Study on Characteristics of Harmful Algal Blooms in the South Sea of Korea by using Satellite and In-Situ Data

Widhiyanuriyawan Denny, Dae Hyun Kim, Yong-Hyun Chung, Hong-Joo Yoon, *Member, KIMICS*

Abstract— Harmful Algal Blooms (HABs), caused by *Cochlodinium polykrikoides* that causative fishery mortality, impact on aquaculture and economic loss appear particularly in summer and fall seasons in the Korean seas. It was studied on characteristics of HABs in the South Sea of Korea by using satellite and *in-situ* data. The *in-situ* data encompassed oceanic and meteorological data from July to October 2002–2008 and satellite data from July to October 2002–2006. Chlorophyll concentrations were calculated using Sea-viewing Wide Field-of-view Sensor images by an Ocean Color (OC4) algorithm, and HABs were estimated using the Red tide index Chlorophyll Algorithm (RCA). The HAB occurrences were dominant when water temperature was 22.6–28°C in August. The frequency of the individual numbers during 2002–2008, the HABs more than 1000 cells/ml (alert condition), were 73.57 %. In meteorological data from July to September during 2002–2008, the average precipitation, the mean air temperature, the mean wind speed and direction, and the sunshine were 9.31 mm/day, 24.07ºC, 2.34 m/s and easterly, and 1–11 h, respectively. Our results suggest that the upwelling is caused by southwesterly wind in summer season and the Tsushima Warm Current which have influenced on the dispersion and moving of HAB (chlorophyll). In addition, the fresh water from Nakdong River, as the source of nutrients, also influences the occurrence of HABs.

Index Terms— HABs, SeaWiFS, OC4, Red tide index Chlorophyll Algorithm.

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I. INTRODUCTION

Harmful algal blooms (HABs), which occurs in the South Sea of Korea mostly because of the dominant causative species *C. polykrikoides*, are particularly present in summer and fall seasons [1, 10]. Considerable economic losses due to HABs were estimated at $95 million and $19 million USD in 1995 and 2003, respectively [9]. Monitoring toxin levels and closing selected fisheries are some approaches to reducing the public health risks associated with these human and natural hazards.

The previous studies explained the influence of environmental conditions such as oceanic parameters e.g., water temperature, salinity, nutrient and metrological parameters e.g., air temperature, precipitation, wind and sunshine on HABs [7, 8, 11, 13]. This paper deals with study of characteristics of HABs by using *in-situ* data and retrieved satellite data of ocean and atmosphere which are very well in spatial and temporal.

II. STUDY AREA, DATA AND METHODS

A. Study Area

The study areas were Tongyeong and Busan, which located in south east of the South Sea of Korea (Fig.1). These regions were affected by Sacheon River which most supply freshwater to Tongyeong coastal area and Nokdong River which supply freshwater to Busan coastal area and the Tsushima Current which consists of warm salt water.

B. Data and Methods

The *in-situ* data used in this research were obtained from several institutions as follows: Oceanic data (the individual number of *C. polykrikoides* and water temperature) from National Fisheries Research and Development Institute (NFRDI) for 2002–2008, meteorological data (air temperature, precipitation, wind speed and direction, and sunshine duration) from the Korea Meteorology Administration (KMA) for July to October 2002–2008, and satellite data from

Sea-viewing Wide Field-of-view Sensor (SeaWiFS) L1A images from the Korean Ocean Research and Development Institute (KORDI) for 2002–2006. In addition, Sea Surface Temperature (SST) NOAA AVHRR (1 x 1 km^2 spatial resolution) was obtained from NFRDI. The SeaWiFS ocean color data were processed using SeaDAS 5.2 software from the National Aeronautics and Space Administration to generate L2 SeaWiFS, which revealed Ocean Color (OC4) and water-leaving radiance (Lw 443) of output binary data in HDF format (1 x 1 km^2 spatial resolution). Furthermore, a computer program of Matlab 2007b was used to process these data and to calculate the Red tide index Chlorophyll Algorithm (RCA), which estimated the quantity of HABs in terms of chlorophyll-a concentration [2]. With this program, we used gap-filling (single pixel dropout or clouds

