river plume, the rising nutrient loading from rivers and mariculture along the Subei coast, could contribute to sustaining green algal blooms. The highest chlorophyll-a concentration appeared in 2012 of the study area. The horizontal distribution of nitrate, phosphate and silicate generally decreased from the nearshore to offshore waters from the 1980s to the present. A zone of high nutrient concentrations was generally found in the southwestern southern Yellow Sea (121–123°E, 32–33°N) over the past three decades, which may be primarily induced by the input of the Yangtze river plume into this area. The lowest nutrient concentrations were found in the mid-north of the southern Yellow Sea (122–124°E, 34–36°N). A zone of high DO concentrations was identified in the northeastern region of the study area (122–123.5°E, 35–36°N). Though ammonium values fluctuated during 1984–2012, nitrate and DIN concentrations increased across the 30 years of sampling, implying the intense influence of terrestrial discharge to the southern Yellow Sea. And the high nitrogen levels may be one of the most important contributors to green algal blooms in this area. Phosphate concentrations fluctuated from the 1980s to 2005 and have since decreased. A large upward spike in the N/P ratio was apparent in 2008 and since, and the DO concentration decreased sharply in the same year. Concentrations of dissolved inorganic nutrients and oxygen were generally high in winter, lower in summer.

1. Introduction

Nitrogen (N), phosphorus (P) and silicon (Si) are essential biogenic elements for phytoplankton growth in seawater, and dissolved oxygen (DO), pH and carbon are also important (Giblin et al., 2010; Yu et al., 2013). Biogenic elements determine the geochemical characteristics of the sea and in particular its degree of eutrophication. Owing to the close correlations of biogenic elements with primary productivity, terrestrial input, and other environmental conditions, it is necessary to investigate the chemical oceanography (such as the spatiotemporal variation, transport regime or sources) of biogenic elements in coastal waters. The chemical oceanography of biogenic elements in the southern Yellow Sea (SYS), the present study area, however, has remained poorly defined. Liu et al. (2000) discussed the spatiotemporal distributions and transfer of nutrients in the Yellow Sea (YS) and the

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East China Sea (ECS) based on prior studies. Recent progress on the biogeochemistry of major elements in the YS was reviewed by Wang et al. (2001), who emphasized the need for additional, future work on the variation of biogenic elements in the region.

The SYS has been considered one of the most prolific fishing grounds in the China Sea, attracting a lot of attention for its high productivity. The fishery resources of the SYS have declined in recent decades because of harmful algal blooms (HABs), over-exploitation and climate change (Zheng et al., 2006; Zhang et al., 2008; Tang et al., 2010). Since 2007, green tides have become a severe problem that impacts the coastal areas of the SYS, even affecting the hosting of the 2008 Olympic Games (Xia et al., 2009; Wang et al., 2011; Gao et al., 2012; Liu et al., 2013a). In 2013, green tides affected 29,733 km^2 in the SYS, an area markedly greater than in 2011 and 2012 (SOA, 2013). Because the occurrence of the macroalgal bloom was related to high nutrient levels (Shi et al., 2013; Liu et al., 2013a), it is especially important to study the chemical oceanography of biogenic elements in the SYS.

In this paper, we determined the decadal shifts in nitrate, phosphate, silicate, N/P ratio, and dissolved oxygen concentrations away from shore in the SYS from the 1980s to 2012, evaluated spatial differences and effects of the hydrographic factors and diverse nutrient sources, especially the Yangtze plume, and interactions of the nutrients, oxygen and primary production.

2. Materials and methods

2.1. Study area

The study area of the present study is located at ~120–125°E, 32–37°N, covering most of the SYS (Fig. 1). The SYS is a semi-enclosed continental shelf and marginal sea located between northern China and the Korean peninsula (Fig. 1A). It is part of the northwestern Pacific Ocean, linking with the North Yellow Sea to the north and the East China Sea to the south (Lin et al., 2005). It is also characterized by a wide shelf area near Northeast Asia, which has a shallow basin with an average depth of 44 m (Fu et al., 2009). Shandong peninsula and Jiangsu province locate in the west bank of the SYS, containing the higher population, more fertilizer used in agriculture and the developed mariculture along the coastal waters (Fig. 1B). Lianyungang, Yancheng and Nantong are three main coastal cities in Jiangsu province, where set up large areas of coastal animal aquaculture pond systems. Additionally, Guanhe River and Sheyang River are two major rivers flowing through the Jiangsu province, discharging large amounts of nutrients into seawater in the west coast of SYS (Liu et al., 2013a).

