

# Report of HABs case study in the southeastern coast of Korea

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## 1. Introduction

### 1.1. Objective

The objective of conducting the HAB case study in the southeastern coast of Korea is to establish the most effective and laborsaving ways for sharing among the NOWPAP member states, information on HAB events and associated oceanographic and meteorological conditions. Furthermore, common HAB issues within the NOWPAP region will be identified through the case study. In the case study, red-tide and toxin-producing planktons will be referred as HAB species.

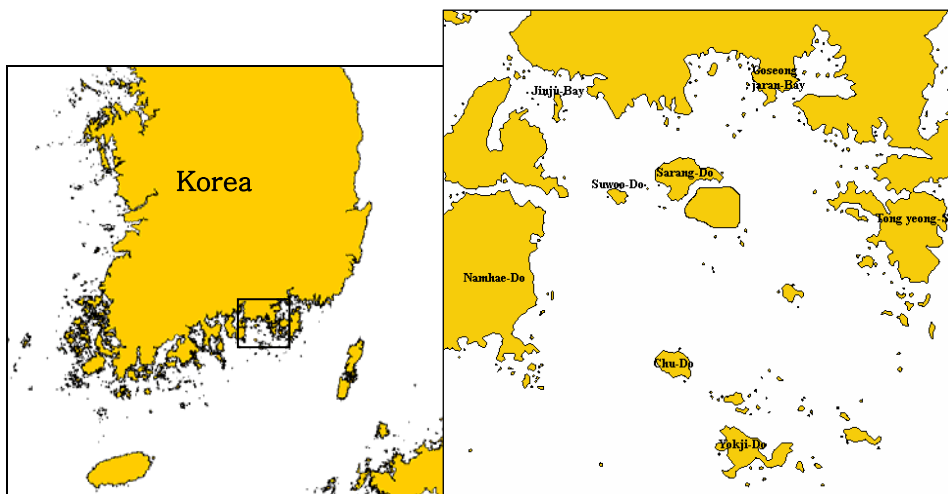
### 1.2. Definitions and rules used in the HAB case study

Mention that in general, the scientific names in the 'Integrated Report' and 'Booklet on Countermeasures' will be used in this case study.

### 1.3. Overview of the target sea area

#### 1.3.1. Location and boundary

The target sea area (longitude :  $34^{\circ}35' 43''$  -  $34^{\circ}57' 54''$  , latitude:  $127^{\circ}30' 11''$  -  $128^{\circ}56' 60''$  ) is located in the eastern part of South Sea, Korea, which faces the East China Sea. The bay surrounded by Goseong-jaran Bay, and Jinju Bay has shellfish farms including oyster, mussel and fish farms shown in right and left below of Fig. 1. Fishmans are usually culture of rockfish, parrot fish and red sea bream etc..



**Figure 1. Target sea area for the case study of Korea**

#### 1.3.2. Environmental/geographical characteristics

Three sides of the target sea are surrounded by land such as Tongyeong-Si, Namhae-Si, Goseong-Si. Its south is opened to offshore and has long ria coast with irregular coast line. The depth of water is generally less than 10 m and the area has a less wave due to geographic characters of deeper depth of water in offshore. While, this area is directly affected by a Tsushima warm current with abundant nutrient supply and smooth current flow. Therefore, fishery industry including fish farming has been developed in this area. However, since 1995, *Cochlodinium polykrikoides* blooms have occurred in this area in every August and September, causing numerous fishery damages.

## 2. Methodology used in the case study of the southeastern coast of Korea

### 2.1. Methodology used in the case study

HAB and dominant species are regularly investigated during March to November by NFRDI's personnel. HAB species is identified and reported to NFRDI by local fishery stations whenever HABs occur in waters. However, once HAB initiate, all relevant agency conducts their daily HAB monitoring using vessel and helicopter. National Maritime Police Agency(NMPA) is responsible for HABs monitoring by helicopter. NFRDI's personnel monitor all southern coasts for forecasting occurrences and dispersal of HABs during July to September.

All the collected data from field survey, meteorology and remote sensing by NOAA and MODIS are sent to HAB emergency center under NFRDI. HABs emergency center deploy and forecast dispersal of HABs.

### 2.2. Warning/action standards against HAB events

HABs monitoring system covering whole Korean waters was established for minimization of fishery damages. To give previous attention to fishermen and aquaculturists, NFRDI deploy alert system. It consists of Red Tide Attention, Red Tide Alert and Warning Lift. The notice of attention and alert are issued when the density of *C. polykrikoides* exceed 300 cells/mL and 1,000cells/mL, respectively as in Table 1.

When HAB attention and alert issues, we lead the way to withdraw feeding, supply the liquid oxygen and disperse of yellow clay.

**Table 1. HAB warning/action standards of Korea**

Warning Class	Scale	Cell density(cells/mL)
Red Tide Attention	HAB blooms and over radius 2-5km (12-79km <sup>2</sup> ) and potential fishery damages	<ul style="list-style-type: none"> <li>○Dinoflagellates: depends on cell size and toxicity               <ul style="list-style-type: none"> <li>- <i>Chattonella</i> sp. : over 50</li> <li>- <i>Cochlodinium</i> sp. : over 300</li> <li>- <i>Gyrodinium</i> sp. : over 500</li> <li>- <i>Karenia mikimotoi</i>: over 1,000</li> <li>- Etc. : over 30,000</li> </ul> </li> <li>○Diatom: over 50,000</li> <li>○Mixed blooms: over 40,000 cells (over 50%) of dinoflagellate</li> </ul>
Red Tide Alert	HAB blooms and over radius 5km (79km <sup>2</sup> ) and fishery damages	<ul style="list-style-type: none"> <li>○Dinoflagellates: depends on cell size and toxicity               <ul style="list-style-type: none"> <li>- <i>Chattonella</i> sp. : over 100</li> <li>- <i>Cochlodinium</i> sp. : over 1,000</li> <li>- <i>Gyrodinium</i> sp. : over 2,000</li> <li>- <i>Karenia mikimotoi</i>: over 3,000</li> <li>- Etc. : over 50,000</li> </ul> </li> <li>○Diatom : over 100,000</li> <li>○Mixed blooms : over 80,000 cells (over 50%) of dinoflagellate</li> </ul>
Warning Lift	HABs are extinct, no risk of fisheries damages	

- The president of NFRDI can authorize red tide attention in case of alarming potential bloom damages regardless cell densities.

Source: National Fisheries research and Development Institute (<http://portal.nfrdi.re.kr/redtide/index.jsp>)

In NFRDI, harvested shellfish are routinely monitored to confirm the presence of algal toxins. Safety limits are established by the Government, which are 80 $\mu$ g/100g for PSP. So, NFRDI notifies fisherman not to harvest the shellfish when the toxin level exceeds over 80 $\mu$ g/100g meat.

HAB species, its abundances and economic damages are monitored by NFRDI's personnel, and these data were sent to fishers and relative institutes through ARS(automated telephone response system), SMS service, satellite TV, facsimile, and internet web site (<http://www.nfrdi.re.kr>).

### 2.3. Target HAB species

Dinoflagellates such as *Akashiwo sanguinea*, *Cochlodinium polykrikoides*, *Prorocentrum minimum*, *P. dentatum*, *Ceratium furca* and *Heterosigma akashiwo*, were found to be the major dinoflagellates in the case study area. But this case study area is not present the algal toxin from *Alexandrium* spp..

*C. polykrikoides* is a major causative organism of HABs for fishery damages in Korea. They exclusively formed monospecific bloom of high density in the summer season. Major blooms occurred in end of July to end of September, its blooms have caused mortality of farming fish every year. Other than *C. polykrikoides*, fish kills have not been reported by organisms listed in Table 2. In addition, *Chattonella* spp. causing fishery damages in Japan have occurred in Korean waters but no fish kills occurred.