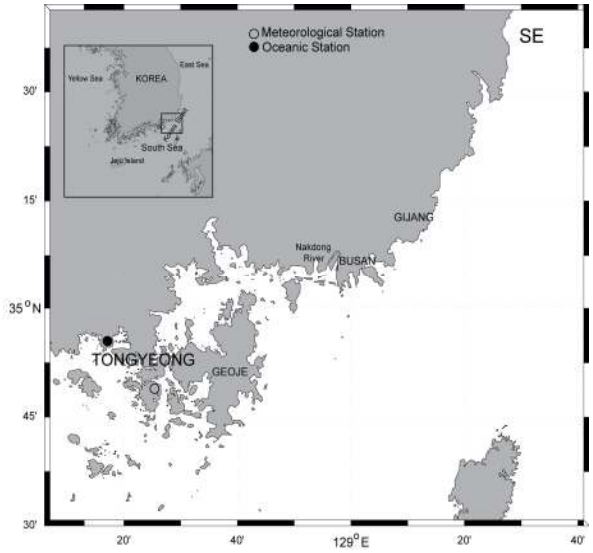

Fig. 1 Southern East of the South Sea of Korea.

III. RESULTS AND DISCUSSION

A. Oceanic Data

The individual number (cells/ml) of *C. polykrikoides* and water temperature of the *in situ* data were obtained from NFRDI. The distribution of *C. polykrikoides* and water temperature in the Tongyeong coastal area were recorded from July to September from 2002–2008 is depicted in Fig. 2. Highest HABs occurrences in August, both of the Tongyeong and Busan, can be identified by Fig.2.

Fig.3 shows that the water temperature favorable for HABs event ranging between 22.6 ºC and 28ºC and classification of the suspected areas for HABs based on the maximum number of individual number of *C. polykrikoides* [6] show condition alert (>1000 cells/mm) for Tongyeong and Busan was 73.57% and 59.52%, respectively. This indicates that the southern east area is having high potential of HABs.

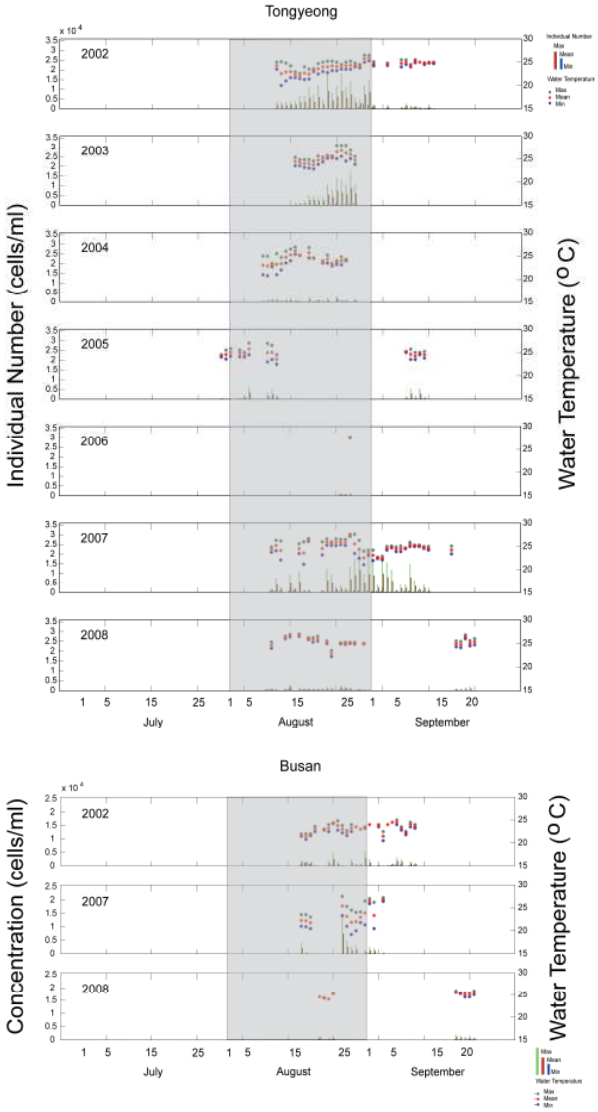

Fig. 2 Water temperature and individual number of *C. polykrikoides*, 2002–2008 in Tongyeong and Busan.

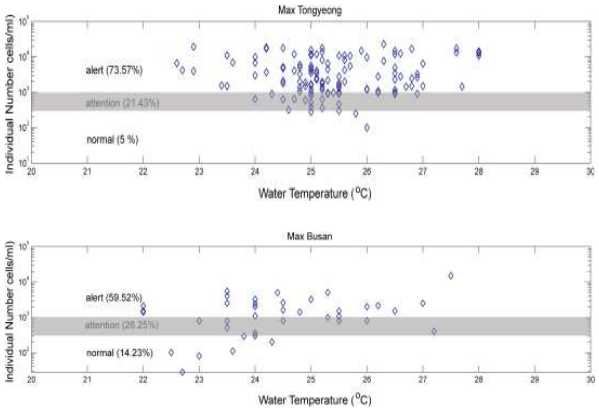

Fig. 3 The individual number of *C. polykrikoides* water temperature of HAB occurrences in 2002–2008.

