OUTBREAK OF HARMFUL ALGAL BLOOMS RELATED WITH TEMPERATURE DISTRIBUTION DERIVED FROM IN-SITU AND REMOTE SENSING EXPERIMENTS IN THE KOREAN WATERS

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ABSTRACT ... The red tide related with *Cochlodinium Polykrikoides* bloom has been frequently occurred around the South Sea of Korea and caused the economic loss in the coastal breeding grounds. The outbreak scale was usually change by physical, biological and environmental condition at each years. Relatively large-scale red tide occurred in 1995, 1997, 1999, 2001, 2002 and 2003 through spatial scale, duration and maximum density. Compared the scale of red tide with physical condition around the South Sea, the lower coastal temperature on August around the South Sea corresponded with the large scale red tide. By serial oceanographic investigations on August in the South Sea and estimated wide area temperature information by satellite, SSTA around the South Sea and wide area was negative when the outbreak of red tide was large scale. From the results of temperature difference between surface and 30m layers, the occurrence of enormous red tide has a tendency when the temperature gradient around the seasonal thermocline was weakened. Larger Kuroshio volume transport in the upstream was also corresponded with the large scale red tide.

KEY WORDS: Red tide, SST, Kuroshio, Thermocline

1. INTRODUCTION

Red tide is defined that red discoloration of marine waters caused by the presence of enormous numbers of certain microscopic algae with a long history. Outbreaks of red tide are clearly increased during last 20 years and threaten a human health and fisheries resource. The species of alga occurred red tides are known about 300 species in diatoms, dinoflagellates, silicoflagellates, prymnesiophytes and raphidophyte. In these species, 60~80 species called harmful algal bloom (HAB hereafter) species by biotoxin, physical stress, hypoxia, decrease of luminous intensity and state of incongruent with nutrients. The 90% of harmful bloom species belong to the dinoflagellates (Smayda, 1997).

The study about harmful bloom threatened a human health and occurred damage of fisheries has been globally and actively carried out (Watras *et al.*, 1982, Lefebvre *et al.*, 2002). In Korea, the red tide was frequently occurred around some coastal area in 1980's, though it was intermittently occurred in 1970's. It, however, has been occurred not only inner bay and coastal area but also offshore for a long time after 1990's. The species caused by HAB in the Korean Waters is mainly *Cochlodinium Polykrikoides* during last a few years. *Cochlodinium Polykrikoides* bloom greatly occurred around the South Sea and East Sea of Korea in 1995 with large damage of fisheries. These natural phenomena should be extensively occurred year after year in summer and cause the enormous economic loss and the wastes of oceanic ecosystem since 1995.

The cause about the outbreak of HAB is not so clear yet, though a few hypotheses were explained. Compared the integrated and accumulated oceanographic and atmospheric data with the data about the outbreak of HAB since 1995, oceanic conditions are quantitatively and qualitatively examined when the red tide was greatly occurred in the Korean Waters in this study. As a matter of course, enormous biological phenomena could not explained just physical variation. Through the physical view for the outbreak of HAB, however, it could be considered that this study is helped for the clarification of the cause about the outbreak of HAB in the Korean Waters.

2. DATA AND METHODS

The data about the outbreak of HAB is used to the spatial map about the outbreak of HAB through the coastal investigation by Marine Harmful Organism Team in National Fisheries Research and Development Institute (NFRDI) and East, South and West Sea Fisheries Research Institute in NFRDI from 1995 to 2005.

To compare the outbreak of HAB with temperature, using temperature data are three types; one is the serial oceanographic investigation with bi-monthly time scale for examination about the onshore and offshore temperature distribution and the temperature difference between surface layer and sub-surface layer by Ocean Research Team and South Sea Fisheries Research Institute in NFRDI (Figure 1). Another is the coastal oceanographic data with once a day in fixed area along the Korean coastal line, where we used two stations data for comparing temperature variation with the outbreak of HAB in Yeosu and Sorido. The other is the Multi-Channel Sea Surface Temperature (MCSST) data set by Naval Research Laboratory (NRL) for examination the temperature variation of wide area. From this data set, the snapshot of MGSST anomaly is used for comparing with the outbreak of HAB in the Korean Waters.

To examine current variation within the outbreak of HAB, temporal variation of Kuroshio, which distinctly influences oceanic condition and oceanic ecosystem in the Korean Waters, is examined by the volume transport of Kuroshio at PN-line, where locates in the upstream area of Kuroshio in East China Sea, from Nagasaki Marine Observatory in Japan Meteorology Agency.

