VALIDATION OF COCHLODINIUM POLYKRIKOIDES RED TIDE DETECTION USING SEAWIFS-DERIVED CHLOROPHYLL-A DATA WITH NFRDI RED TIDE MAP IN SOUTH EAST KOREAN WATERS

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Abstract. Annual summer red tides of *Cochlodinium polykrikoides* have happenned at southern coastal of the South Korea, accounted economic losses of 76.4 billion won in 1995 on fisheries and other economic substantial losses. Therefore, it is important to eliminate the damage and losses by monitoring the bloom and to forecast their development and movement. On previous study, ocean color satellite, SeaWiFS, standard chlorophyll-a data was used to detect the red tide, using threshold value of chlorophyll-a concentration ≥ 5 mg/m^3, resulted a good correlation using visual comparison. However, statistic based accuracy analysis has not be done yet. In this study, the accuracy of detection method was analyzed using spatial statistic. Spatial statistical match up analysis resulted 68% of red tide area was not presented in satellite data due to masking. Within red tide area where data existed, 36% was in high chlorophyll-a area and 64% was in low chlorophyll-a area. Within the high chlorophyll-a area 13% and 87% was in and out of the red tide area. It was found that the accuracy of this detection is low. However if the accuracy was yearly splitted, its found that 75% accuracy on 2002 where visually red tide detected spead out to the off-shore area. The fail and false detection are not due to the failure of the detection method but caused by limitation of the technology due to the natural condition i.e. type of red tide spreading, cloud cover and other flags such as turbid water, stray light etc.

Keywords: *cochlodinium polykrikoides*, *chlorophyll-a, SeaWiFS, red tide*

1 INTRODUCTION

Red tide of *Cochlodinium polykrikoides* frequently occurs every summer at southern coastal of the South Korea. This phenomenon was studied by Lee (2005), Kim *et al.* (1997), and Lee (2006). Red tide is commonly caused by nutrient enrichment. The results of nutrient loading to inland and coastal waters are often an increase of algal biomass, frequently dominated by one or more species. The increase of algal biomass sometimes changes the color of seawater and forms red tide.

Monitoring the bloom and forecasting its development and movement are important to reduce the damage and impact (Stumpf 2001). The synoptic and frequent coverage characteristics of remote sensing data are effective ways to monitor the bloom. Monitoring from satellite is becoming operational in China, Japan, Korea, Philippines and USA, and application utilization of satellite data currently employing for other species were suggested to be applicable to *Cochlodinium* events in some regions (Doucette and Lee 2008). The characteristic of red tide is not always the same among places. Remote sensing monitoring method might work well in some places, but do not work in other place.

Stumpf *et al.* (2003) developed a method to detect *Karenia brevis* bloom using anomaly of chlorophyll-a extracted from the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) data in Gulf of Mexico, and this method was validated by Tomlinson *et al.* (2004). The Stump *et al.* (2003) method used SeaWiFS chlorophyll-a concentration anomaly for several days and different from Winarso (2012) method that used daily SeaWiFS chlorophyll-a concentration with threshold value ≥ 5 mg/m^3. However, the method of Stump *et al.* (2003) has not worked well in South Korean Waters (Ishizaka and Winarso 2007) due to the other caused of alga bloom, such as upwelling and eddies or other common oceanographic phenomenon. It is also due to different red tide temporal in origin place of developed method.

Winarso (2012) proposed a method to detect red tide in South Korean Waters using SeaWiFS standard chlorophyll-a. The threshold of chlorophyll-a concentration ≥ 5 mg/m^3 of corresponded visually to NFRDI Red Tide Map, because the maximum chlorophyll-a concentration when the red tide is not occurred was around 5 mg/m^3. However, this study still be analyzed visually which do not have real statistical analysis. The validation using spatial data is required. Validation of red tide detection by SeaWiFS standard chlorophyll-a with threshold ≥ 5 mg/m^3 was done using NRFDI Map spatially.

