



Resolving the complex relationship between harmful algal blooms and environmental factors in the coastal waters adjacent to the Changjiang River estuary



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ABSTRACT

The sea area adjacent to the Changjiang River estuary is the most notable region for harmful algal blooms (HABs¹) in China as both diatom and dinoflagellate blooms have been recorded in this region. Affected by the Changjiang diluted water (CDW²) and currents from the open ocean (i.e., Taiwan warm current, TWC³), the environmental conditions in the coastal waters adjacent to the Changjiang River estuary are quite complex. To obtain a better understanding of the mechanisms of HABs in this region, analyses based on field investigation data collected by the National Basic Research Priority Program (CEOHAB I⁴) were performed using principle component analysis (PCA⁵), multiple regression analysis (MRA⁶) and path analysis (PA⁷). The results suggested that phosphate and silicate are the major factors that directly affect the diatom bloom, while dissolved inorganic nitrogen (DIN⁸), temperature and turbidity are the factors that influence the dinoflagellate bloom. CDW and the TWC have different roles in affecting the two types of algal blooms. CDW, which has a high concentration of nitrate and silicate, is essential for the diatom bloom, while the intrusion of the TWC (mainly Kuroshio subsurface water that is rich in phosphate at the bottom) is critical for the maintenance of the dinoflagellate bloom. The results of this study offer a better understanding of the mechanisms of HABs in the East China Sea.

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1. Introduction

The sea area adjacent to the Changjiang River estuary is the most notable region for harmful algal blooms (HABs) in China (Zhou and Zhu, 2006; He et al., 2013). A large number of HAB events have been reported in this region since the beginning of the 21st century. From 2000 to 2014, approximately 660 HAB events

were recorded in the East China Sea (ECS⁹), and most of them occurred in the sea area adjacent to the Changjiang River estuary (data from the State Oceanic Administration of China, Wang and Wu, 2009). The HABs that recently appeared in the ECS were mainly formed by harmful dinoflagellates, such as *Prorocentrum donghaiense*, *Karenia mikimotoi* and *Alexandrium* spp. (Lu and Goebel, 2001; Tang et al., 2006; Zhou and Zhu, 2006). These extensive dinoflagellate blooms pose potent threats to marine ecosystems in the ECS and lead to serious impacts on marine fisheries and public health (Anderson et al., 1996, 2012; Zhou and Zhu, 2006).

Studies on harmful algal blooms over the last decade have indicated an apparent shift of major bloom-forming species from diatoms (such as *Skeletonema* spp.) to dinoflagellates in the ECS around the year 2000, and both diatom blooms and dinoflagellate blooms have been observed in spring (Guo et al., 2014; Zhou and Zhu, 2006). Diatom blooms generally occurred in March, followed

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¹ HABs: harmful algal blooms.

² CDW: Changjiang diluted water.

³ TWC: Taiwan warm current.

⁴ CEOHAB: A national basic research priority program “ecology and oceanography of harmful algal blooms in China”.

⁵ PCA: principle component analysis.

⁶ MRA: multiple regression analysis.

⁷ PA: path analysis.

⁸ DIN: dissolved inorganic nitrogen.

⁹ ECS: East China Sea.

by extensive dinoflagellate blooms lasting from May to June. Previous studies indicated that HABs were affected by many environmental factors and hydrodynamic processes (Chen et al., 2003; Acevedo-Trejos et al., 2013), and nutrient over-enrichment was considered to be the most important driver for large-scale blooms in highly eutrophic systems (Anderson et al., 2002). In addition, the formation and distribution of HABs were also affected by temperature, salinity, and photosynthetically active radiation (Gao and Song, 2005). To date, most studies have focused on the effects of a single factor or the combined effects of several factors on HABs (Zhu et al., 2009b). There is little knowledge concerning the effects of environmental factors on the two different types of microalgal blooms in the ECS.

The coastal waters adjacent to the Changjiang River estuary, which are influenced by both Changjiang diluted water (CDW) and the Taiwan warm current (TWC), are very complex in terms of their hydrological and hydrodynamic conditions (Qi et al., 2014). CDW is characterized by low-salinity (generally lower than 29), a high nutrient concentration and a high N/P ratio, and often imparts strong stratification and phosphorus stress on the phytoplankton community in spring (Zhang et al., 2007a; Liu et al., 2013). The TWC, which is a warm current flowing northward along the southeast coast of China, is composed of two different water masses during spring and summer. The surface water of the TWC is formed by the mixing of Taiwan Strait water and Kuroshio surface water, while the deep water of the TWC is mainly from the subsurface water of the Kuroshio current in the sea area northeast of Taiwan (Yang et al., 2012; Lian et al., 2016). The intrusion of Kuroshio subsurface water, as well as the prevailing monsoon during summer, was believed to be major factors driving the coastal upwelling in the sea area adjacent to the Changjiang River estuary (Zhang et al., 2007b). The upwelling can bring high-salinity seawater that is rich in phosphate to the surface during spring and summer time (Yang et al., 2013), which will affect hydrodynamic processes, such as stratification, and the distribution pattern of nutrients in this region (Chen et al., 2004). Therefore, both CDW and the TWC are important for controlling the physical, chemical and biological factors in the sea area adjacent to the Changjiang River estuary. To link these factors to the distribution and dynamics of algal blooms in this region, it is necessary to understand the formation mechanisms of HABs and predict the long-term changes of HABs in this region.