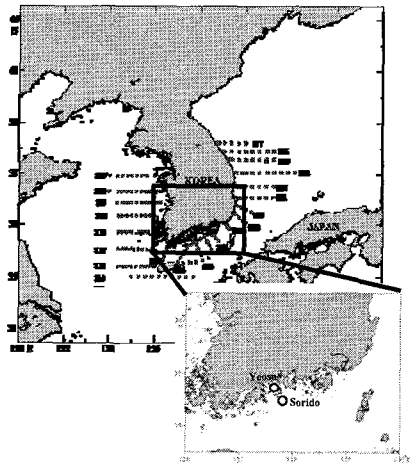

Figure 1. Location maps of serial oceanographic investigation and used coastal temperature stations by NFRDI (small map).

3. RESULTS

3.1 The Outbreak scale of HAB in the Korean Waters

Marine Harmful Organism Team in NFRDI has been carried out the monitoring for the occurrence state of red tide with twice a month around the coastal area using R/V and helicopter from May to October every year. From these monitoring, they reported the spatial map about the outbreak of HAB (Figure. 2). Extensive scale of red tide, which it extended to the eastern coast of Korea, were occurred in 1995, 1997, 1999, 2001, 2002 and 2003. Especially extensive scale of it appeared in 1995, 2001 and 2003. The outbreak of HAB in 1996, 1998, 2000, 2004 and 2005 had been a lull, though it locally occurred around the coast of South Sea in Korea. Trend of the outbreak of HAB during last 11 years is comprehensively described in Table.1. The red tide generally occurred from early or mid August, though it occurred on mid July in 2005, ended between late September and mid October. Duration of red tide in the Korean Waters is about 27 days~62 days, when the longest duration is 62 days in 2003. Maximum density of *Cochlodinium Polykrikoides* is about 5,800~48,000 *inds./ml*, the higher concentrated red tide, which is larger than 30,000 *inds./ml*, appeared in 1995, 1999, 2001, 2002 and 2003. (Table 1)

In comprehensive for spatial scale, duration and maximum density, the red tide occurred as larger scale in 1995, 1997, 1999, 2001, 2002 and 2003, as smaller scale in 1996, 1998, 2000, 2004 and 2005. The larger and smaller red tide generally occurred with year-to-year variation before 2001, though it irregularly occurred since 2002.

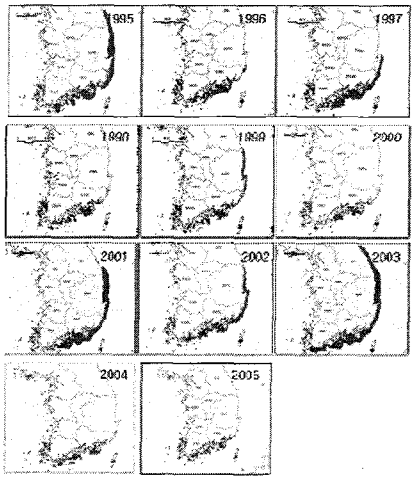

Figure 2. The spatial map about the outbreak of HAB along the Korean coast from 1995 to 2005.

Table 1. The outbreak scale of HAB during last 11 years.

Items	'95	'96	'97	'98	'99	'00	'01	'02	'03	'04	'05
Duration (days)	55	28	27	34	54	29	41	57	62	30	58
Max. density (10^3 *inds/ml*)	30	23	20	22	44	15	32	30	48	5.8	25
Damage (10^7 KRW)	764	21	15	1.6	3.2	2.6	84	49	215	1.2	10

3.2 Temporal and spatial variation of temperature

To examine the relationship between the outbreak of HAB and coastal temperature, which has been obtained by coastal oceanographic investigation in NFRDI, temporal variations of monthly mean temperature in Yeosu and Sorido, where the locations indicated in Figure 1, on August during last 11 years are shown in Figure 3. In case of August, the relatively high temperature was shown in 1996, 1998 and 2004, when the red tide was lull, though the highest temperature appeared in 2001, when the scale of red tide was large. In these results, monthly mean temperature on August was lower during the red tide was enormous.

Using the data obtained by serial oceanographic investigation on August during last 11 years, surface temperature anomaly distributions were shown in Figure 4. The distributions of surface temperature anomaly on August were well expressed within the outbreak of HAB. The negative temperature anomaly appeared around the southeastern coast of Korean Peninsula in 1995, 1997, 1999, 2001, 2002 and 2003. It clearly corresponded to the enormous outbreak of HAB, though the negative temperature anomaly also appeared in 2000, when the red tide was lull. These results explained the relatively lower surface temperature related with the outbreak of HABs. It could be caused by the weakened seasonal thermocline and deep surface mixed layer make much easier to supply the nutrients from lower layer and this supplies generate the well condition of *Cochlodinium Polykrikoides* bloom (Lim *et al.*, 2003).

