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

Contents lists available at ScienceDirect

Continental Shelf Research

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

Controlling factors of summer phytoplankton community in the Changjiang (Yangtze River) Estuary and adjacent East China Sea shelf

Zhibing Jiang [a,b,c], Jianfang Chen [a,b], Feng Zhou [b], Lu Shou [a,*], Quanzhen Chen [a], Bangyi Tao [b], Xiaojun Yan [c], Kui Wang [a]

[a] Key Laboratory of Marine Ecosystem and Biogeochemistry, Second Institute of Oceanography, State Oceanic Administration, Hangzhou 310012, China
[b] State Key Laboratory of Satellite Ocean Environment Dynamics, Second Institute of Oceanography, State Oceanic Administration, Hangzhou 310012, China
[c] Key Laboratory of Applied Marine Biotechnology, Ministry of Education, Marine College of Ningbo University, Ningbo 315211, China

ARTICLE INFO

Article history:
Received 30 November 2014
Received in revised form
4 April 2015
Accepted 7 April 2015

Keywords:
Changjiang Estuary
East China Sea
Phytoplankton
Physicochemical factors
Changjiang Diluted Water
Taiwan Warm Current

ABSTRACT

We analyzed the composition and distribution of phytoplankton in relation to physicochemical factors in the Changjiang (Yangtze River) Estuary and adjacent East China Sea shelf in June and August 2009. Diatoms and dinoflagellates dominated the community, particularly in eutrophic inshore waters controlled by the Changjiang Diluted Water (CDW), coastal current, and upwelling. However, high densities of cyanobacteria and cryptophytes were observed in the oligotrophic offshore waters influenced by the Taiwan Warm Current (TWC) and Kuroshio. In June, the northeastward CDW plume combined with the Yellow Sea Coastal Current induced algal bloom in the northern part of the CE. In August, the enhanced CDW formed two narrow, low-salinity tongues that extended eastward and southward (associated with the upwelling and coastal current), resulting in phytoplankton blooms off the CE and in the Zhejiang coastal waters, respectively. Phytoplankton abundance in August was considerably higher than in June, with increased solar radiation, CDW, and upwelling. The maximum abundance occurred on the surface in inshore turbid waters and on the subsurface (5–30 m) in offshore clear waters with increased stratification. Based on multidimensional scaling and cluster analysis, we found appreciable spatio-temporal variations in algal community composition. Different ecological groups corresponded with hydrographic distributions. Canonical correspondence analysis showed that nutrients, salinity, temperature, and suspended particulate matter were the main variables associated with community distribution. We suggest that the variations in summer phytoplankton community are highly correlated with the significant monthly and spatial variability in physicochemical properties, which are primarily controlled by the CDW and TWC.

1. Introduction

Large estuaries and adjacent coastal oceans, as transition zones between rivers and oceans, are subjected to the mutual effects of rivers and oceans. The phytoplankton in these environments are inevitably influenced by physical and chemical factors induced by abundant loading of riverine materials (e.g., freshwater associated with nutrients and sediments), highly variable inshore–offshore water exchange, oceanic circulation, and water mass movement (Dagg et al., 2004). Thus, phytoplankton are generally spatially and temporally dynamic in biomass and community composition in such areas, where the strong interaction between rivers and oceans yields highly fluctuating physical and chemical gradients (Smith and Demaster, 1996; Lohrenz et al., 1999; Harrison et al., 2008; Zhu et al., 2009).

Freshwater inflows provide high levels of nutrients (e.g., N, P, and Si) and other biogenic elements in the river plume along the salinity gradient that stimulates the primary production and the algal bloom adjacent to estuaries (Gong et al., 1996; Ning et al., 1998; Lohrenz et al., 1999; Dagg et al., 2004; Harrison et al., 2008; Frame and Lessard, 2009). In addition, the freshwater discharge or salinity variation associated with the addition of terrigenous nutrient (nutrient concentrations and ratios changes) affects the planktonic community structure and production in the estuaries and coastal oceans (Smayda, 1997; Li, 2002; Irwin et al., 2006; Chen et al., 2009; Jiang et al., 2014). These areas are generally characterized by abundant nutrients, a high phytoplankton biomass and primary production, and strong biological activities. Furthermore, massive sediment inflows as well as intense tidal

