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Seasonal phytoplankton response to physical processes in the southern Yellow Sea

Xin Liu [a], Bangqin Huang [a,*], Qiu Huang [a], Lei Wang [a,e], Xiaobo Ni [b], Qisheng Tang [c], Song Sun [d], Hao Wei [e], Sumei Liu [f], Chaolun Li [d], Jun Sun [e]

[a] State Key Laboratory of Marine Environmental Science, Fujian Provincial Key Laboratory of Coastal Ecology and Environmental Studies, Xiamen University, 361005 Xiamen, China
[b] State Key Laboratory of Satellite Ocean Environment Dynamics, Second Institute of Oceanography, State Oceanic Administration, 310012 Hangzhou, China
[c] Yellow Sea Fisheries Research Institute, Chinese Academy of Fishery Sciences, 266071 Qingdao, China
[d] Key Laboratory of Marine Ecology and Environmental Sciences, Institute of Oceanology, Chinese Academy of Sciences, 266071 Qingdao, China
[e] College of Marine Science and Engineering, Tianjin University of Science and Technology, 300222 Tianjin, China
[f] Key Laboratory of Marine Chemistry Theory and Technology, Ministry of Education, Ocean University of China, 266100 Qingdao, China

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ABSTRACT

The Yellow Sea (YS) is a semi-enclosed marginal sea in the West Pacific. As part of the China GLOBEC-IMBER program, the present study set out to investigate the mechanisms involved in the seasonal patterns of phytoplankton biomass and community structure in the southern YS. During four cruises in April and October 2006, and March and August 2007, the phytoplankton spring bloom, the Yellow Sea Warm Current (YSWC) and the Yellow Sea Cold Water Mass (YSCWM) were the most remarkable biogeochemical events in the study area, involving significantly different phytoplankton communities. During cold seasons nutrient-rich water was observed, coincident with the occurrence of the YSWC, which is considered to be warm and saline water from the northward Kuroshio branch current (Cheju Warm Current). However, low Chl *a* concentrations (<0.6 mg m^{-3}) and a high relative abundance of prasinophytes (29% of Chl *a*, average value of the euphotic zone, and the same below) were observed in the YSWC area in March. During April a spring bloom occurred with very high concentrations of Chl *a* (7.69 mg m^{-3}) and fucoxanthin (1.98 mg m^{-3}), and was dominated by diatoms. The mechanism and processes of the spring bloom in the central YS are very complex and possibly unique, and the YSWC affects the distribution of nutrients and hydrological environment for phytoplankton growth. Low Chl *a* biomass (0.2 mg m^{-3}) and a low contribution of diatoms, but a high contribution of cyanobacteria (36%) were observed in the stratified central YS in August when the YSCWM prevailed, and a high relative abundance of chrysophytes (38%) was observed in October when the YSCWM was decaying. In a word, significant seasonal variations of phytoplankton biomass and community structure were observed in the central rather than the coastal area. These results were considered as the physical–chemical–biological characteristics of the unique ecosystem in the central YS.

1. Introduction

The Yellow Sea (YS) is a semi-enclosed marginal sea with depths ranging from 20 to 90 m in the western Pacific Ocean, bounded by China and Korea. It is famous for its high productivity and abundant fishery resources. Recently, environmental problems in the YS became the center of interest of oceanographers both in China and Korea and much related research work (e.g. the China GLOBEC-IMBER program and China Jellyfish Program) is in progress (Sun et al., 2011; Tang et al., 2007, 2010).

