SATELLITE DETECTION OF RED TIDE ALGAL BLOOMS IN TURBID COASTAL WATERS

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ABSTRACT: Several planktonic dinoflagellates, including *Cochlodinium polykrikoides (p)*, are known to produce red tides responsible for massive fish kills and serious economic loss in turbid Northwest Pacific (Korean and neighboring) coastal waters during summer and fall seasons. In order to mitigate the impacts of these red tides, it is therefore very essential to detect, monitor and forecast their development and movement using currently available remote sensing technology because traditional ship-based field sampling and analysis are very limited in both space and temporal frequency. Satellite ocean color sensors, such as Sea-viewing Wide Field-of-view Sensor (SeaWiFS), are ideal instruments for detecting and monitoring these blooms because they provide relatively high frequency synoptic information over large areas. Thus, the present study attempts to evaluate the red tide index methods (previously developed by Ahn and Shanmugam et al., 2006) to identify potential areas of red tides from SeaWiFS imagery in Korean and neighboring waters. Findings revealed that the standard spectral ratio algorithms (OC4 and LCA) applied to SeaWiFS imagery yielded large errors in Chl retrievals for coastal areas, besides providing false information about the encountered red tides in the focused waters. On the contrary, the RI coupled with the standard spectral ratios yielded comprehensive information about various ranges of algal blooms, while RCA Chl showing a good agreement with in-situ data led to enhanced understanding of the spatial and temporal variability of the recent red tide occurrences in high scattering and absorbing waters off the Korean and Chinese coasts. The results suggest that the red tide index methods for the early detection of red tides blooms can provide state managers with accurate identification of the extent and location of blooms as a management tool.

KEY WORDS: Ocean color, Red tide algal blooms, SeaWiFS, Turbid waters, Korea

1. INTRODUCTION

Red tide algal blooms occur frequently in the coastal areas of Korean South Sea (KSS) (Kim et al., 1990; Ahn et al., 2006), East China Sea (ECS) (Chen et al., 2003), Yellow Sea (YS), Bohai Sea (BS) (Tang et al., 2005) and Japanese Sea (JS) (Fukuyo et al., 1990) (Fig. 1). These blooms are dominated mostly by *Cochlodinium polykrikoides* (hereafter referred to as *C. polykrikoides*), *Alexandrium tamarense*, *Prorocentrum dentatum* and *Ceratium furca,* causing massive mortalities of aquaculture fish and numerous ecological and health impacts since the last few decades. In the KSS, Kim et al. (1998) have documented several *C. polykrikoides* bloom events along with an extensive event in summer 1995, which caused heavy mortalities of aquaculture fish amounting to a loss of ~US$ 95.5 million. It was already reported from South China Sea during March and April 1998 that HABs appear to have caused tremendous damage to the coastal aquaculture industry, wiping out 1500 tonnes of farmed fish, which was equivalent to half of the entire Hong Kong aquacultural production of 1997 (Anderson, 1998). A recent report showed evidence of *Ceratium furca* that dominated a 5000 km^2 area of the Bohai Sea during summer, causing an economic loss amounting to about US$ 62 million (EQB, 2000). Enhanced anthropogenic nutrification as one of the most pervasive changes altering coastal environments and a steepening of the nutricline by intervening physical phenomena offshore were suggested to be the main causes of frequent and spatially widespread HABs responsible for deteriorating the health of the ecosystem of the coastal and oceanic environment (Shumway, 1990).

To detect and monitor these algal blooms, this study attempts to evaluate the previously developed red tide index (RI) methods (Ahn and Shanmugam, 2006) and other standard bio-optical algorithms using SeaWiFS imagery acquired over Korean and neighboring waters.