* Corresponding author. Fax: +86 571 88071539.
E-mail address: shoulu981@sina.com (L. Shou).

http://dx.doi.org/10.1016/j.csr.2015.04.009
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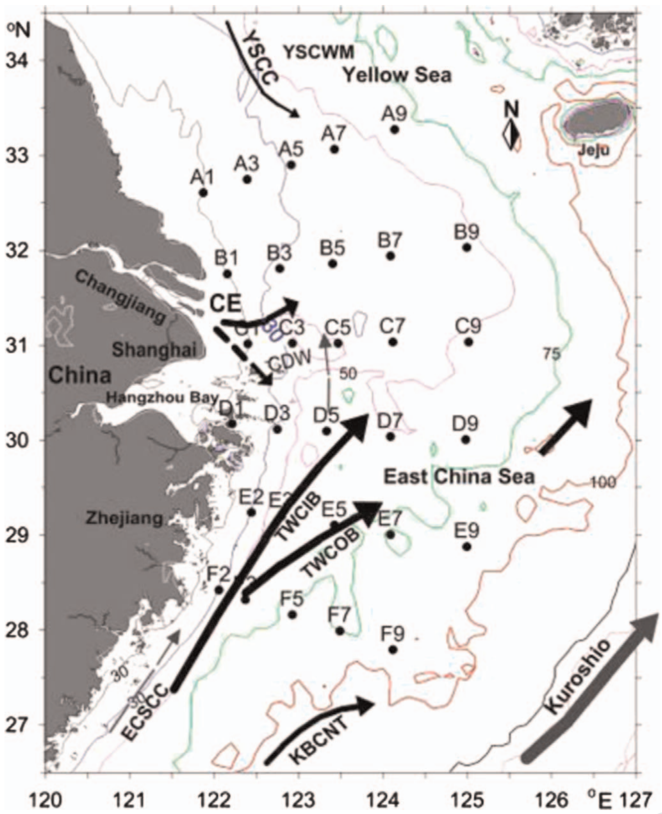

Fig. 1. Sampling stations and a schematic showing the summer surface circulation in the Changjiang Estuary (CE) and adjacent East China Sea (ECS) shelf (after Katoh et al., 2000; Ichikawa and Beardsley, 2002; Su and Yuan, 2005; Yang et al., 2011; Fig. S1). CDW: Changjiang Diluted Water; YSCC: Yellow Sea Coastal Current; ECSCC: ECS Coastal Current; YSCWM: Yellow Sea Cold Water Mass; TWC: Taiwan Warm Current; TWCIB: TWC inshore branch; TWCOB: TWC offshore branch; KBCNT: Kuroshio Branch Current northeast of Taiwan.

forcing and wind induce bottom resuspensionthat results in increased turbidity (Domingues et al., 2011). The sediment suspension and turbulence caused by runoff, tides, and waves influence the irradiance environment experienced by phytoplankton through an increase in vertical mixing by light penetration (Cloern, 1987; Dagg et al., 2004). This attenuation suppresses phytoplankton growth and productivity in many estuaries, despite high nutrient levels (Cole et al., 1992; Smith and Demaster, 1996; Lohrenz et al., 1999; Domingues et al., 2011). Moreover, changes in photosynthetic parameters have been associated with variations in community composition and structure and with photoacclimation resulting from vertical mixing and tides (Smith and Demaster, 1996; Goldman and McGillicuddy, 2003; Zhu et al., 2009; Key et al., 2010; Wang et al., 2014b).

In summer, the East China Sea (ECS) experiences significant circulations and water masses, including the Changjiang Diluted Water (CDW), Taiwan Warm Current (TWC), Kuroshio, Coastal Current, Yellow Sea Cold Water Mass, Shelf Mixed Water, and upwelling in the Changjiang (Yangtze River) Estuary (CE) and Zhejiang coastal waters (ZCW) (Fig. 1; Su and Yuan, 2005). The CE receives large amounts of freshwater associated with abundant nutrients and sediments from the Changjiang (Edmond et al., 1985) and induces the CDW to extend southward and/or northeastward under prevailing southerly winds (Beardsley et al., 1985; Lie et al., 2003). Therefore, the CE and ZCW are characterized by abundant nutrients and high turbidities, whereas the offshore oligotrophic open sea is nutrient-limited (Wang et al., 2003, 2013, 2014a). Consequently, phytoplankton in the CE and adjacent shelf exhibit complex spatio-temporal heterogeneity, which varies with the highly variable environmental conditions in summer (Furuya et al., 2003; Zhu et al., 2009).

