Estuarine, Coastal and Shelf Science 173 (2016) 49–56

Contents lists available at ScienceDirect

Estuarine, Coastal and Shelf Science

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

Temporal-spatial variations and developing trends of Chlorophyll-a in the Bohai Sea, China

Yanzhao Fu, Shiguo Xu*, Jianwei Liu

Faculty of Infrastructure Engineering, Dalian University of Technology, Dalian 116024, China

ARTICLE INFO

Article history:
Received 28 September 2015
Received in revised form
7 February 2016
Accepted 20 February 2016
Available online 23 February 2016

Keywords:
Chlorophyll-a
MODIS
Mann–Kendall
Hurst index
Bohai Sea

ABSTRACT

The patterns of sea surface Chlorophyll-a (Chl-a) have regional and dynamic features. An understanding of the Chl-a dynamics and whether its trends in the past will be persistent in the future is important for restoration of ecosystem. Spatial and temporal variations of sea surface Chl-a concentrations in the Bohai Sea were investigated with data remotely sensed by MODIS from 2003 to 2014. The goals of this research are to identify the phytoplankton dynamics and detect their correlation with environmental changes and anthropogenic activities. Based on an indicator system built with Mann–Kendall Test and Hurst Exponent, our research shows that the Chl-a concentration in the surface layer is heterogeneous in both temporal and spatial scale. It is higher in costal zones, particularly near the Qinhuangdao coast. The occurrence of spring and summer blooms has a one-month time lag from south to north. An increasing trend that was persistent is evident offshore and a decreasing trend that was persistent is seen near the coast, which may indicate an expansion of eutrophication from coast to deep sea. The seasonality of the phytoplankton bloom is basically driven by vertical structure of water column. Climate and mariculture activity are significant correlated with the Chl-a trends. River discharge and suspended sediment also influence Chl-a.

1. Introduction

Phytoplankton accounts for almost 50% of the earth's primary production which makes it the fundamental component of oceanic food webs (NRC, 2001). It dictates the fate of biogeochemical cycle including fish, mammals, birds and even the global climate processes (NRC, 2001; Platt and Sathyendranath, 2008). As the main pigment of phytoplankton, Chlorophyll-a (Chl-a) is considered an indicator or index of phytoplankton biomass (Cullen, 1982), and hence reflects oceanic primary production (Bierman et al., 2011). Y. Huot et al. (2007) compared 6 indices of phytoplankton biomass for measuring the maximum photosynthetic rate. They found that Chl-a concentration was the most appropriate proxy of phytoplankton biomass for primary productivity studies. Therefore, understanding the spatial and temporal variation of Chl-a helps to identify marine physical and biological conditions (Bacher et al., 2003).

Traditional techniques of collecting marine Chl-a data involve ship measurements and targeted campaigns of *in situ* sampling. These methods are challenging when consider the fast growing rate of phytoplankton, variable marine environment, and the high cost to get long-term data sets (Bierman et al., 2011). Especially in developing countries, field data is limited due to the time and high cost involved. Remote sensing technology could cover these gaps since its potential in providing continuous and large-scale data set. It presents a synoptic view with fine resolution of Chl-a distribution unachievable by other methods, and provides continuous data that support the discovery of the coastal and offshore Chl-a variability in high temporal resolution. These make remote sensing technique a rich source of data. The technology has been used successfully in identifying the variability of Chl-a. Platt and Sathyendranath (2008) reviewed ecological indicators for the pelagic ecosystem and found that remote sensing was an important tool for detection of the interaction between the ecosystem and the environment. Ndungu et al. (2013) explored the spatial-temporal changes of Chl-a with Moderate Resolution Imaging Spectroradiometer (MODIS) data and compared the results with that from *in situ* measurements. They pointed out that satellite data could provide reliable information on the general trends. However, they also reported that the accuracy of the ocean colour satellite data was affected by the reflectance of turbidity. Gong et al. (2003) also reported the Chl-a concentration

* Corresponding author.
E-mail address: sgxu@dlut.edu.cn (S. Xu).

http://dx.doi.org/10.1016/j.ecss.2016.02.016
0272-7714/

may have been overestimated due to sediment re-suspension caused by wind and tidal currents.

Despite the uncertainties, remote sensing technology still show its potential in Chl-a study. Ndungu et al. (2013) suggested that the remote sensing data could provide reliable information in spatial-temporal variation and should be interpreted as an index of Chl-a. Other researchers also distilled ecological information from satellite-derived Chl-a. Kiyomoto et al. (2001) jointly used Coastal Zone Colour Scanner (CZCS) data and *in situ* data to explore the temporal-spatial variability of Chl-a in the East China Sea. Liu and Wang (2013) analysed trends of Chl-a derived from Sea-viewing Wide Field-of-view Sensor (SeaWiFS) and MODIS sensors in the Bohai and Yellow Sea. They found that the Chl-a concentrations showed different patterns in coastal waters and offshore waters. The concentrations on the continental shelf were relatively higher than those offshore. The maximums usually occurred in winter or spring.