In the past few decades, a number of studies have been carried out in the YS both to investigate the circulation features and for water mass analysis (Huang et al., 2005; Lie, 1986; Lie et al., 2009; Park, 1986). Based on these studies, four major water masses are often distinguished in the YS. Among them, the Yellow Sea Cold Water Mass (YSCWM) is the most particular phenomenon, and this prevails from summer to fall with the boundary and temperature–salinity structure remaining almost unchanged each year (Zhang et al., 2008; and references therein). Briefly, it occurs in the central YS, and the primary characteristics are strong stratification and a very low temperature (<10 °C) in the deep waters in summer. In winter, the temperature and salinity are higher in the central area than in the surrounding water, which is associated with the Yellow Sea Warm Current (YSWC). As early as 1934, the YSWC was reported as a mean flow transporting saline water originating from the Kuroshio, and oceanic materials from the East China Sea, through the YS (Lie, 1986; Uda, 1934). On the other hand, along both the Chinese and Korean coasts, there are several coastal water currents, which flow southward, especially during winter. These coastal currents

* Corresponding author at: College of the Environment and Ecology, Xiamen University, Xiamen, Fujian 361005, China. Tel./fax: +86 592 2187783.
E-mail address: bqhuang@xmu.edu.cn (B. Huang).

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are usually characterized by low temperature, low salinity and rich nutrients (Chen, 2009). Besides these, the Changjiang (Yangtze) River, as one of the largest rivers in the world, affects both the northern East China Sea and the southern YS. Overall, these water masses interact differently during different seasons (Lie, 1986; Lie et al., 2009).

Although many studies provide strong evidence concerning the circulation features and water mass properties, extensive studies on the biogeochemical responses of these water masses are still needed. It is known that the YSWC transports warm and saline water to the YS, however the nutrient properties and phytoplankton responses of the YSWC are still unclear. The YSCWM not only influences temperature, but also distribution of the phytoplankton biomass, bacterial abundance and production (Hyun and Kim, 2003; Fu et al., 2009; Zhang et al., 2009). Studies show that there are large spatial and temporal variations of size-fractioned Chl *a* in the YS, and picophytoplankton is consistently of absolute dominance (>40%) in the central YS when the YSCWM prevails (Fu et al., 2009; Zhang et al., 2009). On the other hand, this deep cold water mass is a key player in the spatial variations of the dominant zooplankter, *Calanus sinicus* (Wang et al., 2009). Moreover, long-term observations indicate that the YS ecosystem is sensitive to environmental changes, including climate changes and anthropogenic impacts (He et al., 2013; Lin et al., 2005). Although the need for more field work on the ecosystem, particularly the structure and function of the communities and the relationships with biogeochemical processes have been suggested (He et al., 2013; Lin et al., 2005), there have never been any reports concerning the seasonal variations on phytoplankton community composition coupled with the physical processes in the YS.

In previous studies, the YSWC and the YSCWM are observed in the central area in different seasons, thus if the seasonal patterns of phytoplankton biomass and community structure in the central area are different from those in the coastal area. What are the roles of the YSWC and the YSCWM on the distributions of phytoplankton biomass and community structure in the YS? Our goal was to better understand the seasonal phytoplankton response to physical processes in the central YS.

2. Materials and methods

Four cruises were carried out on the R/V Beidou during 14–28 April 2006, 17 October–3 November 2006, 17–23 March 2007 and 3–9 August 2007 (Fig. 1). At each station, hydrographic measurements and water samples were conducted using a Seabird SBE 19 CTD profiler equipped with a 12 Niskin bottle Rosette sampler. Two stations (B2, B3) were not sampled during the April cruise, one station (H2) during the October cruise, and Transect Y (Stations Y2–8) during the August cruise.