**Table 2. Target HAB species in this case study (NFRDI)**

	Harmful Red-tide causative species	Toxin-Producing Plankton
Dinophyceae		
<i>Akashiwo sanguinea</i>	○	-
<i>Cochlodinium polykrikoides</i>	○	-
<i>Prorocentrum dentatum</i>	○	-
<i>Prorocentrum minimum</i>	○	-
<i>Ceratium furca</i>	○	-
Raphidophyceae		
<i>Heterosigma akashiwo</i>	○	-

Source: National Fisheries research and Development Institute (<http://portal.nfrdi.re.kr/redtide/index.jsp>)

## 3. Monitoring framework and parameters of HAB

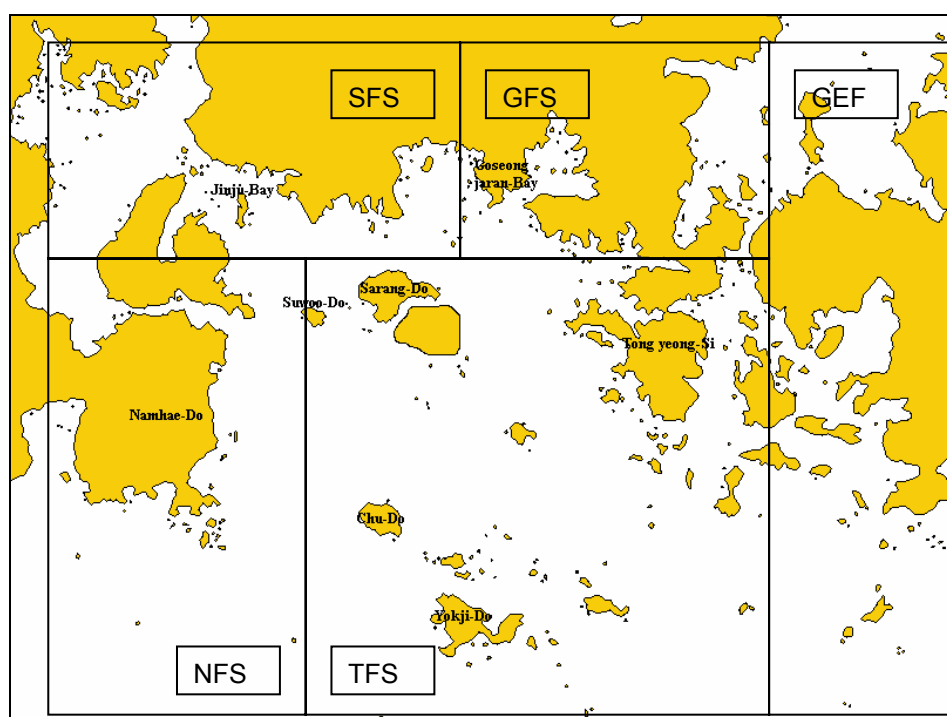
### 3.1. Monitoring framework

In NFRDI of Korea, HABs have been regularly monitored to prevent HABs induced fishery damage. HAB species, its abundances and economic damages are monitored by the system. The routine monitoring has been conducted by National Fisheries Research and Development Institute(NFRDI)'s personnel. Also, focused HAB monitoring survey has been conducted by each fishery station located in Korean-wide(Fig. 2). The detailed monitoring on HABs is conducted by NFRDI, SFRDI, and Aquaculture Environment Research Center. Monitoring areas are shown in Table 3.

**Table 3. Monitoring organization and monitored sea areas**

Monitoring organization	Monitored sea area
National Fisheries Research and Development Institute	Southeastern Sea
South Sea Fisheries Research and Development Institute (SSFRDI), Aquaculture Environment Research Center	South Sea, Tongyeong, Geoje
Tongyeong fishery station(TFS)	Mireuk Do, Sarang Do
Sacheon fishery station(SFS)	Jinju Bay
Goseong fishery station(GFS)	Goseong Bay, Jaran Bay
Geoje fishery station(GEFS)	Geoje Do
Namhae fishery station(NFS)	Namhae Do, Changsun Do

Source: National Fisheries research and Development Institute (<http://portal.nfrdi.re.kr/redtide/index.jsp>)



**Figure 2. Monitor sea area in the case study of southeastern coast of Korea**

### 3.2. Monitoring parameters

In the southeastern coast of Korea, the following four types of HAB related surveys are conducted: regular HAB monitoring survey, focused HABs monitoring survey, HABs in the South Sea investigation and regular shellfish poisoning survey. Regular HABs monitoring has been carried out monthly at 90 stations from March to November by NFRDI to investigate the status of water quality and phytoplankton dominant species. Most of the coastal environmental parameters are monitored simultaneously. Focused HABs monitoring survey is conducted when water discoloration, HAB events or fishery damage occur. HABs in the South Sea investigation is conducted during early HAB's blooms to their extinction area and used for HAB's warning. From this results of survey, we are forecasting of occurrence and dispersal of HABs. Regular

shellfish poisoning survey is conducted regularly at fixed locations to check presence of HAB species that induce shellfish poisoning contamination.

This case study focus mainly on the results of the focused HABs monitoring survey, which monitors HAB causative species, cell density, affected area, fishery damage, water temperature and salinity. Table 4 shows the objective and monitoring parameters of each survey.

**Table 4 Objectives and monitoring parameters of each HAB survey**

Survey type	Main objectives	Monitoring parameter				Monitoring frequency
		HAB	Water quality	Meteorology	Others	
Regular HAB monitoring survey	To investigate the status of water quality and phytoplankton dominant species	-All HAB species -Cell density -Water color	-Water temp. -Salinity -DO -Transparency -Nutrients -Chl.a	none		9/year (March - December)
Focused HABs monitoring survey	To check presence of HAB area and species composition	-HAB species (dominant/causative spp.) -Cell density -Bloom area -Water color	-Water temp. -Salinity	-Weather -Cloud cover -Wind direction/speed		Immediately after water discoloration is reported
HABs in the South Sea investigation	To forecasting occurrence and dispersal of HAB	-HAB species (dominant/causative spp.) -Cell density -Water color	-Water temp. -Salinity -DO, pH -Transparency -Nutrients -Chl.a	- wind direction/speed - current flow - precipitation - solar irradiance - typhoon		6-7/year (each other week)
Regular shellfish-poisoning survey	To check presence of HAB sp. that induce shellfish poisoning Contamination of shellfish products	-Species that induce shellfish poisoning -Cell density -Water color	-Water temp. -Salinity -DO		Shellfish contamination	30/year (4/month)

Source: National Fisheries research and Development Institute (<http://portal.nfrdi.re.kr/redtide/index.jsp>)

### 3.3. Data and information used

All the collected data are sent to HABs emergency center in NFRDI, immediately. Table 5 shows the monitoring parameters that will be referred in the HABs case study. HAB's species, cell density, and bloom areas are investigated for early warning blooms, and water quality is investigated for distribution of HABs. When the *C. polykrikoides* bloom is outbroken, it gradually develops into plume like patch and get enlarged around plume in slightly eutrophic water. Their movement and distribution is dependent on the wind direction and tidal current. The bloom approaches the coast at flood current and wind. So, we investigated all parameter such as water quality and meteorology in HABs in the South Sea investigation. Total data for HAB's monitoring is used for warning and predicting HAB's migration and dispersal.