The variability of Chl-a is influenced by a number of factors. Tang et al. (2003) investigated spatial and temporal variations of Chl-a in the Gulf of Tonkin with SeaWiFS data and found that the variations were correlated with seasonal monsoon offshore, while river discharge inshore. Radiarta and Saitoh (2008) used empirical orthogonal function analysis to identify the spatial and temporal patterns of SeaWiFS derived Chl-a. They found that local forcing of Oyashio water, wind condition and surface temperature play key roles in the mechanisms of Chl-a variation. In addition, Tian et al. (2016) studied Landsat images and found that reclamation of coastal lands might put threat to coastal hydro-environment. These results suggest separate forcing mechanisms are responsible for the occurrence of different Chl-a patterns.

Previous studies have investigated the variations of Chl-a with satellite data, but few studies have investigated whether the trends were persistent in the future. Researches have shown that climate variables and river discharge can present persistence (Koirala et al., 2011; Kolman et al., 2015). If its indicators are persistent, then there should be persistence in Chl-a. In the present study, MODIS ocean colour images from 2003 to 2014 in the Bohai Sea were analysed. An indicator system based on Mann–Kendall test and Hurst exponent was build up, with the aims to identify the spatial and temporal patterns of Chl-a and to determine whether there is persistence. This study also explored whether the variability of Chl-a was attribute to climate variables, Yellow River discharge and mariculture in reclamation ponds.

2. Materials and methods

2.1. Study area

The Bohai Sea, located in the north of China, is a semi-enclosed inland sea (Fig. 1). The sea is a shallow shelf sea with a mean depth of about 18 m. It connects with the Yellow Sea through the narrow pathway of the Bohai Strait. This special geographic condition gives the sea longer water residence time and provides longer retention time for pollutants. The Sea is under the influence of the eastern Asian monsoon. The mean wind directions from north and north-west prevail in winter, whereas in summer favoured wind direction is from the south. There are four large to medium-sized rivers discharge into the Bohai Sea which are the Yellow River, the Haihe River, the Luanhe River, the Liaohe River. The Yellow River is the second longest river in China. It flows across large areas of agricultural regions and brings about large amount of fresh water and nutrients into the Bohai Sea. The sea is an important site for fishery and aquaculture, which account for 44% of the total mariculture production of the country. The majority of productions are shellfish and finfish. The eutrophic state of the sea especially near the coast

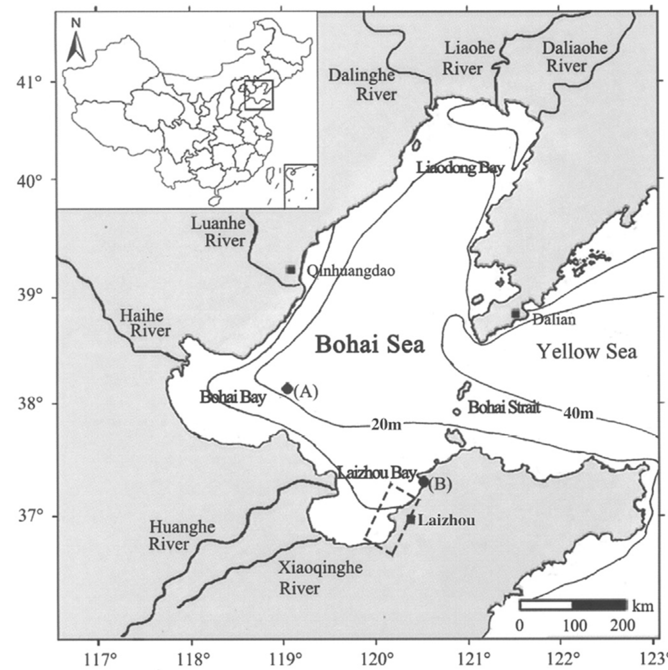

Fig. 1. Map of the study area with bathymetry (A is the oil platform A meteorological station; B is the Longkou meteorological station; polygon is the maricuture area).

is severe. Over the last decades, water quality problems including red tides occurred in the Bohai Sea (Zhang et al., 2012). The increased land-sourced contaminants from high density of population, intensely cultivated catchment area and industrial development are reported as the main cause of phytoplankton biomass (Peng, 2015; Strokal et al., 2014; Wang et al., 2009; Wu et al., 2013). In 2009, the country issued the Bohai Sea Environmental Protection General Planning document (2008–2020) to control the environmental problems. One of its strategies was to improve environmental monitoring and prediction.

2.2. Source of In situ data

The monthly temperature and wind stress data from 2003 to 2014 measured at the oil platform A and Longkou Station (Fig. 1) were used to explain Chl-a variations offshore and near the coast, respectively. They were downloaded from China Meteorological Administration website (http://data.cma.gov.cn/).

The annual maricuture production data from 2003 to 2012 that used to explore the influence on Chl-a concentration were obtained from the annual reports of Laizhou.

2.3. MODIS data collection: Chl-a and sea surface temperature (SST)

The monthly MODIS and SST level 3 data from 2003 to 2014 were obtained from the National Aeronautics and Space Administration (NASA) Goddard Space Flight Centre website (http://oceancolor.gsfc.nasa.gov). The data were representations of binned data products interpreted from MODIS Aquarius data by NASA OBPG (Ocean Biology Processing Group) with most recent updated algorithms and instrument calibration (O'Reilly et al., 2000). The format of the dataset was Standard Mapped Image (SMI), which was a regular grid of equidistant cylindrical projection of the earth. The spatial resolution was about 4 km.