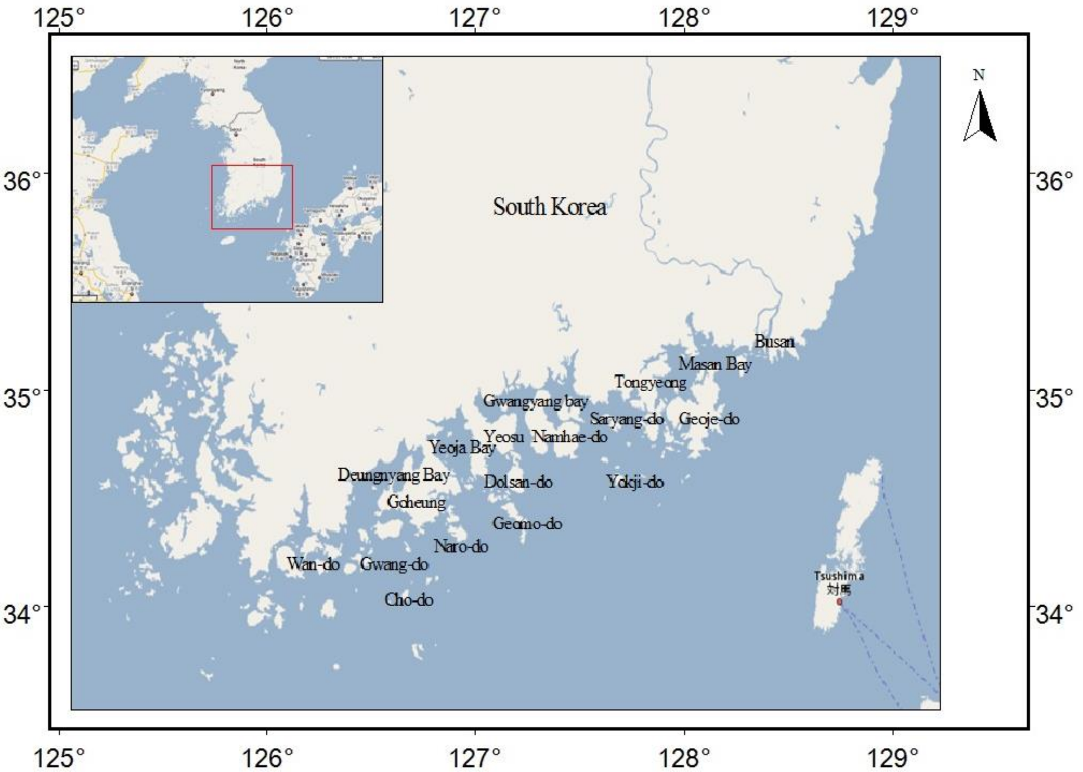

Figure 1-1: Map of study area and geographic names where red tide occurred

2 MATERIALS AND METHODOLOGY

2.1 Satellite Data

As this research was further development and analysis of the previous research, the main data of this research was the same as the data used by Winarso (2012), which was the ocean color satellite chlorophyll-a data from SeaWiFS sensor provided by the National Aeronautics and Space Administration (NASA) ocean color homepage. Similarly, we used standard level 2 data of 2000-2004 which was used to extract daily chlorophyll-a data by merging more than 2 datasets in same day if any (Winarso 2012). In order to eliminate low quality pixels, flag data were removed. Cloud free chlorophyll-a data within red tide season during 2000-2004 were selected and analyzed.

Normalized water-leaving reflectance at wavelength 555nm (nLw 555) used as indicator chlorophyll-a overestimation. SeaWiFS standard algorithm has good performance for clear waters (Case 1) and it is well known that this algorithm generated overestimation at coastal turbid water (Gohin *et al.* 2005). The suspended material concentration can be deduced from the reflectance at 555 nm, R[555], as reported for the Bay of Biscay seawaters (Froidefond *et al.* 2002). Strong relationship between the nLw 555 and total suspended material concentration indicated high turbidity could lead to the over-estimation of SeaWiFS chlorophyll-a (Tan *et al.* 2006).

2.2 In-Situ Data

We used the same field based red tide information and maps of previous study (Winarso 2012), which were taken from NFRDI Harmful Algal Blooms Report in Korea Coastal Waters during 2000–2004. The data collection was taken from water sampling, visual observation by ship, from land and helicopter and from fisherman information (Winarso 2012).

The data in paper print document was digitized into vector-based GIS data to make able to analyze with GIS. Coordinate system of the digitized map was converted to same as satellite chlorophyll-a data to overlay the data.

2.3 Spatial Match Up Analysis

Two different chlorophyll-a concentrations of ≥ 5 and ≥ 7.59 mg/m^3 were defined as threshold for match up analysis. The value of ≥ 5 mg m^{-3} was decided as threshold value referred to maximum value on average composite for 5 years (2000-2004) and one evidence when typhoon generate high nLw555 but chlorophyll-a concentration not more than 5 mg/m^3 concentration of ≥ 7.59 mg/m^3 was used as option treatment to know what the accuracy increase or not.

