Continental Shelf Research ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Continental Shelf Research

journal homepage: www.elsevier.com/locate/csr

# Long-term variation of nutrients in the southern Yellow Sea

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ARTICLE INFO

*Article history:*
Received 3 February 2015
Received in revised form
8 July 2015
Accepted 6 August 2015

*Keywords:*
Southern Yellow Sea
Nutrient
Riverine input
Atmospheric deposition
Long-term environmental evolution

ABSTRACT

Nutrients play a major role in sustaining marine ecosystems. However, in the past few decades, nutrient inputs from land have significantly changed worldwide, resulting in the variations in nutrient concentrations and compositions in marginal seas. Based on historical data, the long-term variation patterns of nutrients and its compositions, as well as its potential influencing factors, were presented in the southern Yellow Sea. The concentrations of $NO_3$-N and dissolved inorganic nitrogen (DIN) in the southern Yellow Sea have been continuously increasing from the 1980s, with a most rapid increase after the mid-1990s. While the concentrations of $SiO_3$-Si and $PO_4$-P generally exhibited a decreasing trend before the mid-1990s, and then gradually increased. The N/P ratio has been continuously increasing from the 1980s and run up to a level of $>16$ at the end of the last century. The Si/N ratio decreased rapidly from the mid-1980s to the mid-1990s and then maintained a low level of $\sim 1$ at the end of the last century and at the beginning of this century. Similar to the variation of $SiO_3$-Si, the Si/P ratio decreased from the 1970s to the mid-1990s and then started to increase gradually. There was an evolution trend from N limitation to P and Si limitation in the southern Yellow Sea. The variations in the concentrations of nutrients were related to the variations of the riverine flux and atmospheric deposition, and especially the long-term variations of $PO_4$-P and $SiO_3$-Si concentrations were both consistent with the variation of precipitation. In addition, the nutrient transport from the Kuroshio Subsurface Water to the continental shelf, in combination with the cultural eutrophication in the coastal zones, may also influence the nutrient levels in the southern Yellow Sea under the global change.



## 1. Introduction

The concentration and composition of nutrients have an important impact on the growth and reproduction of phytoplankton and the variation of their communities (Justic et al., 1995; Yunev et al., 2007; Zhou et al., 2008). In recent decades, human perturbations have rapidly accelerated eutrophication in coastal and estuarine waters (Anderson et al., 2002; Masó and Garcés, 2007; Yu and Shen, 2011). Consequently, a significant and disproportionate increase in the nutrient concentrations has been a widespread environmental problem in marginal seas (Jickells, 1998; Paerl, 2006; Danielsson et al., 2008). Because of its distinct impacts on the marine ecosystems (e.g. phytoplankton biomass increase, diatom–dinoflagellate ratio alteration, and frequent harmful algal blooms), the long-term variation of nutrients in marginal seas has gradually become an important topic in marine biogeochemistry, and some studies have been carried out to illustrate its evolution and a succession of ecological impacts in different areas (Anderson et al., 2002; Paerl, 2006; Yunev et al., 2007; Zhou et al., 2008; Yu and Shen, 2011). Also, changes in nutrients are associated with hypoxia and ocean acidification in the coastal ocean (Rabalais et al., 2014; Cai et al., 2011).

Under the double influence of human activities and natural changes, abnormal disastrous ecological events, such as red tide (Zhou and Zhu, 2006), anoxia (Zhu et al., 2011) and jellyfish bloom (Sun, 2012), frequently occurred in Chinese marginal seas from the late 1990s. Consequently, the stability of the marine ecosystem has been severely threatened, and the evolution of physical–ecological environments in Chinese marginal seas has become a scientific issue that has drawn great attention (Yu et al., 2000; Shen, 2001; Zhang et al., 2004; Wang, 2006; Zhou et al., 2008; Wei et al., 2010a; Ning et al., 2009, 2010, 2011; Sun et al., 2011; Jiang et al., 2014).