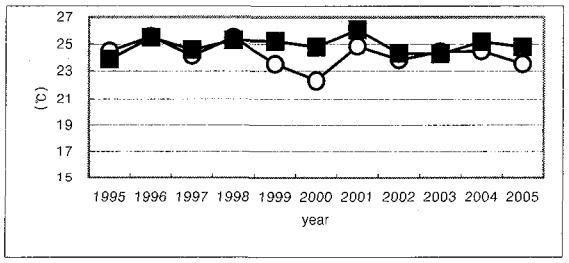

Figure 3. Temporal variation of monthly mean coastal temperature at Yeosu (closed square) and Sorido (open circle) on August from 1995 to 2005.

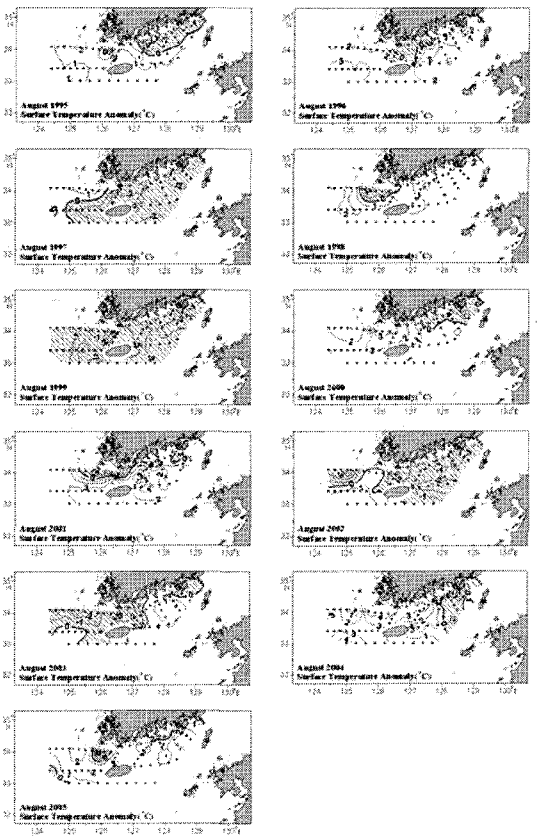

Figure 4. Distribution of sea surface temperature anomaly in the South Sea of Korea from 1995 to 2005 (shaded marks indicate negative value.)

Actually, we examine that weakened thermocline formed during the enormous outbreak of HAB. Figure 5 shows the spatial distribution of the temperature difference between surface and 30m layer in the South Sea of Korea during last 11 years. When the red tide was enormous in 1995, 1997, 1999, 2001, 2002 and 2003, temperature differences were about 3~7℃ around the coastal area. When the red tide was lull, on the other hand, those were about 4~10℃ around the coastal area. Except in 1998, the large temperature difference between surface and 30m layer was clearly corresponded with the lull red tide year.

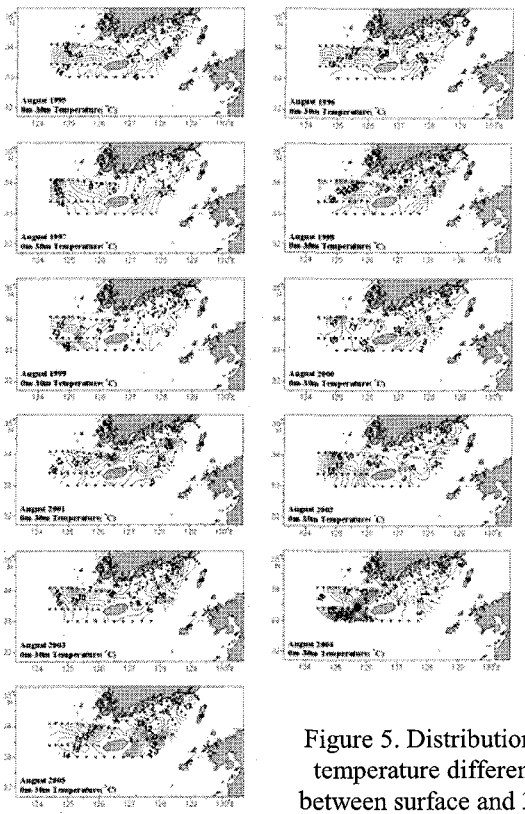

Figure 5. Distribution of temperature difference between surface and 30m layers in the South Sea of Korea from 1995 to 2005.