In order to reduce error caused by different map projections of satellite with red tide map and by a limited coverage of in-situ map, the match up analysis was conducted with 2.5 km^2 and 10 km^2 mesh sizes. It means that 1 single point of red tide information is assumed to be 2,5 km^2 or 10 km^2 area of red tide. The match up was conducted by overlaying satellite chlorophyll-a data and NFRDI red tide map. For each mesh, there were six combinations from two cases from NRFDI maps (non-red tide and red tide) and three cases from satellite chlorophyll maps (no data, low chlorophyll-a, high chlorophyll-a). We specifically analyzed four combinations; red tide with high and low chlorophyll-a and no data, and non-red tide with high chlorophyll-a. The 41 cloud free satellite data during 2000–2004 were analyzed.

3 RESULTS AND DISCUSSION

Data comparison of satellite chlorophyll-a and NFRDI map resulted that chlorophyll-a data was missing for 68 percent of red tide area (Table 3-1). The percentage decreased by increasing the mesh size of comparison. The percentage did not change significantly by increasing threshold value. Highest percentage of no satellite data within red tide area was 79% on 2002 and it was followed by 2001, 2003 and 2004. The lowest percentage with no satellite data was in 2000 (Table 3-2). It seems to be related to cloud distribution and the intensity. Percentage of high satellite chlorophyll-a area within red tide area was 36 %, and this means 64% area is reported as red tide, was not on high satellite chlorophyll-a area.

The percentage of high chlorophyll-a area increased when the mesh size of compared area increased, 55% was high chlorophyll-a area. However, increase of threshold value resulted decrease of high chlorophyll-a area percentage, 21% was on high chlorophyll-a area. The percentage of high chlorophyll-a area was different on each year, highest in 2002 reach 75% and the lowest is in 2004. It seems related with spatial distribution characteristics were different (Table 3-2).

Table 3-1: Comparison between high satellite chlorophyll-a area and NFRDI red tide map

Threshold **Mesh Size**	**≥ 5 mg/m³** **2.5 km**	**≥ 5 mg/m³** **10 km**	**≥ 7.59 mg/m³** **2.5 km**
Percent of no data within red tide area	68	42	69
Percent of data exist within red tide area	32	58	31
Percent of high chl-a area within data exist	36	55	21
Percent of low chl-a area within data exist	64	45	79
Red Tide Within HCA	13	33	13

Note: red tide area as reported by NFRDI

Table 3-2: Comparison between high satellite chlorophyll-a area and NFRDI red tide map area for each year of data period

Threshold ≥ 5 mg/m³ **Mess Size 2.5 km**	**2000**	**2001**	**2002**	**2003**	**2004**
Percent of no data within red tide area	51	73	79	53	56
Percent of data exist within red tide area	49	27	21	47	44
Percent of high chl-a area within data exist	36	36	75	14	11
Percent of low chl-a area within data exist	64	64	25	86	89
Red Tide Within HCA	23	19	9	6	16

Note: Red tide area as reported by NFRDI

Occurrence of red ride of *C. polykrikoides* during 2000–2004 could be clearly seen from satellite chlorophyll-a data when image was cloud free (Winarso 2012). Red tide on August 20-24, 2001 and September 21 – October 3, 2003 were identified by high chlorophyll-a and confirmed by NFRDI red tide map. This was different from the result of Suh *et al.* (2004) who could not detect red tide actifities from August to September 2000 and 2001 while the red tide blooms occurred at the same time. They used average chlorophyll-a value of 18 x 18 km area, and it might be the cause of failure of detection of red tide. Full resolution SeaWiFS data with 1 km is required to detect and describe red tide of *C. polykrikoides* in this area.

However, for overall matchup between NFRDI red tide maps with high chlorophyll-a area during 2000 – 2004 resulted that only 36% red tide area confirmed in high chlorophyll-a area. The slightly different between the observations of local experimental station with SeaWiFS observation because the local experimental station identified a small and/or red tide remnant, which may not be detected in the remote sensing images (Ishizaka *et al.* 2006).