**Table 5. Monitoring parameters referred in the HAB case study**

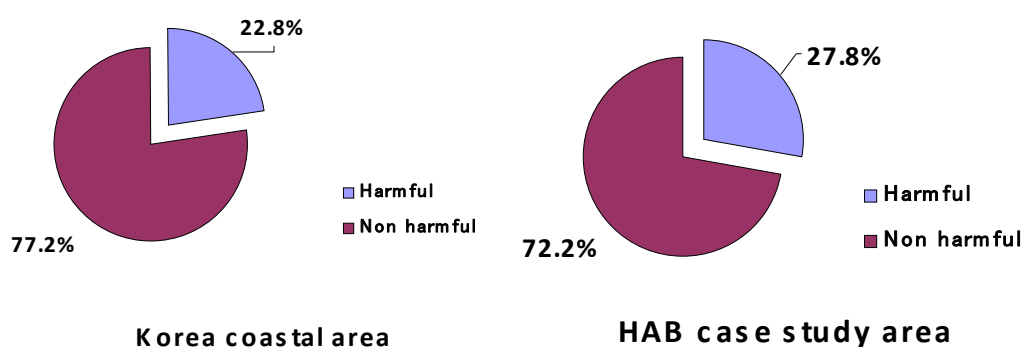
	Monitoring parameter	Survey type
HAB	- HAB species (dominant/causative spp.) - Cell density - Bloom area	Focused HABs monitoring survey HABs in South Sea investigation
Water quality	- Water temp. - Salinity - DO	Focused HABs monitoring survey
Others	- Water quality Transparency, Nutrients, Chl.a - Meteorology Weather, Cloud cover, Wind direction/speed, current flow, precipitation, solar irradiance, typhoon	Regular HABs monitoring survey HABs in the South Sea investigation

#### 4. Status of HAB events

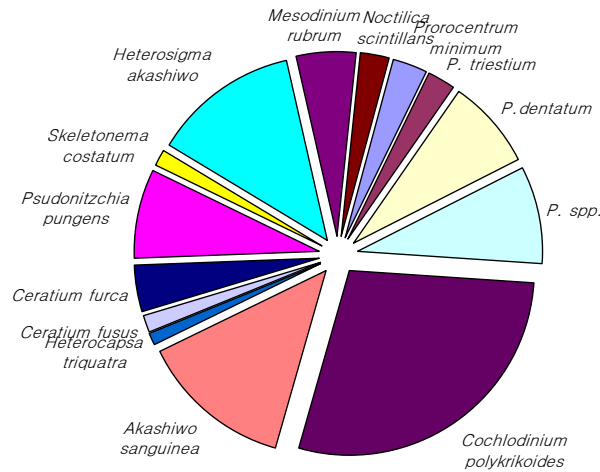
##### 4.1. Status of HAB events from year 1995-2007

From year 1995-2007, a total of 795 HAB events were recorded, in which 184 events(22.8%) induced fishery damage in Korea. Especially, a total of 169 HAB events were recorded, in which 47 events(27.8%) induced fishery damage in the case study area(Fig. 3). The most frequently observed HAB species were *C. polykrikoides*, *Heterosigma akashiwo*, *Prorocentrum dentatum*, *Akashiwo sanguinea* and, which was recorded 181 times. HAB species that inflicted the most fishery damage was *C. polykrikoides*. HAB by dinoflagellates are much more frequent than by diatoms(Fig. 4).

This frequency of HABs is determined from data of local fishery office, and a bloom occurrence in each territory was counted as a single HAB occurrence and additional HAB event was added if the dominant species is changed to other organism.



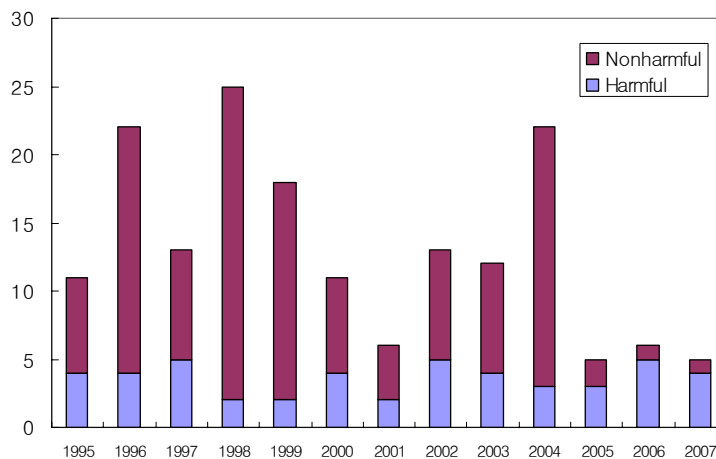
**Figure 3. Percentage of harmful and non harmful red tides in Korea(1995-2007).**



**Figure 4. Percentage of HAB species in the southeastern coast of Korea(1995-2007).**

#### 4.2. Yearly trends of HAB events

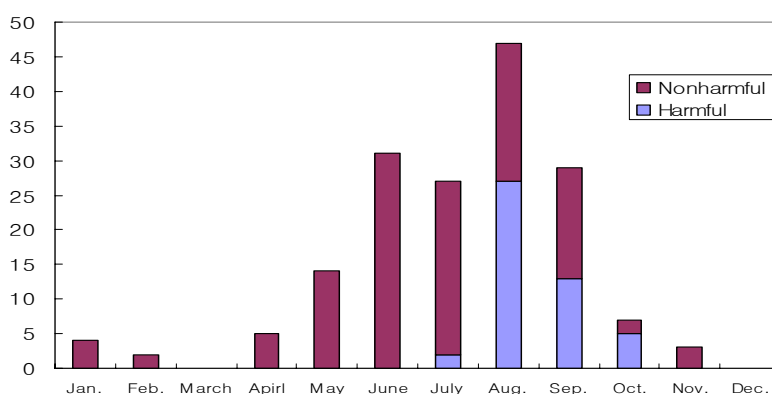
During the 13 years between 1995 and 2007, a total of 169 HAB events were recorded, in which 47 events induced fishery damage in HABs case study area(Figure 5). Since 2005, non-harmful red tide occurrences have been decreased, and the non-harmful red tide occurred only 1-2 times during 2005-2007. Total frequency of HABs has decreased in general.



**Figure 5. Number of HAB events in case study area (1995-2007)**

#### 4.3. Yearly trends of HAB season

According to the HAB data from 1995-2007, the highest peak season was high temperature season from June to September, of total red tide occurrences, 57% blooms occurred in August(Fig. 6). And fishery damage occurred most frequently during August. The Majority of the events during the high water temperature season were attributed to the *C. polykrikoides* blooms.



**Figure 6. Number of HAB events by month in the southeastern coast of Korea(1995-2007)**

#### 4.4. Yearly trends of causative species

Table 6 shows the HAB species that were recorded in the southeastern coast of Korea between 1995-2007 and their frequency of occurrences. A total of HAB species were recorded and the most frequent species were dinoflagellates such as *C. polykrikoides*, *Akashiwo sanguinea*, and *Heterosigma akashiwo* etc. The organism causes fishery damages is *C. polykrikoides*. HABs by dinoflagellates are much more frequent than by diatoms. HAB, in general, begins to occur from January to February almost every year, and shows its peak from August and September during which *C. polykrikoides* makes its blooms.

**Table 6. HAB species recorded and their frequency of occurrences in the southeastern coast of Korea(1995-2007)**

Genus and Species	1995-1997	1998-2000	2001-2003	2004-2006	2007 onwards	Total
<b>Dinophyceae</b>						
<i>Prorocentrum minimum</i>	2	3				5
<i>P. triestium</i>	1	1	2			4
<i>P. dentatum</i>	2		3	8		13
<i>P. spp.</i>		8	5	1		14
<i>Cochlodinium polykrikoides</i>	13	8	11	11	4	47
<i>Akashiwo sanguinea</i>	6	8	4	3	1	22
<i>Heterocapsa triquatra</i>	1	1				2
<i>Ceratium fusus</i>	1		1			2
<i>Ceratium furca</i>	1	6				7
<b>Bacillariophyceae</b>						
<i>Pseudo-nitzschia pungens</i>	2		3	8		13
<i>Skeletonema costatum</i>	1	1				2
Diatoms	1					1
<b>Raphidophyceae</b>						
<i>Chattonella antiqua</i>						
<i>C. marina</i>						
<i>Heterosigma akashiwo</i>	4	11	3	3	0	21
<b>Others</b>						
<i>Mesodinium rubrum</i>	1	3		5		9
<i>Noctilica scintillans</i>		3		1		4
Others	1	11	1	5		18
<b>Total</b>	<b>37</b>	<b>64</b>	<b>33</b>	<b>45</b>	<b>5</b>	<b>184</b>

Note: The underlined species caused significant fishery damage

## 5. Status of recent HAB events and results of environmental monitoring

### 5.1. Number of HAB events

Records of HAB events in 2007 are provided in Appendix. In 2007, a total of 38 HAB events were recorded, in which 21 events induced fishery damage. The most frequently observed HAB species was *C. polykrikoides* and *Chattonella* spp. In the case study area, a total of 6 HAB events were recorded, in which 5 events induced fishery damage. The organism causes fishery damages was *C. polykrikoides*.