To examine the relationship between the outbreak of HAB and the wide area temperature information, the snapshots of sea surface temperature anomaly (SSTA) around the mid August during last 9 years obtained by NRL were used (Figure 6). This SSTA calculated by subtracting a climatological field from the temperature field produced by MODAS (Modular Ocean Data Set) with OI (Optical Interpolation). The climatological sea surface temperature field is interpolated from UWM (University of Wisconsin-Milwaukee) / COADS (Comprehensive Ocean-Atmosphere Data Set) 1-degree monthly sea surface temperature climatology. In these SSTA snapshots, it could be found out that negative SSTA around the South Sea of Koran Peninsula appeared in 1997, 1999, 2002 and 2003. On the other hand, significantly positive SSTA appeared in 1998, 2000, 2004 and 2005, though positive SSTA in 2001 was dominant except around the coastal area of South Sea. When the red tide was enormous in the Korean Waters, tendency of SSTA was clearly negative in the wide area.

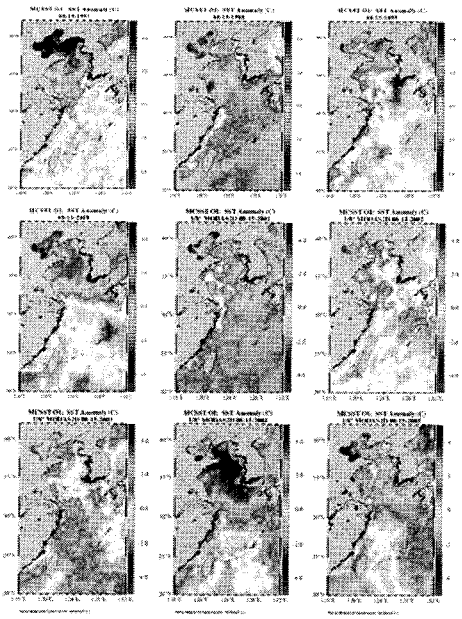

Figure 6. Snapshot of sea surface temperature anomaly on mid August by MCSST information using MODAS with OI around the East China Sea and Yellow Sea from NRL achieved data set.

3.3 Kuroshio Volume transport

Nagasaki Marine Observatory in Japan Meteorology Agency seasonally carried out serial oceanographic-meteorological investigation since 1971 on PN-line (Figure 7). From these investigations, they estimated the Kuroshio volume transport filtered out short time fluctuation less than one-year period by moving average with 4 times investigations as statistics method (Nagasaki Marine Observatory, 2005). Since 1995, relatively large Kuroshio transport appeared in 1997~1998 and in 2001~2003. Except in 1995 and 1998, tendency between the Kuroshio volume transport and the outbreak of HAB in the Korean Waters almost corresponded, that is, large volume transport in upstream of Kuroshio corresponded with the enormous outbreak of HAB and small it corresponded with the lull outbreak of HAB.

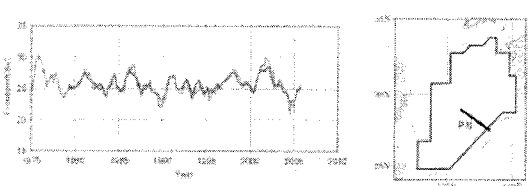

Figure 7. Temporal variation of observed (red) and estimated (blue) Kuroshio volume transport (left panel) at PN-line (right) (e.g., NMO, 2005).

4. CONCLUSION AND DISCUSSION

In spite of some studies about the physical process related with the outbreak of HAB in the Korean Waters (Suh *et al.*, 2003; Lee and Kang, 2003), the physical mechanism of red tide in the Korean Waters was not clear yet. Therefore, it is needed to clarify significant relationship between oceanographic conditions and the outbreak of HAB for the early stage prediction about the scale of red tide.

In this study, we examined the multiple comparisons for the outbreak of HAB and physical components. At first, the lower coastal temperature on August around the South Sea corresponded with the enormous outbreak of HAB. By serial oceanographic investigations on August in the South Sea, SSTA around the South Sea was negative when the outbreak of HAB was enormous. Moreover, SSTA in the wide area included East China Sea examined by MODAS with OI from NRL was also negative during enormous red tide. From the results of temperature difference between surface and 30m layers, the occurrence of enormous red tide has a tendency when the temperature gradient around the seasonal thermocline was weakened. When Kuroshio, which has been greatly influence oceanographic ecosystem in the Korean Waters, volume transport was larger, the red tide occurred enormous.

In this study, we can found out tendency the physical oceanographic conditions when the enormous red tide occurs. Exceptions, however, were existed and quantitative descriptions were insufficient

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