The initial, growing, extension and termination stages of red tide were determined when daily or near daily time series when cloud free data existed, specifically time change of spatial extent and distribution could be seen which was not shown in red tide map (Winarso 2012) the sample image was shown in Figure 3-1. SeaWiFS-derived chlorophyll-a estimation seemed to be helpful in defining the locality, spatial extension and distribution of red tide (Ahn *et al.*, 2006).

Relatively low density of red tide cell often resulted low satellite chlorophyll-a concentration was one of cause discrepancy between NFRDI red tide map and satellite chlorophyll-a detection. Gárate-Lizárraga *et al.* (2004) found good correlation between cell numbers of *C. Polykrikoides* with chlorophyll-a concentration. If the cell number of red tide is low, the chlorophyll-a concentration is also low and red tide cannot be observed by satellite. Some cases were found in 2004 when cell density of red tide was low and high chlorophyll-a area was not observed in the reported red tide area.

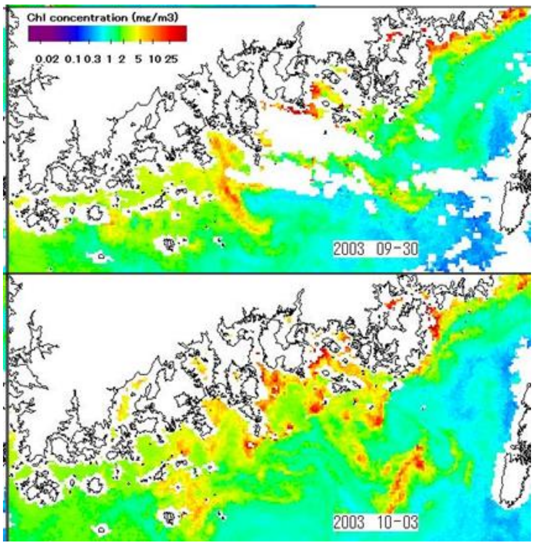

Figure 3-1: SeaWiFS-derived Chorophyll-a Image at the research location (Winarso 2012)

The cloud cover problem was found in match up result that 68% red tide area was in no-data exist (Table. 3-1), no-data exist caused by cloud cover and masking. However, some crucial period of red tide occurrences lost due to cloud cover. Combining and substitution with field data is necessary. Cloud cover and flags masking resulted no-data exist, the amount of data decreased significantly. Few data available produce bias in analysis and sampling error. Bias in monthly and annual average chlorophyll estimation could be produced from irregular temporal measurement of ocean color sensor (Gregg and Casey 2007).

Spatial match up analysis resulted within data exist in red tide area 36% was high chlorophyll-a area and 64% was low chlorophyll-a area (Table 3-1). Loss of data due to masking along shoreline seems main factor of this result, because red tide usually happen along shoreline where usually masking area present, then the probability high chlorophyll-a area in the masking area was high. No satellite data exist expected to be located in high chlorophyll-a area reducing the percentage of high chlorophyll-a area in red tide area. This result has become new evident for the limitation of satellite detection of red tide which was previously analyzed by Winarso (2012).

Increasing compared mesh size area reduce the possibility of no-satellite data to became part of high area, because within at one area of 1 mesh size, if red tide exist then the whole one area is defined as red tide area. The percentage of high chlorophyll-a area increased from 36% to 55% because of bigger mesh size. It can be assumed that there were differences positioning measurement between locations of red tide from field with position of red tide in satellite image. The field sampling might not in the maximum high chlorophyll-a. Field observation had difference way how to delineate red tide area compared with satellite way, because this match up was area by area, was not match up area to point.

Increasing of threshold value did not change the result significantly. Increasing of threshold value actually reduces high chlorophyll-a area, but it did not increase percentage of high chlorophyll-a area within red tide area. Because increase of threshold value could reduce the high chlorophyll-a area in non-red tide area, the border of high chlorophyll-a area and low chlorophyll-a area locate not in core of red tide area but outside of red tide area. The threshold value should be decided correctly and critical parameter for red tide detection. It might be different for each location depend on the normal variation of the chlorophyll-a concentration when red tide is not present.

Annual match up analysis resulted in 2002 percentage of red tide area with in data exist was high, reached 75%, that means the accuracy of detection was high too (see Table 3-2.). High chlorophyll-a area has good correspondence with red tide area in 2002 where red tide spread out offshore wider than other years (Winarso 2012). This result supported our statement that not good correspond between high chlorophyll-a area and red tide was due to loss of data in near shoreline along the coast where red tide usually happens, not due to the failure of detection method.