Since 1959, numerous phytoplankton studies based on microscopic observations in the CE and adjacent areas (see references in Jiang et al., 2014) have used plankton nets with 76-μm mesh, despite non-colonial species with a small cell size being easy lost. A few studies have sampled water to qualitatively explore the composition and distribution of phytoplankton community in summer (Luan et al., 2006; Wang et al., 2008). The flow cytometry (Chiang et al., 2002; Jiao et al., 2002, 2005; Lee et al., 2014), pigment signature (Ning et al., 1988; Gong et al., 1996, 2003; Furuya et al., 2003; Chen et al., 2009; Zhu et al., 2009; Zhou et al., 2012; Wang et al., 2014b), and satellite remote sensing of chlorophyll a (Chla) concentration (Ning et al., 1998) have also been widely applied. These studies have preliminarily indicated that hydrodynamics, nutrients, and turbidities profoundly influenced the phytoplankton biomass and composition. However, these studies have rarely focused on the phytoplankton community composition and distribution in summer in relation to variable physicochemical factors. Moreover, relevant analyses have been limited mostly by the spatial (from river mouth to 123°E, 29°N–32°N) and temporal (only one cruise in summer) scales. Literature on the responses of the phytoplankton community to highly complex hydrographic and chemical conditions during summer remains poorly documented.

During summer, obvious monthly and spatial changes in physicochemical properties in the CE and adjacent ECS were observed, particularly the variations in wind field and river discharge associated with nutrients and sediments, turning and extension of the CDW, front shifting of the river plume, improvement of the light penetration and temperature elevation caused by increased solar irradiation, intensification of thermohaline stratification, increase in upwelling events, and increase in the incursion of the TWC under the prevailing southwestern monsoon (Edmond et al., 1985; Chen et al., 2003; Lie et al., 2003; Su and Yuan, 2005; Jiang et al., 2014; Zhou et al., 2015). In this context, we assumed that the phytoplankton in the CE and adjacent shelf exhibited significant spatio-temporal changes during summer that were primarily controlled by the CDW and TWC. To test this hypothesis, we conducted two interdisciplinary field surveys in June and August 2009. We examined how highly variable circulations and water masses (particularly the CDW and TWC) control the summer phytoplankton (species richness, abundance, dominant species, ecological group, and community composition). The region of interest (27.75°N–33.25°N, 122°E–125°E) ranged from the CE to the middle shelf (< 100 m in depth), which is considerably larger than that in previous studies. The present study addresses the inadequacy of spatial and temporal scales used in previous studies to understand more clearly the effects of physicochemical processes on the phytoplankton community in the CE and adjacent shelf.

2. Data and methods

2.1. *Study area and Sampling station*

Two cruises were conducted in the CE and adjacent shelf on the ship *Beidou* during early summer (1–11 June 2009) and mid-summer (14–24 August 2009). The sample sections (A–F) were plumbed to the coastline, and 30 stations were established (Fig. 1). In general, the CE and adjacent ECS shelf are mainly influenced by the eutrophic, low-salinity, inshore (i.e., CDW and coastal current) and oligotrophic, high-salinity, offshore (i.e., TWC and Kuroshio) current systems (Fig. S1; Edmond et al., 1985; Ichikawa and Beardsley, 2002; Su and Yuan, 2005; Chen, 2009; Yang et al., 2011; Zhou et al., 2015). The Kuroshio mainstream flows northeastward

Please cite this article as: Jiang, Z., et al., Controlling factors of summer phytoplankton community in the Changjiang (Yangtze River) Estuary and adjacent East China Sea shelf. Continental Shelf Research (2015), http://dx.doi.org/10.1016/j.csr.2015.04.009