### 5.2. Period of HAB events

A total of 39 HAB events were recorded, in which 22 events(44.7%) induced fishery damage in Korea, 2007. Especially, a total of 6 HAB events were recorded, in which 5 events(83.4%) induced fishery damage in the case study area(Fig.7)

According to the HAB data in 2007, it occurred from April to November, HAB occurred during July to October, and 60% of HABs occurred in July and August (Fig. 8). The blooms in this case study area mostly occurred in July and August and fishery damage occurred most frequently during August.

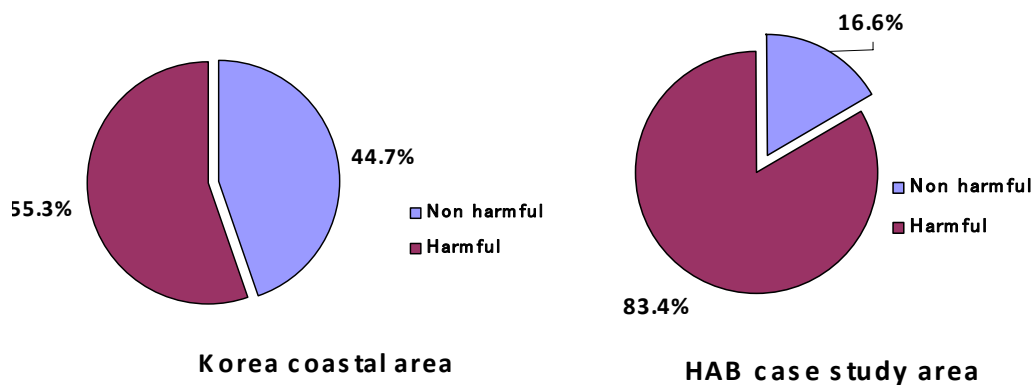


Figure 7. Percentage of harmful and non harmful red tides in Korea(2007).

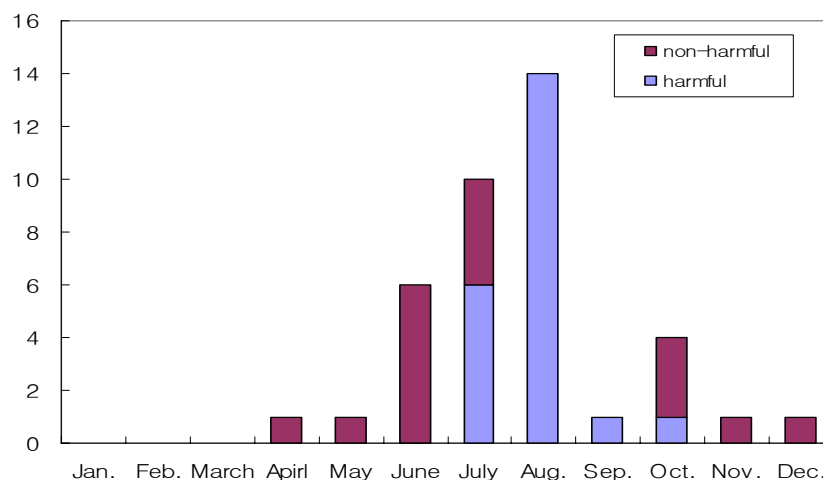


Figure 8. Number of HAB events by month in the southeastern coast of Korea (2007)

### 5.3. Duration of HAB events

The blooms in this case study area mostly occurred in July and August and fishery damage occurred most frequently during August. Duration of HAB event mainly are 29-42 days recorded in the southeastern coast of Korea (Table 7). High density blooms lasted for a long time since blooms were dispersed to other areas through wind or current.

**Table 7. Numbers of HAB events caused fishery damages by duration (no. of days)**

	Duration	Organism
Yeosu	42	<i>C. polykrikoides</i>
Namhae	42	"
Tongyeong	35	"
Geoje	35	
Goseong	29	
Sacheon	3	
Taeon(West Sea)	10	<i>Chattonella</i> spp.

Source: National Fisheries research and Development Institute (<http://portal.nfrdi.re.kr/redtide/index.jsp>)

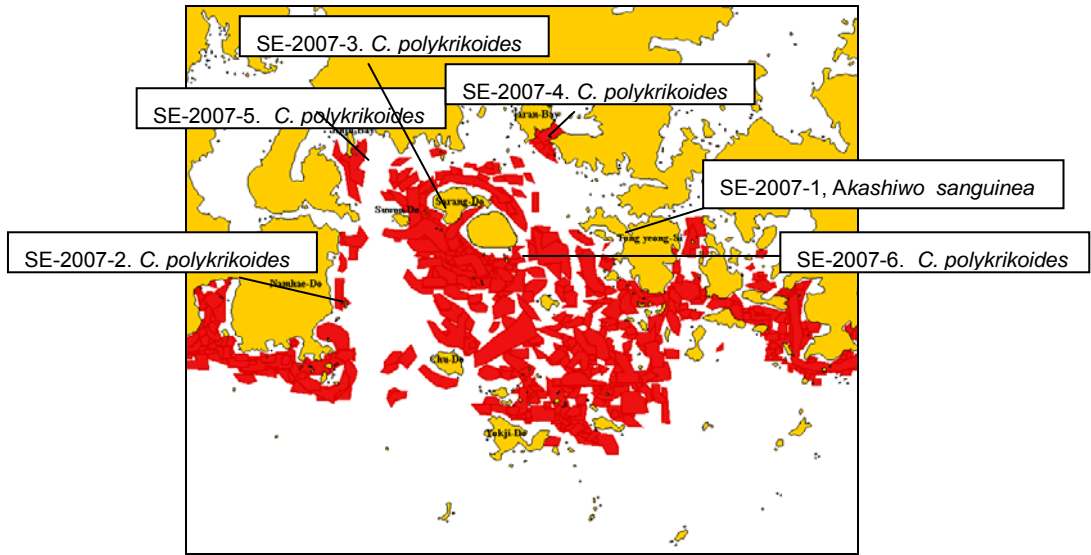
### 5.4. Location of HAB events

Table 8 shows the number of red tide occurrences in the case study area in 2007. Figures 9 and 10 show the location of the HAB events. In 2007, *C. polykrikoides* blooms were dominant except for 1 event, one bloom event occurred in Mizo, South Sea for 42 days, and HABs occurred in Tongyeong, Goseong, and Jinju Bay. In this year, the number of HAB event was low but the blooms dispersed to other areas and high density blooms resulted in numerous fishery damages.