The southern Yellow Sea is a semi-enclosed marginal sea of the Northwest Pacific Ocean, and is located between the mainland of China and the Korea Peninsula (Fig. 1). The coastal regions on either side of the southern Yellow Sea are densely populated, and the high socio-economic development is significantly causing severe stress on the marine environment. Influenced by the relatively intense land–ocean interactions, the southern Yellow Sea area can directly or

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http://dx.doi.org/10.1016/j.csr.2015.08.003
0278-4343/

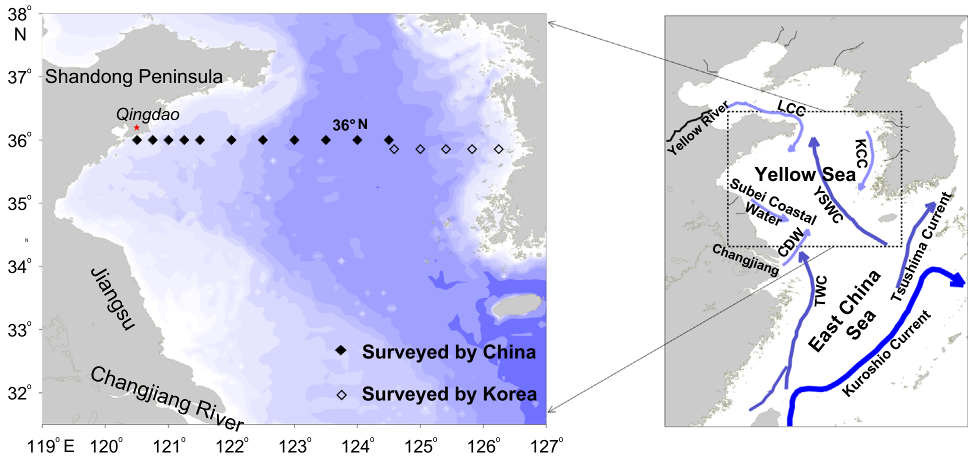


**Fig. 1.** Schematic illustration of the stations for historical data along the 36°N transect, and currents in the southern Yellow Sea. The lines with an arrow represent the Lubei coastal current (LCC), Yellow Sea warm current (YSWC), Changjiang River diluted water (CDW), Taiwan warm current (TWC), and Korea coastal current (KCC) (adapted from Guan, 1994 and Yuan et al., 2008). This is the general current field in winter except for the CDW.