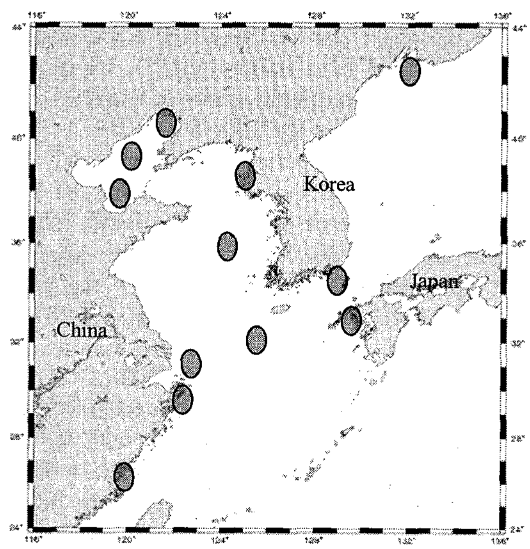


Figure 1. Locations of red tide algal bloom occurrences in Korean and neighboring waters

2. PRILIMINARY RESULTS

Fig. 2 show the results of red tide index methods applied to SeaWiFS images of 5 July 2001 and 22 August 2001. High red tide indices are represented by red color which clearly indicates potential areas of red tides off the Korean and Chinese coasts, while low induces as represented by green and blue colors stand for turbid and clear ocean waters. In the BS region, the OC4 algorithm produced abnormally high Chl concentrations (>15 mg m^{-3}) in proximity to the coast which is subjected to huge amounts of suspended sediments (SS) and dissolved organic matter (DOM) discharged from the 17 rivers nearby. The OC4 algorithm also gave a negative indication for the presence of red tides to the north and southeast (entrance) of BS (not shown). The lack of a red tide signature depicted from the OC4 algorithm was caused by ineffective atmospheric correction and standard bio-optical algorithms. This was in contrast with red tide index methods that provided a more comprehensive assessment about the existence of different red tide blooms and their controlling optical properties.

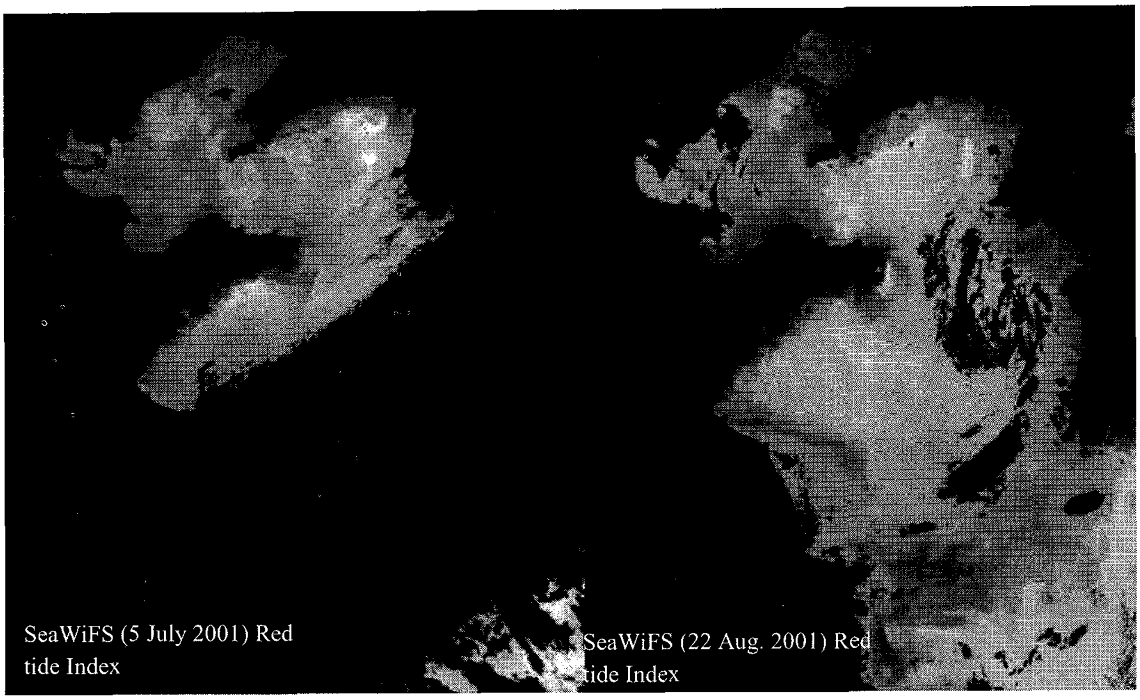
Figs. 3a-d compare the ability of detecting a highly toxic *C. polikrikoides* blooms by OC4 and RI algorithms applied to SeaWiFS image of 19 September 2000. This was a period of intensive red tide outbreaks and a large exchange between coastal and offshore water mass properties caused by costal runoff and the intrusion of the TWC from offshore. Note that areas with intense *C. polikrikoides* blooms around Korean South Sea (KSS) coastal bays previously masked by the SeaWiFS atmospheric correction (SAC) algorithm were successfully recovered by the spectral shape matching method (SMMM). In these areas, the bloom of *C. polikrikoides* revealed higher indices (red color) than those of other algae observed in the Bohai Sea that exhibited RI <4. RCA yielded Chl >15 mg m^{-3} (Fig. 3c). The spatial patterns of high RI and RCA Chl were consistent with the intense phase of *C. polikrikoides* bloom (>1.5×10^4 cells ml^{-1}), which drifted southwestward along the Kosong coastal areas of the KSS. In contrast, OC4 Chl provided false information for many of these coastal areas, thus limiting the utility of SeaWiFS data for mapping and monitoring red tides in the KSS.