B. Meteorological Data

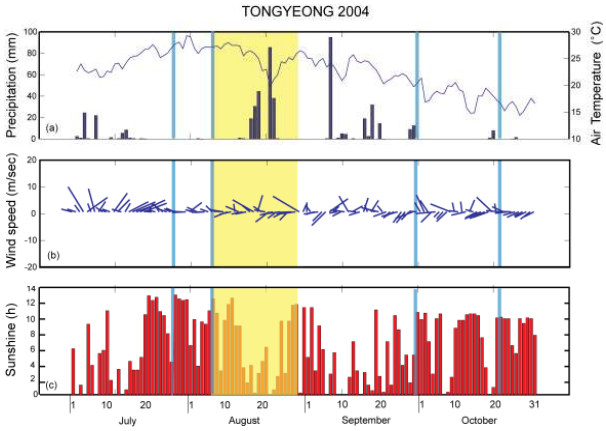

Fig. 4 (a) Daily accumulation of precipitation (bar graph) and mean daily air temperature (line graph), (b) daily mean wind speed and direction, and (c) accumulated sunshine recorded in 2004. The region in yellow denotes the occurrence of HABs based on oceanic data. The region in light blue represents satellite images data.

Fig. 4 shows data for July to October 2004. The air temperature ranged from 20.8 to 28°C in the summer (July–September 2004) and began to decrease in the fall (first week in October) shown in Fig. 4a. Rainy conditions were prevalent in July and September, with high precipitation in August, 85.5 mm (Fig. 4a). Fig. 4 also depicts HABs occurrence, which is represented in yellow colored mark from 7 August to 29 August. 2004. The mean air temperature, wind speed and direction, and sunshine duration the HABs occurrence on 7–29 August (22 days) were 25.29°C, 2.34 m/s (southwesterly), and 1–11.1 h, respectively. In addition, the oceanic data from NFRDI showed that the water temperature range and individual number varied from 20.8.4°C to 26.9°C and from 20cells/ml to 3000 cells/ml, respectively. Long time occurrences of HABs probably cause of raining events on 17–19 August and 22–23 August. These conditions possibly occurred because nutrients from terrestrial wastewater, pollutants related raining and surface runoff into the estuary from discharge of Sacheon's flow while the warm water temperatures in coastal area can promote breeding and blooming of *C. polykrikoides*. The mean of air temperature, precipitation and sunshine duration from July to October 2002–2008 was 24.07ºC, 9.31 mm/day, and 2–11h, respectively.

The histogram in Fig. 5a shows a dominant southwesterly wind from July to October 2002–2008. A positive skewness denotes a mode of 1.85 m/s less than the mean wind speed (2.34 m/s; Fig. 5b), which indicates a calm or light wind. Calm wind (2–4 m/s) is favorable for HABs [13]. The southwesterly wind blows along the coast of the South Sea of Korea following *C. polykrikoides* bloom formation and propagation to the east that is driven by a northeastward shore current [4].

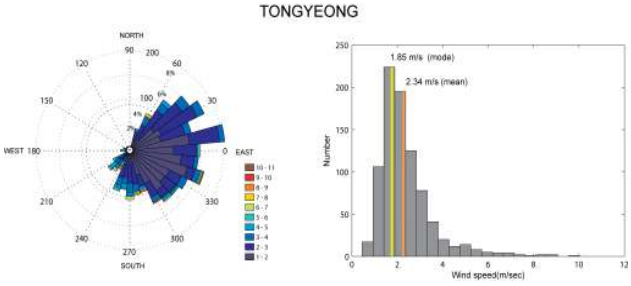

Fig. 5 Histogram of (a) wind direction and (b) wind speed from July to October 2002–2008.

C. Satellite Data

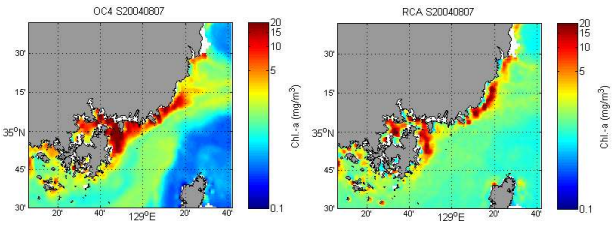

Fig. 6 SeaWiFS satellite data using OC4 algorithm and RCA for 7 August 2004.