4 CONCLUSION

Spatial match up analysis resulted high chlorophyll-a area was good parameter to detect red tide when the red tide was spread out to the off-shore area. Negative result expected due limitation of remote sensing such as masking area at near shoreline where red tide usually started and happened, not due to the failure of detection method. When red tide was spread out to offshore area, a good result was obtained because the red tide spread out to minimum masking area at offshore increasing high chlorophyll-a area that correspond to red tide area.

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REFERENCES

Ahn, YH, Shanmugam P, Ryu JH, *et al,* (2006), Satellite Detection of Harmful algal bloom occurrences in Korean waters. Harmful Algae 5: 213–231.

Doucette, GJ, and Lee CK, (2008), Preface to the Harmful Algae Special Issue: Recent progress on the research and management of *Cochlodinium* blooms. Harmful Algae 7: 259–260.

Froidefond, JM, Lavender S., Laborde P., Herbland A., *et al,* (2002), SeaWiFS Data Interpretation in a Coastal Area in the Bay of Biscay. International Journal on Remote Sensing 23(5): 881–904.

Gárate-Lizárraga, López-Cortes DJ, Bustillos-Guzmán JJ, *et al,* (2004), Blooms of *Cochlodinium polykrikoides* (Gymnodiniaceae) in the Gulf of California, Mexico. Rev. Biol. Trop, Vol 52, supl 1, San José.

Gregg, W., and Casey NW, (2007), Sampling Biases in MODIS and SeaWiFS Ocean Chlorophyll Data. Remote Sensing Environmental 111: 25–35.

Gohin, F., Saulquin B., Oger-Jeanneret H., *et al,* (2005), Toward a Better Assessment of the Ecological Status of Coastal Waters Using Satellite-Derived Chlorophyll-a Concentrations. Remote Sensing of Environment112(8): 3329-3340.

Ishizaka, J., Kitaura Y., Touke Y., *et al,* (2006), Satellite Detection of Red Tide in Ariake Sound, 1998–2001. J. Oceanography 62: 37−45.

Ishizaka, J., and Winarso G., (2007), Detection of *Cochlodinium Polykrikoides* Bloom Using Remote Sensing at South Korean Seawaters. Presented on Japan Oceanography Society Meeting, Tokyo University of Marine Science, 2007 (not published).

Lee, CK, (2005), National Report on HABs in Korea. NOWPAP-CEARAC, Toyama City Toyama Japan.

Lee, YS, (2006), Factor Affecting Outbreaks of High-Density *Cochlodinium Polykrikoides* Red Tides in the Coastal Seawaters Around Yeosu and Tongyeong, Korea. Mar. Poll. Bull. 52: 1249 – 1259.

Kim, HG, Lee SG, and Ahn KH, (1997), *In*: Ahn, KH, (Ed.) Recent Red Tides in Korean Waters. Kudeok Publishing, Pusan, 280.

Stumpf, RP, (2001), Applications of Satellite Ocean Color Sensors for Monitoring and Predicting Harmful Algal Blooms. J. Human Ecol. Risk Assess. 7: 1363–1368.

Stumpf, RP, Culver ME, Tester PA, *et al,* (2003), Monitoring *Karenia Brevis* Blooms in the Gulfof Mexico Using Satellite Ocean Color Imagery and Other Data. Harmful Algae News 2: 147−160.

Suh, YS, Jang LH, Lee NK, *et al,* (2004), Feasibility of Red Tide Detection Around Korean Waters Using Satellite Remote Sensing. J. Fish. Sci. Tech. 7: 148−162.

Tan, CK, Ishizaka J., Matsumura S., *et al,* (2006), Seasonal Variability of SeaWiFS Chlorophyll a in the Malacca Straits in Relation to Asian monsoon. Cont. Shelf Res. 26: 168–178.

Tomlinson, MC, Stumpf RP, Ransibrahmanakul V., *et al,* (2004), Evaluation of the use of SeaWiFS imagery for detecting *Karenia brevis* harmful algal blooms in the eastern Gulf of Mexico. Remote Sens. Env. 91: 293–303.

Winarso G., (2012), Red Tide Detection Using Seawifs Standard Chlorophyll-A Algorithm in South East Korean Waters. Internasional Journal of Remote Sensing and Earth Sciences 9(1): 53-62.