**Table 8. Number of HAB events by area**

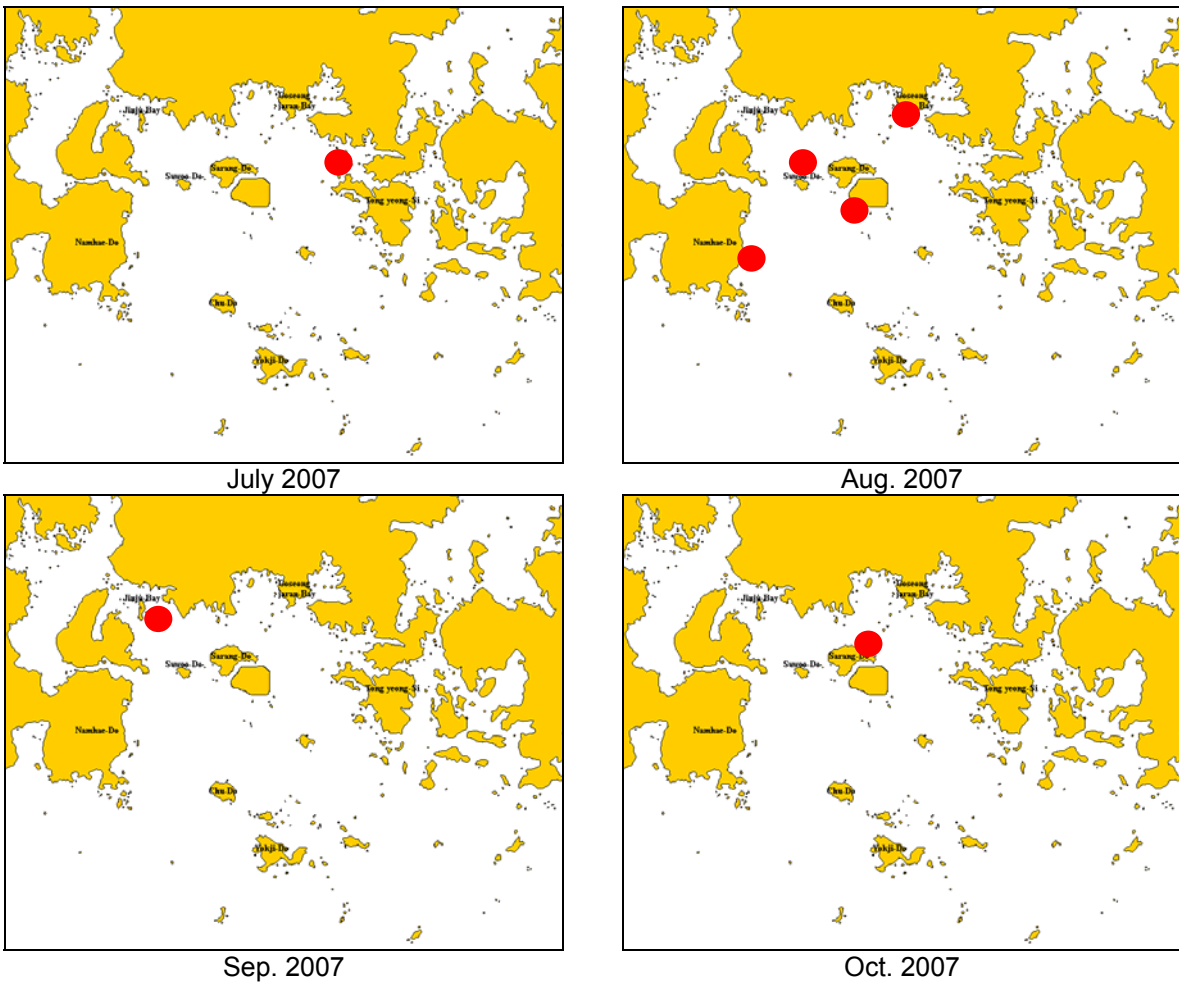
Year	Sea area		No. of events	Causative species
	Sub-area	Spot		
2007	Tongyeong	Tongyeong Dosan	1	<i>Akashiwo sanguinea</i>
	Tongyeong-Namhae	Namhae Mizo	1	<i>Cochlodinium polykrikoides</i>
		Tongyeong Sarang Suyou-do	1	
		Goseong Bay	1	
		Jinju bay	1	
		Upper Sarang-do	1	
Total		6		

Source: National Fisheries research and Development Institute (<http://portal.nfrdi.re.kr/redtide/index.jsp>)



**Figure 9. Location of HAB events (event no. and causative species)**

Note : Red one is dispersal area of HAB



**Figure 2. Location of HAB events by months (red dots show the location of HAB event)**

## 5.5. Causative species

Table 9 shows the HAB species that were recorded in the southeastern coast of Korea. A total of HAB species was recorded and the most frequent species were dinoflagellates such as *Akashiwo sanguinea* and *C. polykrikoides*. HAB occurred in Tongyeong became extinct on 17<sup>th</sup> September and then the blooms re-occurred in upper Sarang-do and became extinct.

**Table 9. HAB species recorded in the southeastern coast of Korea in 2007 and their frequency of occurrences**

Genus and Species	2006 onwards	Total
Dinophyceae		
<u><i>Cochlodinium polykrikoides</i></u>	5	5
<i>Akashiwo sanguinea</i>	1	1
Total	6	6

Note: The underlined species caused significant fishery damage

Source: National Fisheries research and Development

## 5.6. Maximum density of each HAB event

Table 10 shows the maximum density of each HAB event that occurred in the case study in year 2007. Within these HAB events, maximum densities peaked on 4<sup>th</sup> September at 32,500 cells/mL in Namhaedo and dominant species was *C. polykrikoides*. The usual number of maximum cell density in Korea remains at the level of several thousands cells/mL.

**Table 10. Maximum density of HAB events that occurred in the southeastern coast of Korea**

Year	Event No.	Causative species	Maximum density (cells/mL)	Affected Area (km <sup>2</sup> )
2007	SE-2007-1	<i>Akashiwo sanguinea</i>	500	No info.
2007	SE-2007-2	<i>C. polykrikoides</i>	32,500	50
2007	SE-2007-3	<i>C. polykrikoides</i>	23,000	70
2007	SE-2007-4	<i>C. polykrikoides</i>	4,000	3
2007	SE-2007-5	<i>C. polykrikoides</i>	2,000	2
2007	SE-2007-6	<i>C. polykrikoides</i>	2,130	2.

## 5.7. Status of HAB induced fishery damage

Table 11 shows the fishery damage caused by HAB in the southeastern coast, 2007. Large fishery damages occurred in Southern and Eastern coast due to HABs in offshore. *C. polykrikoides* blooms occurred and caused fishery damages in the mid August. Approximately 10 million U.S. dollar losses and 25 million fish kills (Rockfish, parrot fish etc.) in farms were estimated during the blooms.

**Table 11. Fishery damage caused by HAB in the southeastern coast of Korea in year 2007**

Month/ Year	Event No.	Sub-area	Spot	Causative Species	Fishery damage		
					Fish/Shellfish Species	Quantity (million ind.)	Economic loss (1,000 won)
Aug. 2007	SE-2006-3	Tongyeong	Tongyeong Sarang Do	<i>C. polykrikoides</i>	Rockfish, Parrot fish etc.	Rockfish, 2, Parrot fish 1 , etc. 1.9	7,337
Aug, 2007	SE-2006-2	Namhae- Do	Namhae- Do Mizo	<i>C. polykrikoides</i>	Red sea bream, Bass, Rockfish, parrot fish	Rockfish, 0. 688, Red sea bream 0.389, Parrot fish 0.15, Bass 0.61, Sea bastes 0.149	3,664

Source: National Fisheries research and Development Institute

### 5.8. Status of target species

In previous year, *Prorocentrum* spp., *Heterosigma akashiwo*, *Akashio sanguinea* blooms were dominant in Bay and *Noctiluca* blooms occurred in Yokjido. While *A. sanguinea* and *C. polykrikoides* blooms occurred in eastern part of South Sea. *A. sanguinea* blooms lasted for short time but *C. polykrikoides* blooms occurred over 40 days. High density blooms lasted for long time since blooms were dispersed to other areas through wind or current. Blooms in eastern part of South Sea occurred at high density and lasted for long time occurring from the end of July, which is early than last year blooms occurred in mid August.

### 5.9. Environmental monitoring results during HAB events

During the focused HABs monitoring survey, water temperature and salinity are measured. Table 12 shows the data obtained for each HAB event. During the HAB events, water temperature ranged between 22.4-26.5C°, salinity between 31.1-33.2.