Satellite data for the OC4 and RCA images are shown in Fig. 6. Based on pixel percentage of images in these area show percentage color more than 5 mg/m^3 for OC4 and RCA is 48.33%, 4.84%, respectively. The difference in estimating HABs with OC4 and the RCA is in the use of the band-ratio algorithm, which is based on an empirical function of the ratio of blue to green remote sensing reflectance, in the OC4 algorithm [10]. The high concentrations in coastal areas as estimated by the OC4 algorithm had a large error in chlorophyll retrieval due to the lack of chlorophyll-a in water, but with suspended sediment and other dissolved organic matters (case-2 waters). Both of OC4 algorithm and RCA for satellite data showed in southern east Sea of Korea from July to September 2004 and during the August month, of all the years from 2002 to 2008 have potential of the occurrences of HABs (images not shown). However, for larger area include offshore, OC4 is adequate for detecting of HABs. Fig. 7 shows the larger area of coverage for HABs in the South Sea of Korea.

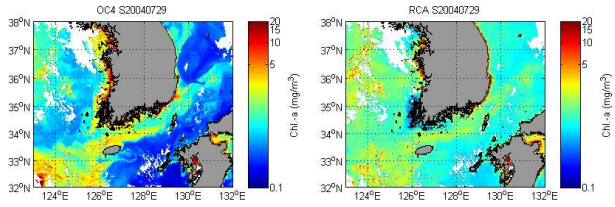

Fig. 7 Satellite image generated using the OC4 algorithm and RCA on 29 July 2004.

Fig. 7 shows massive transport of HABs and chlorophyll-a from the East China Sea. Some studies have suggested that water from the Yangtze River may contribute to the outbreak of *C. polykrikoides* [7, 12]. The beginning of the first bloom on 7 August 2004 (Fig. 2) in the region of South Sea of Korea may have been triggered by the intrusion of *C. polykrikoides* from offshore of the East China Sea brought by the Jeju and Tsushima Warm Currents. These phenomena were shown by both OC4 and RCA images on 29 July 2004 (Fig. 7).

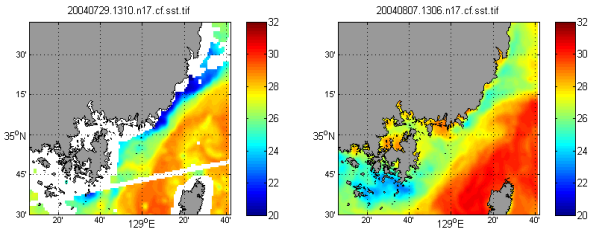

Fig. 8 Satellite SST from NOAA on 29 July 2004 and 7 August 2004.

Satellite SST images in Fig. 8 show that when the massive movement of *C. polykrikoides* from offshore of the East China Sea, water temperature of southern east was less then the offshore on 27 July 2004. In 7 August 2004 the SST in the coastal area of southern east region increased between 26°C and 28°C and the offshore SST was ≥ 26ºC which indicate as the Tsushima Warm Current. Water temperature has the greatest influence on the growth rate of *C. polykrikoides*, which is able to grow at 15–30°C (optimum temperature 21–26°C and salinity 20–36 psu) [3]. The discovered a plume in the east of Busan (Gijang area) is shown in Fig. 6. The high chlorophyll-a concentration in this region also revealed upwelling due to a southwesterly wind that strongly influenced the Tsushima Warm Current [5] and also influences of freshwater from Nokdong River.

IV. CONCLUSSIONS

In this study, *in-situ* data and satellite have been used to characteristic the HABs in the South Sea of Korea. The *in-situ* data show that the range of water temperature, mean air temperature, precipitation, wind speed, wind current and sunshine duration from July to September 2002–2008 was range 22.6–28°C, 24.07°C, 9.36 mm/day, 2,34 (southwesterly) for the condition for HABs. The HABs event occur dominant in August in every year. The high precipitation rate induces more sustainability of blooming for longer period. The ocean color satellite shows the wide areas cover of HABs occurrences and gives information another factor that triggered HABs. SST satellite data show the Tsushima Warm Current in South Sea of Korea that influenced on dynamic phenomena in coastal area such as upwelling which triggered HABs. The future studies will use another satellite data like wind speed, and sea surface height to explore the HABs.

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