Thus, this study focus on: (1) determining the major factors regulating the distribution and dynamics of diatom and dinoflagellate blooms; (2) evaluating the effects of CDW and the TWC on the occurrence of HABs in the coastal waters adjacent to the Changjiang River estuary. To accomplish these goals, a set of statistical methods, including principal component analysis (PCA), multiple regression analysis (MRA) and path analysis (PA), were employed to analyze data collected during field surveys performed by the National Basic Research Priority Program (CEOHAB I). PCA was carried out to classify the environmental factors. MRA was applied to establish multiple regression equations. PA, which can separate direct and indirect effects of independent variables (Light and Marchetti, 2007; Wells et al., 2008; Seo et al., 2010), was performed to compare the roles of different environmental factors. Thus, PCA, MRA and PA were applied to resolve the complex relationships between the various environmental factors and HABs in the sea area adjacent to the Changjiang River estuary.

2. Materials and methods

2.1. Data sources

A data set including chlorophyll-*a*, nutrients, temperature, turbidity and salinity was compiled from cruises performed by

CEOHAB I in 2005 (Fig. 1). Sampling sites were located in the sea area adjacent to the Changjiang River estuary (27°14'–30°32'N and 121°00'–123°23'E). The cruises were organized along seven transects (RA, RB, ZA, ZB, ZC, ZD and ZE) from March 27 (Julian Day 86) to June 17 (Julian Day 168) in the ECS.

The vertical profiles of temperature, salinity and turbidity were measured with a conductivity-temperature-depth recorder (SBE37-CTD¹⁰) and a multi parameter sonde (YSI6600) (Zhu et al., 2009a). Water samples were collected at different depths with a 20-L Niskin bottle at each sampling site. Phytoplankton cells in water were filtered onto glass fiber membranes (Whatman GF/F), and chlorophyll-*a* was extracted with acetone (90%) and measured using a fluorometer (Turner-Designs-Model 10) (Zhou et al., 2004). Water samples for nutrient analysis were filtered through glass fiber membranes and analyzed using colorimetric methods as described in Zhang et al. (2008). The results of the investigation regarding the nutrients and hydrological parameters were published in Zhang et al. (2008) and Zhu et al. (2009b).

The major bloom-forming microalgal species were identified with light microscopes based on their morphological features (Xie et al., 2008). During the cruises, a diatom bloom occurred in early spring, lasting from March 27 to April 12 (Julian Day 86 to 102), and the major bloom-forming species were *Skeletonema* spp. and *Thalassiosira* spp. The dinoflagellate bloom occurred from May 29 to June 17 in early summer (Julian Day 148 to 168), and the major bloom-forming species were *K. mikimotoi* and *P. donghaiense*. Data collected at the surface layer (above 10 m depth) were selected to study the influence of different environmental factors on the diatom and dinoflagellate blooms, and the chlorophyll-*a* data of discrete water sample measured in the laboratory with a fluorometer was used in the statistical analysis.

2.2. Data analysis

Data of chlorophyll-*a* were log 10-transformed before analysis to meet the assumptions of normality, homogeneity of variance, and linearity of the analyses. Data of the environmental factors with different units were standardized to the range of 0–1, and a collinearity diagnosis was performed to filter out environmental factors that had significant collinearity with other independent variables.

PCA, MRA and PA were then applied to study the relationships between the blooms and different environmental factors. PCA was performed to determine the major factors affecting the distribution and dynamics of the blooms. MRA was then conducted to establish multiple regression equations, and the regression coefficients in the regression models were used to calculate the path coefficients.

2.2.1. Principal component analysis

PCA was used to classify the dominant environmental factors and define the effects of the hidden variables (major components) on the biomass of phytoplankton in the study area. The standardized environmental factor datas, including dissolved inorganic nitrogen (DIN), phosphate, silicate, temperature, turbidity and salinity, were used for PCA, and the covariance matrix and its eigenvectors were calculated. The eigenvectors were ordered by the eigenvalues from the highest to the lowest, which assigned the components an order of significance. Only the components whose accumulative contribution rate reached 85 percent were taken into account. Each component had its own characteristics according to the corresponding environmental factors.

¹⁰ CTD: conductivity-temperature-depth recorder.

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