Water samples for nutrients and pigments were taken with Niskin water samplers from 3–6 layers in the water column of bottom depth ranging from 30 to 80 m. Nutrient samples were filtered immediately through acid-cleaned 0.45 μm pore size acetate cellulose filters, and the filtrates were poisoned with saturated $HgCl_2$ solution. Nutrients including NO_3^-, NO_2^-, $PO_4^{3-}$and $Si(OH)_4$ were determined using an autoanalyzer (Model: Skalar SAN^{plus}). The precision of nutrient analysis in this study was ≤3%, and the detection limits of NO_3^-, NO_2^-, PO_4^{3-}, and

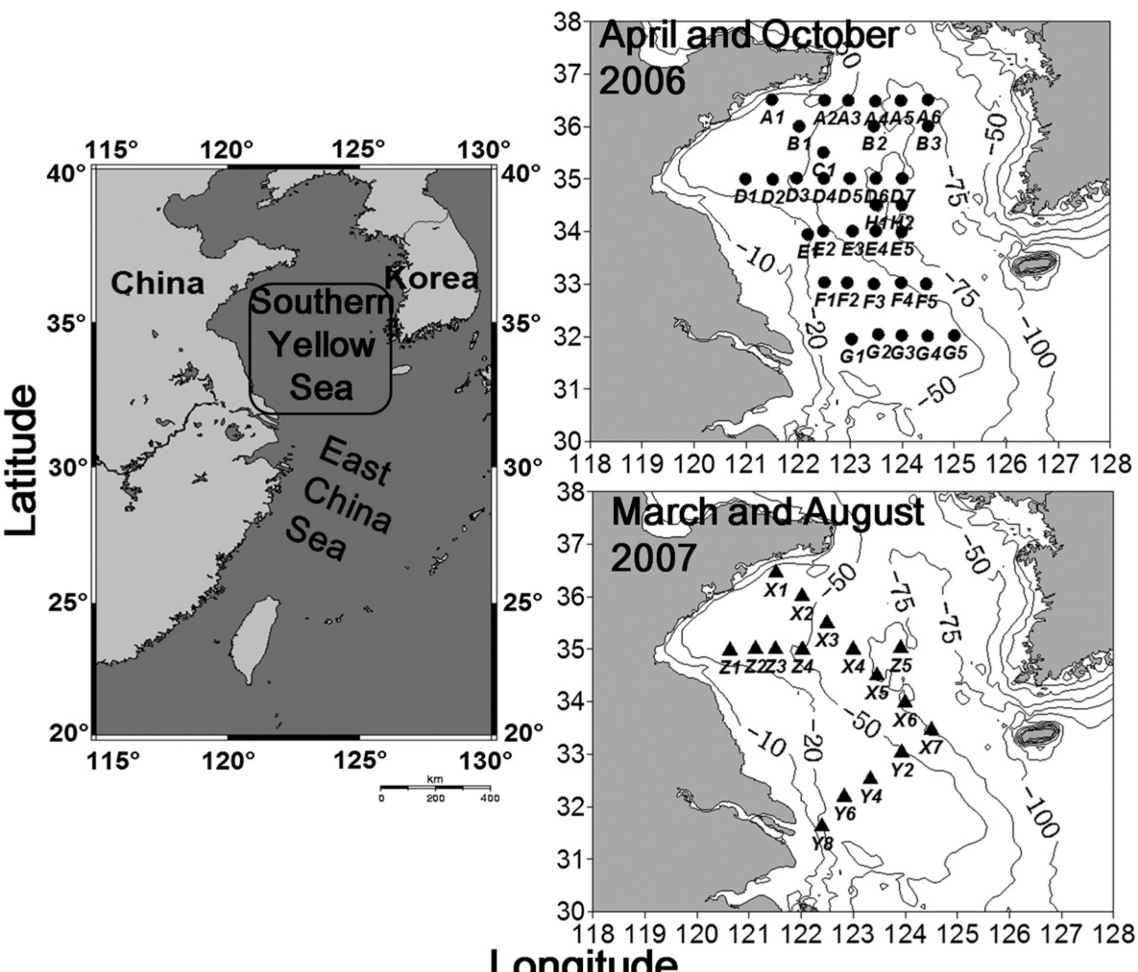

Fig. 1. Map of study area and sampling stations in the southern Yellow Sea during the four cruises in 2006–2007, with isobaths of 10, 20, 50, 75 and 100 m.