**Table 12 Data of focused HABs monitoring surveys in the southeastern coast of Korea**

Year	Event No.	Duration	Spot	Water temp.(C°)	Salinity
2007	SE-2007-1	7. 24-7.30	Tongyeong	22.4-24.5	32.0-33.2
2007	SE-2007-2	8.6-9.15	Namhae	23.3-29.4	28.3-32.0
2007	SE-2007-3	8.9-9.12	Tongyeong	24.0-27.6	30.2-34.0
2007	SE-2007-4	8.11-9.1	Goseong	26.0-29.5	30.3-32.3
2007	SE-2007-5	9.3-9.9	Sacheon	22.1-25.6	30.1-32.8
2007	SE-2007-6	10.19-10.29	Tongyeong	22.5-23.8	32.8-33.2

### 5.10. Water quality parameters of regular HAB monitoring survey

Table 13 shows the results of the regular HAB monitoring survey

**Table 13. Water quality data obtained during regular HAB monitoring survey in the southeastern coast of Korea**

Survey date	Spot	survey point	Water temp.	Salinity	pH	DO (mg/L)	NH <sub>4</sub> -N (mg/L)	NO <sub>2</sub> -N (mg/L)	NO <sub>3</sub> -N (mg/L)	DIP (mg/L)	SIO <sub>2</sub> -Si (mg/L)	Chl-a (μg/L)	Transparency (m)
Jun-07	Tongyeong	3	20.5	33.4	8.06	6.69	0.059	0.006	0.021	0.053	0.182	9.3	3.0
Jun-07		4	21.6	33.5	8.08	6.72	0.019	0.001	0.018	0.082	0.150	2.3	5.0
Jun-07	Goseong-Jaran Bay	5	23.0	25.9	7.96	6.04	0.057	0.001	0.011	0.059	0.545	4.0	3.0
Jun-07		6	22.8	33.5	7.95	5.57	0.018	0.001	0.011	0.063	0.973	1.9	5.0
Jun-07	Sachun	7	21.5	33.5	8.05	7.76	0.013	0.002	0.016	0.051	0.413	5.3	4.0
Jun-07	Jinju Bay	8	21.4	33.4	7.91	6.26	0.033	0.010	0.065	0.064	0.480	2.6	3.0
Jun-07		9	23.6	33.3	7.94	7.56	0.031	0.002	0.016	0.063	0.253	7.1	3.0
Jun-07	Tongyeong off shore	10	20.7	33.5	8.12	7.65	0.022	0.003	0.015	0.049	0.208	0.5	16.0
Jun-07		11	20.7	33.7	8.08	7.73	0.016	0.015	0.016	0.058	0.403	3.4	5.0
Jun-07		12	19.0	33.7	8.12	6.66	0.034	0.005	0.026	0.089	0.298	2.2	5.0
Jul-07	Tongyeong	3	24.6	32.5	8.12	8.92	0.016	0.002	0.071	0.004	0.066	14.0	2.0
Jul-07		4	25.5	32.7	8.06	6.86	0.017	0.002	0.060	0.006	0.278	15.3	6.0
Jul-07	Goseong-Jaran Bay	5	27.4	31.4	8.29	8.32	0.020	0.002	0.035	0.013	0.814	1.3	3.0
Jul-07		6	26.3	31.8	8.10	7.73	0.018	0.002	0.036	0.038	0.052	12.8	6.0
Jul-07	Sachun	7	24.1	32.3	8.11	8.39	0.018	0.004	0.054	0.007	0.095	1.7	3.0
Jul-07	Jinju Bay	8	25.7	31.1	8.27	8.10	0.020	0.007	0.121	0.007	0.139	2.7	3.0
Jul-07		9	26.3	31.1	8.27	7.23	0.020	0.002	0.066	0.000	0.019	0.7	2.0
Jul-07	Tongyeong off shore	10	24.1	32.9	8.08	7.48	0.017	0.001	0.077	0.008	0.126	0.3	11.0
Jul-07		11	24.8	32.5	8.06	7.40	0.020	0.003	0.040	0.014	0.054	0.2	9.0
Jul-07		12	23.6	32.9	8.03	7.73	0.019	0.004	0.071	0.009	0.056	1.0	4.0
Aug-07	Tongyeong	3	22.7	32.8	8.01	7.77	0.010	0.001	0.038	0.010	0.015	12.6	3.0
Aug-07		4	25.0	32.6	7.88	7.49	0.010	0.022	0.012	0.023	0.013	4.0	4.0
Aug-07	Goseong-Jaran Bay	5	25.7	32.0	7.70	7.34	0.010	0.003	0.031	0.013	0.036	8.8	3.0
Aug-07		6	24.0	32.1	7.93	9.03	0.008	0.000	0.026	0.007	0.023	5.2	6.0
Aug-07	Sachun	7	23.5	32.2	7.96	7.41	0.009	0.002	0.038	0.025	0.083	6.0	4.0
Aug-07	Jinju Bay	8	24.5	32.3	7.80	7.10	0.007	0.002	0.033	0.033	0.032	2.4	2.5
Aug-07		9	26.1	31.3	8.00	7.52	0.012	0.011	0.040	0.062	0.047	4.3	3.0
Aug-07	Tongyeong off shore	10	23.7	32.5	8.08	6.95	0.008	0.013	0.120	0.019	0.050	2.6	4.0
Aug-07		11	24.1	32.6	7.97	8.10	0.006	0.000	0.042	0.009	0.015	2.2	5.0
Aug-07		12	23.1	33.0	8.10	8.30	0.015	0.008	0.038	0.016	0.020	5.0	4.0
Sep-07	Tongyeong	3	24.6	30.0	8.12	8.31	0.006	0.008	0.033	0.027	0.024	23.9	1.8
Sep-07		4	24.8	30.9	8.06	6.60	0.010	0.003	0.034	0.007	0.018	7.8	4.0
Sep-07	Goseong-Jaran Bay	5	24.8	30.7	8.19	7.91	0.010	0.006	0.008	0.005	0.178	4.9	1.5
Sep-07		6	24.8	30.8	8.08	7.17	0.020	0.008	0.006	0.010	0.338	2.4	5.0
Sep-07	Sachun	7	24.2	30.0	8.00	6.29	0.016	0.019	0.075	0.036	0.746	4.9	2.0
Sep-07	Jinju Bay	8	24.2	26.6	8.00	6.52	0.030	0.031	0.308	0.035	1.390	8.2	1.2
Sep-07		9	24.8	21.2	8.69	8.50	0.012	0.015	0.027	0.026	0.966	42.0	1.0
Sep-07	Tongyeong off shore	10	24.8	30.5	8.15	6.16	0.012	0.009	0.008	0.005	0.234	4.0	6.5
Sep-07		11	24.8	30.9	8.00	7.77	0.017	0.011	0.006	0.013	0.396	6.8	4.0
Sep-07		12	24.4	30.5	8.11	8.10	0.010	0.018	0.010	0.005	0.336	16.3	3.0

Source: National Fisheries research and Development Institute

### **5.11. Meteorological observation parameters**

NFRDI uses data of wind direction, wind speed, solar irradiance, amount of precipitation, typhoon etc. from KMA for predicting HABs. Wind and current affect HABs dispersal to Eastern coast of Korea. Weather forecast is important for predicting HABs occurrence and dispersal because environmental factors such as amounts of precipitation are related to diatom blooms causing changes in dominant species and harmful blooms extinction.

## 6. Eutrophication monitoring with satellite image

### 6.1. Framework of Satellite image monitoring

The following remote sensing data are available for the HABs case study:

- NFRDI has been receiving SST images derived from NOAA series, ocean color (chlorophyll-a and suspended sediment) images derived from SeaWiFS and MODIS for HABs prediction, respectively.

Observation parameters: sea surface temperature (SST), chlorophyll-a (Chl-a), suspended sediment (SS) etc.

Available data period (SST, Chl-a SS etc ) see table 14.

Observation frequency: 6-8 per a day (NOAA/AVHRR), 1-2 per a day (SeaWiFS and MODIS)

Resolution: 1 km x 1 km, 4 km x 4 km and 9 km x 9 km, respectively.

NOAA/AVHRR has been receiving since 1989 by NFRDI. The data opened to the public via the internet homepage in NFRDI. MODIS data has been receiving since May 2001 by NFRDI. NFRDI also has SeaWiFS data with LAC (local area coverage) spatial resolution supported by KEOC (Korea Earth Observation Center) from 1999. OCM (Ocean Color Monitor) of IRS-P4 Chl-a concentration data has been received from May 2001 to October 2004 in NFRDI. IRS-P4 OCM launched on 26th May 1999 from India. OCM Chl-a data are processed by NASA OC2 algorithm.