Fig. 4 shows the comparison of RI and SeaWiFS Chl along a 120km transect (in Fig. 3b) which lies between the Kosong coastal area west off the Geoje Island and KSS offshore. The SeaWiFS Chl at the start of the transect appeared to be very low (< 8 mg m^{-3}) and abruptly increased (over 30 mg m^{-3}) from 5 to 15 km, but it had a tendency of a sharp decrease (i.e., < 15 mg m^{-3} from 15 to 25km; < 7 mg m^{-3} from 25-70km; < 2.5 mg m^{-3} from 70 to 140km) toward the clear waters offshore the KSS. On the contrary, red tide indices with the distinct boundaries follow a nearly similar trend with SeaWiFS Chl from 0 to 70km and exhibit an abrupt peak with indices of >4 at the western limb of *C. polykrikoides* bloom influenced by the action of eddy feature in the vicinity of Tsushima Strait, where SeaWiFS Chl was much lower (<2.5 mg m^{-3}) and did not represent the westward branch of this bloom extending parallel to the coast of KSS.

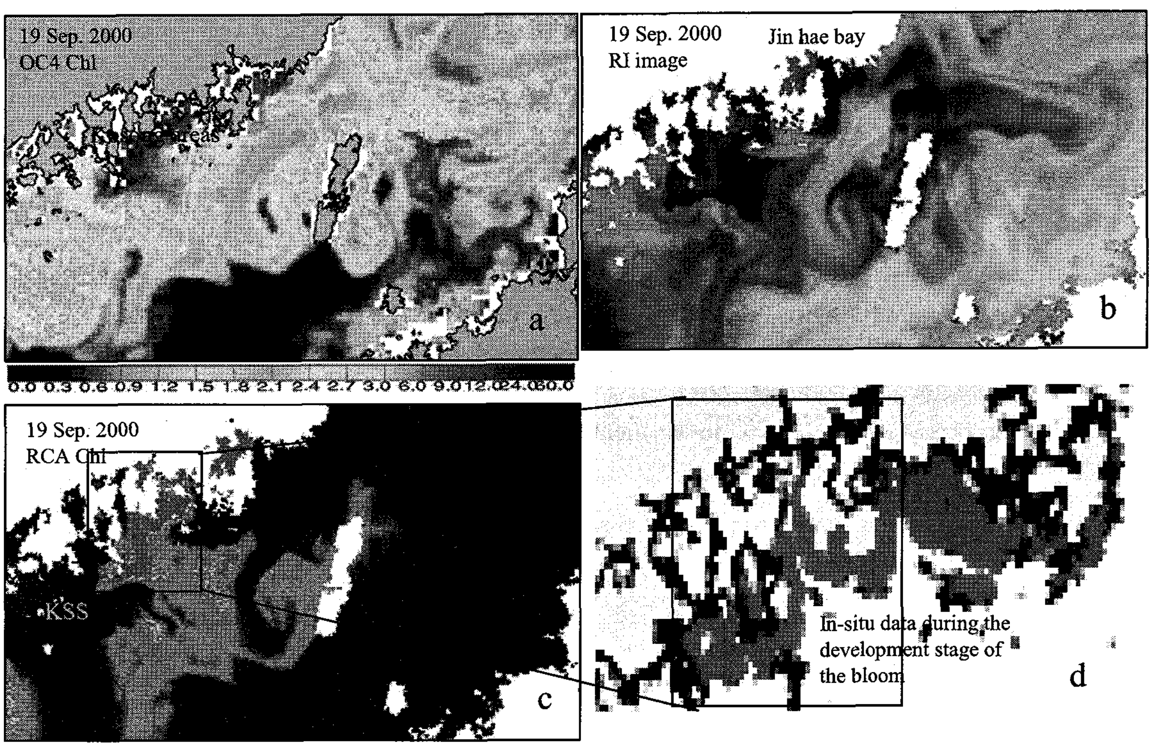
To better illustrate the difference between the established algorithms, in-situ chlorophyll data collected prior to the initiation and during the decomposition phase of an encountered red tide bloom in the YS during mid-February and the first-second week of April 2002 were used. Five transects, A, B, C, D and E, were established traversing across the bloom from bright (high relative reflectance) cold coastal waters in the east to dark (relatively weak reflectance) warm and saline offshore waters in the west. In-situ Chl concentrations from each transect were compared with satellite-retrieved Chl using OC4, LCA and RCA (Fig. 5). Note that because of time difference (as mentioned above) between satellite and field observations, the estimates of Chl by OC4 (Ocean Chlorophyll 4), LCA (Local Chlorophyll Algorithm) and RCA (Red tide index Chlorophyll Algorithm) differed from in-situ Chl data at several locations, particularly the nearshore stations A3, B1, C1, D3 and E5. In-situ Chl showed a negative trend with satellite retrievals in these areas probably because of a high abundance of diatom populations along the coastal areas during the first week-second of April 2002. However, the RCA Chl exhibited a good consistency with in-situ Chl for the offshore stations B5, C5 and D5 (red tides). Comparisons between the satellite Chl estimates showed that all three algorithms gave higher Chl estimates in nutrient-depleted warm and high saline waters offshore and lower estimates in nutrient-enriched coastal cold waters. However, a significant difference between these algorithms was noticed, i.e., the OC4 had the higher Chl values, RCA the moderate values and LCA the low values at all stations. At nearshore stations A3, B1, C1, D3 and E5, OC4 and LCA produced slightly elevated Chl, likely due to interference of high DOM concentrations and/ or possibly high diatom concentrations along the Korean west coastal areas. RCA Chl estimate was <0.7 mg m^{-3} indicative of no HABs in these areas.