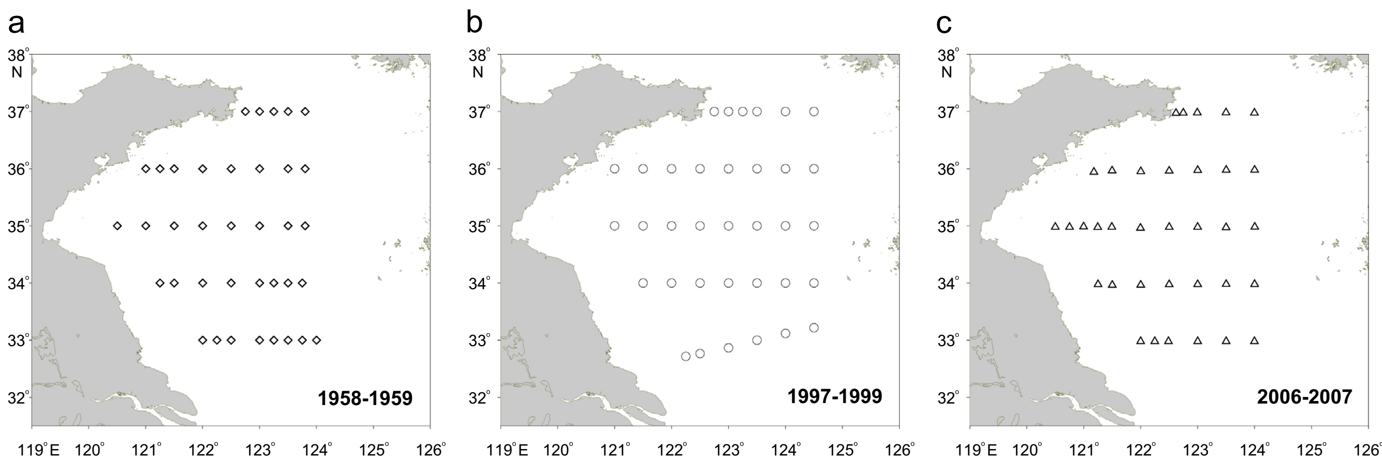


**Fig. 2.** Locations of large area survey stations in the southern Yellow Sea during different time periods.

indirectly receives a large amount of nutrients from rivers, including Changjiang and Yellow Rivers (Liu et al., 2009). Moreover, land-source nutrients can be also brought into the southern Yellow Sea via atmospheric transport (Chung et al., 1998; Zhang et al., 1999). Such by-products related to human activities are responsible for eutrophication in the coastal zone and offshore area (Yu and Shen, 2011; Shi et al., 2013). Nowadays, the human activities in combination with the natural changes have produced relatively prominent effects on the ecosystem of the southern Yellow sea and have resulted in the evolutionary of ecological environment. After entering the 21st century, a massive green alga (Qiao et al., 2008; Sun et al., 2008; Tang et al., 2010) and a jellyfish bloom (Sun, 2012) frequently occurred in the southern Yellow Sea, especially in recent years. In order to examine the changes in the conditions of nutrient in the southern Yellow Sea, Lin et al. (2005) previously studied the variations (1976–2000) of the physical and chemical factors along the 36°N transect (120.75–124.5°E) by using the transect survey data obtained from the China State Oceanic Administration and indicated that the concentration of dissolved inorganic nitrogen (DIN) in this marginal sea had increased, whereas the concentrations of dissolved inorganic phosphate ($PO_4$-P) and dissolved silicate ($SiO_3$-Si) had exhibited an overall decreasing trend. The study conducted by Gao and Li (2009) also showed that DIN in the southern Yellow Sea increased significantly in the 1990s compared to the 1950s, whereas P and Si nutrients decreased. These studies primarily focused on the variation of nutrients in the southern Yellow Sea before 2000; however, the continuous variation of nutrients in the southern Yellow Sea after 2000 is still unclear. In this paper, we fully considered the time series and spatial coverage of the data and used the multi-year continuous historical data of the 36°N (120.75–126.25°E) transect of the southern Yellow Sea in combination with survey data for a large scale area obtained from three different times to further analyze new variation patterns of the nutrients in the southern Yellow Sea, constituting a considerable expansion of previous work. We also explored the potential influencing factors to reveal the typicality of the regional response of this marginal sea to external forcing. This could lay the foundation for diagnosing the changes in the ecological environment and fishery resources in the Yellow Sea. It is significant to better understand the evolution of nutrient in this marginal sea.

## 2. Materials and methods

### 2.1. Data sources

The transect survey data used in the present study included the following: (1) data of the 36°N transect from the State Oceanic Administration (SOA) of China (from 1976 to 2006, and with radial range of 120.75–124.5°E) and (2) survey data of the 35.85°N transect from 1994 to 2004 provided by the Korea Oceanographic Data Center (KODC) (radial range of 124.60–126.25°E). Because of the very small difference between the 36°N and 35.85°N transects in terms of latitude, the 35.85°N transect was treated as the 36°N transect. Thus, the data of a complete transect that crossed the

Please cite this article as: Wei, Q., et al., Long-term variation of nutrients in the southern Yellow Sea. Continental Shelf Research (2015), http://dx.doi.org/10.1016/j.csr.2015.08.003