### 6.2. Parameters of satellite image monitoring

Table 14 shows available remote sensing data for the HAB case study.

**Table 14. Remote sensing data available for the HAB case study**

Organization	Name of system	Monitoring Parameters	Data Set available					
			Sensor	Period of data	Unit of data set	Resolution	Product data level	Processing algorithm
NFRDI	Satellite Ocean Information Lab.	SST (MCSST)	AVHRR (NOAA)	1989.11-continue	Pass	1 km	Level 0	McClain et al (1985) MCSST algorithm
NFRDI	Satellite Ocean Information Lab.	Chlorophyll-a, Suspended sediment (SS)	SeaWiFS (Orbview-2)	1998.9-2007.12	Pass	1 km	Level 0	OC2 algorithm
NFRDI	Satellite Ocean Information Lab.	Chlorophyll-a	OCM (IRS-P4)	2001.5-2004.10	Pass	360m	Level 0	OC2 algorithm
NFRDI	Satellite Ocean Information Lab.	SST, Chlorophyll-a, Suspended sediment (SS)	MODIS (Aqua)	2002. 5-present	Pass	1 km	Level 0	OC3 Chl-a Algorithm, MCSST
			MODIS (Terra)	2001. 7-present	Pass	1 km	Level 0	OC3 Chl-a algorithm

Organization	Name of system	Monitoring Parameters	Data Set available						
			Sensor	Period of data	Unit of data set	Resolution	Product data level	Processing algorithm	
NASA	Ocean Color Web	Chlorophyll a	CZCS (SeaStar)	1978.11-1986.6	Daily, 8-Day, Monthly, Seasonal, Annual	4 km	Level 3	OC4 Chl-a algorithm	
						9 km			
			OCTS (ADEOS)	1996.8-1997.7	Daily, 8-Day, Monthly, Seasonal, Annual	9 km	Level 3		
			SeaWiFS (Orbview-2)	1997.9-2004.12	Daily, 8-Day, Monthly, Seasonal, Annual	1 km	Level 2		
						9 km	Level 3		
						4 km	Level 13		
9 km									

### 6.3. Results of satellite image monitoring

The case study will provide the following information:

- The amounts of cells and dispersal in the South Sea are monitored with SST and Chl-a measured by satellite remote sensing.
- The following table shows satellite images during HAB events.

**Table 15. Satellite images during HAB events in the South Sea of Korea**

Year	Event No.	Duration	Spot	SST, nLw 551, Chl-a
2007	SE-2007-2	2007. 8.17	South Sea of Korea (Sea surface temperature image)	
2007	SE-2007-3	2007. 8.17	South Sea of Korea (nLw 551 image)	
2007	SE-2007-4	2007. 8.17	South Sea of Korea (chlorophyll-a image)	

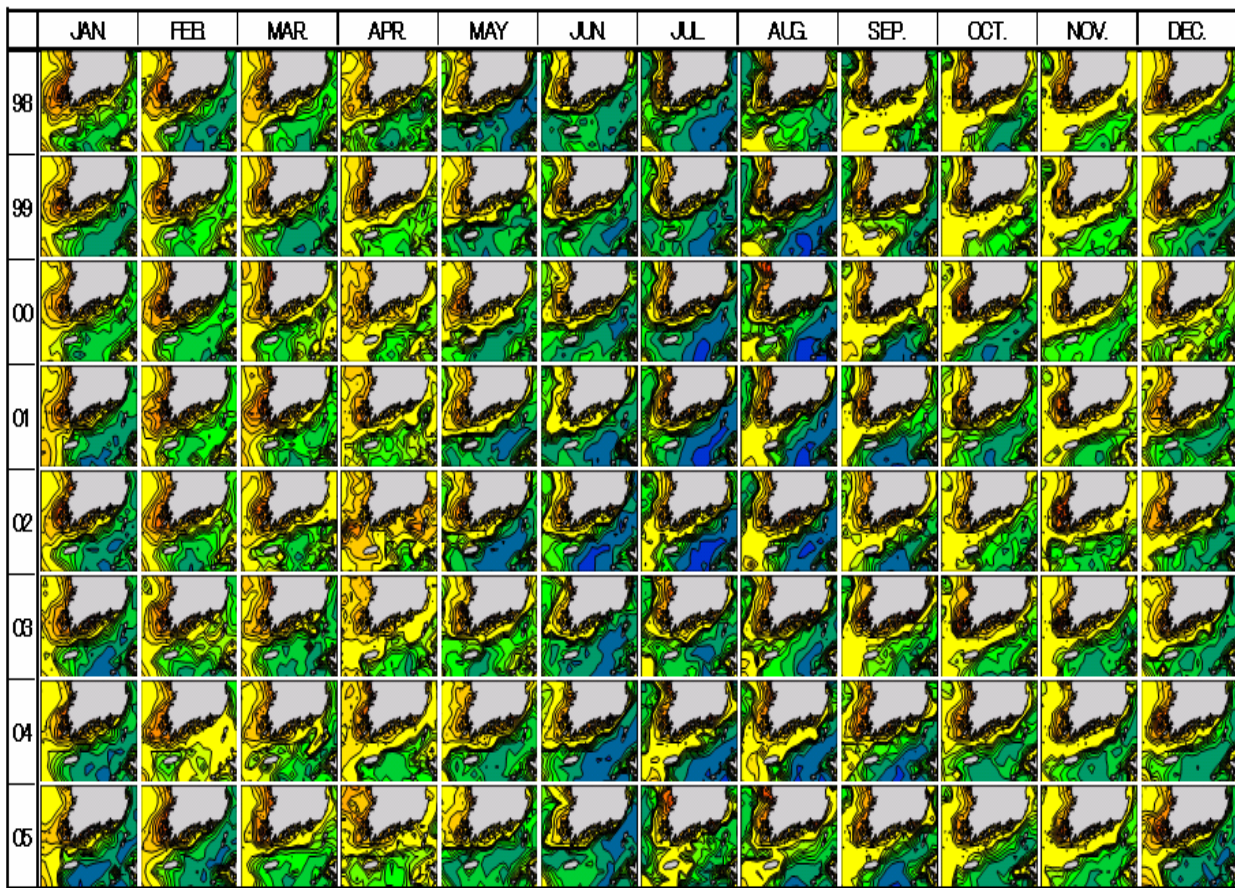


Figure 6. Monthly average SeaWiFS Chl-a imagies in the South Sea of Korea from 1998 to 2005.

## 7. Conclusion

For the last two decades, the economic impact of HABs on fisheries has increased with the increase of scale of HABs in Korea. Particularly, the blooms by fish killing *Cochlodinium polykrikoides* have been the direct and severe impacts on the coastal aquaculture industries in Korea and Japan. Therein, there is growing concerns to minimize fisheries damages by establishing early warning system from the initial stage and take emergent action against the blooms.

In 2007, *C. polykrikoides* blooms lasted for a long time in Korean waters, and high density blooms occurred in the South Sea. Approximately 10 million U.S. dollar losses and 25 million fish kills (Rockfish, parrot fish etc.) in farms were estimated during the blooms. The reason is that Tsushima warm current was weak in the end of July and early August but strong Tsushima warm current after mid August resulted in extinction of cold water column in Geoje-Do and dispersal of HABs in the southern and eastern coast of Korea. Fishery damages mainly occurred in the South and the East Seas. Phytoplankton species succession occurred due to heavy rainfall and nutrient increase, and remained HABs were extinct because of direct/indirect effects of typhoon. Therefore Tsushima warm current, thermocline, wind direction, wind intensity, and amount of precipitation need to be investigated. HABs in the South Sea were dispersed to East Sea by wind direction, wind intensity, and Tsushima warm current. These factors also influence a large scale blooms and cell density. Species succession between *C. polykrikoides* and diatoms due to nutrient supply from heavy rainfall

at the end of red tide occurrences resulted in extinction of HABs. All parameters of HAB are the same in each country.