3. CONCLUSION

The results of our investigation clearly show the advantages of applying RI and RCA algorithms over traditional spectral ratios algorithms to correctly identify the potential areas of red tides and distinguish other phytoplankton blooms from sediment-dominated and non-bloom waters. The spatial patterns of red tides inferred from RI and RCA algorithms appeared to be more consistent with in-situ data than those from standard OC4 and LCA algorithms. This study suggests that information gained from the red tide index methods can be coupled with other environmental data to allow us to predict subsequent development of the blooms in the affected areas and neighboring waters likely to be affected. Such observations will also allow rapid implementation of reasonable and appropriate countermeasures to mitigate the bloom.



Figures 2. Red tide indices from SeaWiFS (on 5 July 2001 and 22 August 2001) in Korean and neighboring waters.



Figures 3a-d. Comparison of red tide detection by SAC-OC4 and SSMM-RI algorithms applied to SeaWiFS image of 19 September 2000 in the KSS. (a) OC4 Chl image, (b) RI image, (c) RCA Chl image and (d) In-situ data collected from theKSS coastal areas during the early stage of C. polykrikoides bloom by NFRDI.

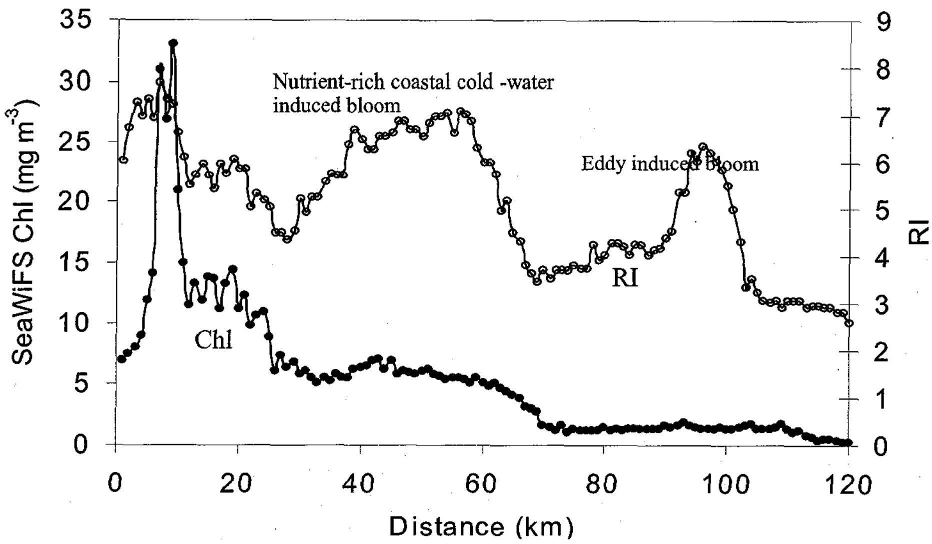