Owing to the year-round influence of several ocean currents, the SYS also has complex hydrographic conditions. The general circulation pattern in the SYS is characterized by a counterclockwise gyre with the northwestward Yellow Sea Warm Current (YSWC) and southward Yellow Sea Coastal Current (YSCC) along the western Chinese coasts (Hu et al., 2013) (Fig. 1B). The Changjiang (Yangtze) Diluted Water (CDW) driven by the summer monsoon flows northeastward into the SYS, and under the influence of the seasonal thermocline, the Yellow Sea Cold Water Mass (YSCWM) is isolated in the central area of the SYS (Lie et al., 2001; Zhang et al., 2008; Liu et al., 2009b). In addition, the Subei and Lubei Coastal Currents, which are located in the western and shallower parts of the SYS, flow southward year-round (Lin et al., 2005), and the Yangtze (Changjiang) River, the largest river in China, carries large amounts of dissolved and suspended matter into the SYS (Hu et al., 2004; Wang, 2006). These ocean currents result in pronounced spatiotemporal variability and in the exchange and distribution of biogenic elements on the SYS.

2.2. Data sources

The data used in the present study are derived from our own observations taken during 6 cruises from 1997 to 2012 in the SYS and from the results of previously published studies in this area. The field data and other key historical data sources for biogenic elements (NO_3–N, NO_2–N, NH_4–N, PO_4–P, SiO_3–Si and DO), N/P ratio, and chlorophyll-a in the study area are listed in Table 1. Additional published references are indicated in each section.

To analyze the horizontal distribution of biogenic elements, N/P ratio, chlorophyll-a, temperature (T) and salinity (S) from the 1980s to 2012 in the SYS, surface survey data from 1984 to 1987, 1996–1998, 2006–2007 and 2012 were selected in the present study to illustrate conditions in the 1980s, 1990s, 2000s and 2010s. Spring data for each period were chosen to maintain consistency in the analysis. The cruise details for each period are shown in Table 2.

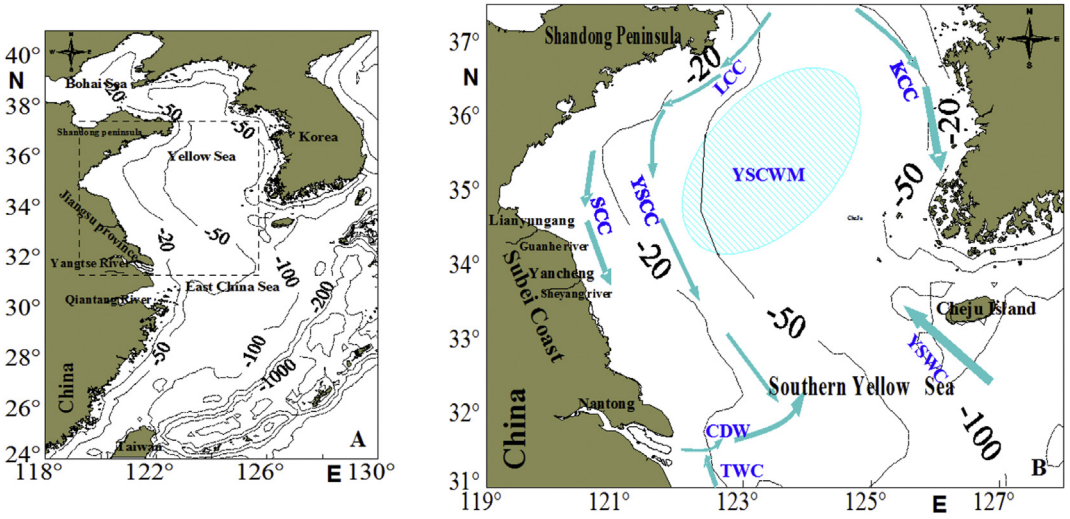

Fig. 1. Maps of the study area with isobath (m). A) map of the Chinese seas, including the entire southern Yellow Sea (the dashed rectangle indicates the study area of the annual and seasonal analyses of biogenic elements in the SYS); B) shows ocean currents in the SYS (note: SCC, Subei Coastal Current; LCC, Lubei Coastal Current; YSCC, Yellow Sea Coastal Current; KCC, Korean Coastal Current; YSWC, Yellow Sea Warm Current; CDW, Changjiang Diluted Water; YSCWM, Yellow Sea Cold Water Mass; and TWC, Taiwan Warm Current).