Herein, information on the bloom for the species would be essential to countermeasure against the blooms. In addition, collaborative research program to get scientific knowledge and networking for the monitoring and prediction of HABs among NOWPAP member countries would be very beneficial in resolving the problems. The information on HABs by collaboration among NOWPAP member countries monitor and control land-based pollutants which might play a key role in accelerating blooms in coastal areas of NOWPAP member countries. Thus, it is highly encouraged to develop Korea appropriate policies and technologies to minimize the loading of land-based pollutants into the sea of NOWPAP area.

## 8. References

- Cho, C. H. 1986. An occurrence and distribution of phytoplankton in Korean coastal waters, 1930's-1980's. Korean J. phycol., 1(1), 135-143 (in Korean).
- Jung, C.S., Choi, W.J., Kim, H.G., Jung, Y.G., Kim, J.B. and Lim, W.A. 1999. Interrelation between *Cochlodinium polykrikoides* blooms and community structure of zooplankton in the coastal waters around Namhaedo in the South Sea of Korea, 1998. Bull. Nat'l Fish. Res. Dev. Inst. Korea 57: 153-161.
- Han, M. S. and K. I. Yoo. 1983. A taxonomical study on the dinoflagellates in Jinhae Bay. 1. Armored and unarmored dinoflagellates. Bulletin of KORDI, 5, 37-47 (in Korean).
- Han, M. S., J. K. Jeon and Y. O. Kim, 1992. Occurrence of dinoflagellate *Alexandrium tamarense*, a causative organism of paralytic shellfish poisoning in Chinhae Bay, Korea. J. Plankton Research, 14(11), 1581-1592.
- Kang, Y.S., Kim, H.G., Lim, W.A., Lee, C.K., Lee, S.G. and Kim, S.Y. 2002. An unusual coastal environment and *Cochlodinium polykrikoides* blooms in 1995 in the South Sea of Korea. Journal of the Korean Society of Oceanography 37(4): 212-223.
- Kim, H.C., Lee, C.K., Lee, S.G., Kim, H.G. and Park, C.K. 2001. Physico-chemical factors on the growth of *Cochlodinium polykrikoides* and nutrient utilization. J. Korean Fish. Soc. 34(5):
- Kim, H. G., J. S. Park, S. G. Lee and K.H. An. 1993a. Population cell volume and carbon content in monospecific dinoflagellate blooms. In: Toxic Phytoplankton Blooms in the Sea. T.J. Smayda and Y. Shimizu, eds. (Elsevier, Amsterdam, 1993), pp. 769 - 773.
- Kim, H. G., J. S. Park, Y. Fukuyo, H. Takayama, K. H. An, and J. M. Shim. 1993b. Noxious dinoflagellate bloom of an undescribed species of *Gyrodinium* in Chungmu coastal waters, Korea. In: Harmful Marine Algal Blooms. (eds.) P. Lassus, G. Arzul, E. Erard, P. Gentien, C. Marcaillou. Lavoisier, Intercept Limited, Paris, New York, 59-63.
- Kim, H. G. J. S. Park, S. G. Lee *et al.* 1994. Eco-toxicological studies of toxic marine phytoplankton in Korean coastal waters. Special report granted by Ministry of Science and Technology. pp. 153.
- Lee, J.B. 1996. Phytoplankton community dynamics and marine environments in the southern and western coastal waters of Korea in May, 1996. Bull. Mar. Res. Inst. Cheju Nat'l Univ. 22: 149-162.

- Lee, J. S., J. K. Jeon, M. S. Han, Y. Oshima and T. Yasumoto. 1992. Paralytic shellfish toxins in the mussel *Mytilus edulis* and dinoflagellate *Alexandrium tamarense* from Jinhae Bay, Korea. Bull. Korean Fish. Soc., 25(2), 144-150.
- Lee, K. W., K. S. Nam, H. T. Huh *et al.* 1980. A preliminary investigation on the monitoring system for the red tides in the Jinhae Bay. KORDI, BSPE: 00022-43-7, (in Korean).
- Lee, K. W., K. S. Nam, H. S. Kwak *et al.* 1981. A study on the monitoring system for the red tides in Jinhae Bay. KORDI, BSPE 00031-56-7, (in Korean).
- Lee, K. W., K. S. Nam and H. S. Kwak *et al.* 1982. Studies on the development of red tide and pollution monitoring system in Jinhae Bay. KORDI, BSPE 00041-66-7, (in Korean).
- Lee, C.K., Kim, H.C., Lee, S.G., Jung, C.S., Kim, H.G. and Lim, W.A. 2002. Abundance of harmful algae, *Cochlodinium polykrikoides*, *Gyrodinium impudicum* and *Gymnodinium catenatum* in the coastal area of South Sea of Korea and their effects of temperature, Korea-20 salinity, irradiance and nutrient on the growth in culture. J. Korean Fish. Soc. 34(5), 536-544.
- Lee, K. W., K. S. Nam, H. S. Kwak *et al.* 1983. A study on the monitoring system for red tides. -Jinhae Bay-KORDI, BSPE 00048-80-7, (in Korean).
- Park, J. S. 1980. Studies on seasonal changes in population and species composition of phytoplankton and their effects on oysters and local fisheries resources as food organisms and as a cause of red tide in the south coast of Korea. Bull. Fish. Res. Dev. Agency, 23, 7-157 (in Korean).
- Park, J. S. 1982. Studies on the characteristics of red tide and environmental conditions in Jinhae Bay. Bull. Fish. Res. Dev. Agency, 28, 55-88 (in Korean).
- Park, J. S., H. G. Kim and S. G. Lee. 1988. Red tide occurrence and succession of its causative organisms in Jinhae Bay. Bull. Nat. Fish. Res. Dev. Agency, 41, 1-26 (in Korean).
- Suh, Y.S. Lee, H.J. Lee, N.K. Ishizaka, J. 2004. Feasibility of red tide detection around Korean waters using satellite remote sensing. J. Fish. Sci. Tech. 7(3): 148-162.
- Yoo, K. I. 1982. Taxonomic study on the causative organisms of red tide. Bull. Environmental sciences. Han Yang Univ., 3, 25-31 (in Korean).

## Appendix

### Records of HAB events in the southeastern coast of Korea

Event No.			Duration (Start)			Duration(End)			Continuous days	Location of occurrence		Causative species	Maximum density (cells,inds/ mL)	Fishery damage			Environmental parameters		Affected Area
Pref. cod	Year	No.	Year	Month	Day	Year	Month	Day		Sub-area	Spot			Fish/Shellfish Species	Quantity (million ind.)	Economic loss (1,000 won)	Water temp.(C°)	Salinity	Size of bloom(km2 )
SE	2007	1	2007	7	24	2007	7	30	7	Tongyeong	Tongyeong Dosan	<i>Akashiwo sanguinea</i>	500			22.4-24.5	32.0-33.2	No info.	
SE	2007	2	2007	8	6	2007	9	15	42	Namhae	Namhae Mizo	<i>C. polykrikoides</i>	32,500	Red sea bream, Bass, Rockfish, parrot fish	Rockfish, 0.688, Red sea bream 0.389, Parrot fish 0.15, Bass 0.61, Sea bastes 0.149	3,664	23.3-29.4	28.3-32.0	50
SE	2007	3	2007	8	9	2007	9	12	35	Tongyeong	Tongyeong Sarang Suyou-do	<i>C. polykrikoides</i>	23,000	Rockfish, Parrot fish etc.	Rockfish, 2, Parrot fish 1, etc. 1.9	7,337	24.0-27.6	30.2-34.0	70
SE	2007	4	2007	8	11	2007	9	1	29	Tongyeong	Goseong Bay	<i>C. polykrikoides</i>	4,000			26.0-29.5	30.3-32.3	3	
SE	2007	5	2007	9	3	2007	9	9	6	Tongyeong	Jinju bay	<i>C. polykrikoides</i>	2,000			22.1-25.6	30.1-32.8	2	
SE	2007	6	2007	10	19	2007	10	29	10	Tongyeong	Upper Sarang-do	<i>C. polykrikoides</i>	2,130			22.5-23.8	32.8-33.2	2	