Figure 4. Comparison of red tide indices and SeaWiFS Chl along a 120km transect which lies between the Kosong coastal areas and Tsushima Strait.

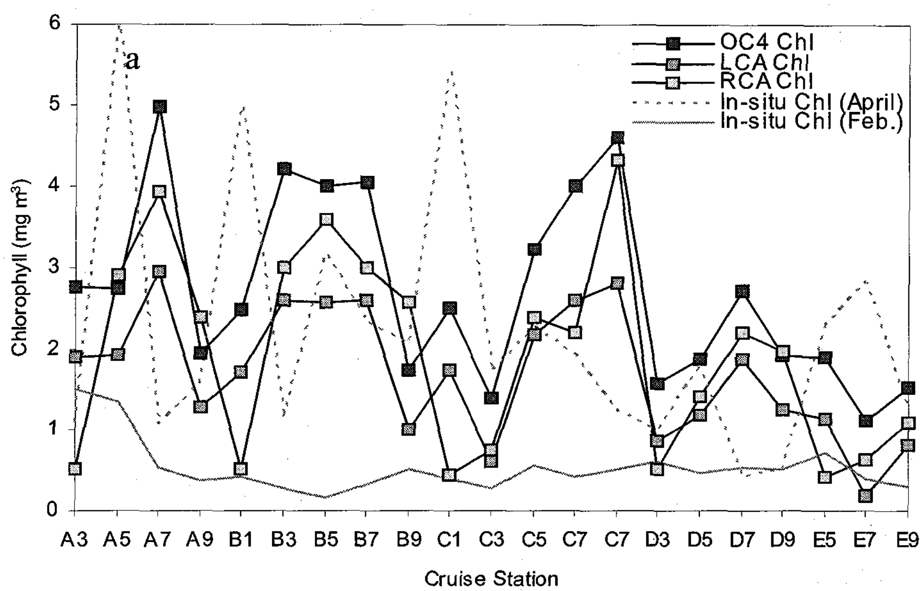


Figure 5. Comparison between satellite and in-situ field chlorophyll concentrations on 27 March 2002 in the central Yellow Sea.

References

Y.H. Ahn and P. Shanmugam, 2006. Detecting red tides from satellite ocean color observations in optically complex Northeast-Asia coastal waters. Remote Sensing of Environment, 103, 419-437.

Ahn, Y.H., P. Shanmugam., J.H. Ryu, and J.C. Jeong, 2006. Satellite detection of harmful algal bloom occurrences in Korean waters. Harmful Algae, 213-131.

Anderson, D.M., 1998. Study of red tide monitoring and management in Hong Kong: literature review and background information. Technical Report No. 1, Hong Kong Agricultural and Fisheries Department, Hong Kong.

Chen, C., J. Zhu., R.C. Beardsley, and P.J.S. Franks, 2003. Physical-biological sources for dense algal blooms near the Changjiang River. Geophysical Research Letters, 30, doi: 10.1029/2002GL016391.

Fukuyo, Y., H. Takano., M. Chihara, and K. Matsuoka, 1990. Red Tide Organisms in Japan. An Illustrated Taxonomic Guide. Uchida Rokakuho, Co., Ltd., Tokyo. pp. 407.

Kim, H.G., J.S. Park, and S.G. Lee, 1990. Coastal algal blooms caused by the cyst-forming dinoflagellates. Bulletin Korean Fisheries Society, 23, 468-474.