Report of HABs case study in the southeastern coast of Korea

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Contents (Draft)

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°35′ 43″ -34°57′ 54″ , latitude: 127°30′ 11″ -128°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..

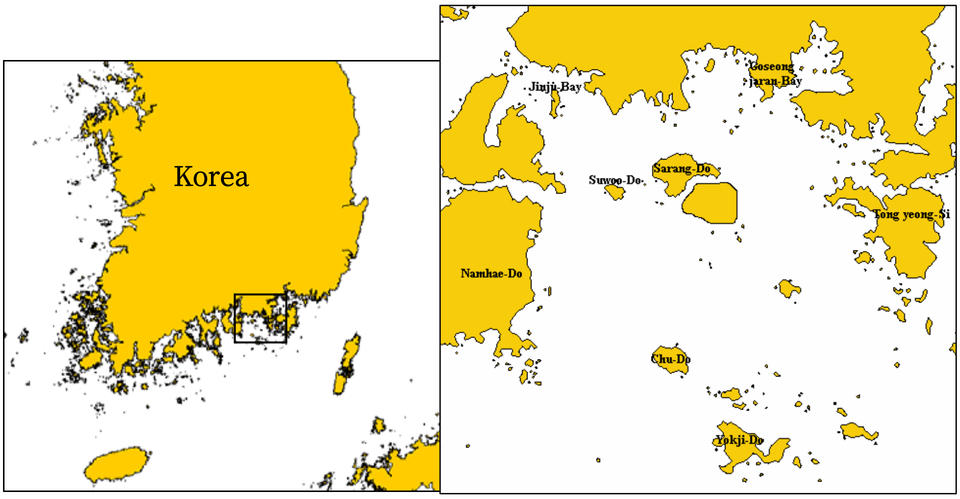


Figure 1. Target sea area for the case study of Korea

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

Waring Class	Scale	Cell density(cells/mL)
Red Tide Attention	HAB blooms and over radius 2-5km (12-79㎢) and potential fishery damages	○Dinoflagellates: depends on cell size and toxicity - *Chattonella* spp. : over 2,500 - *Cochlodinium polykrikoides* : over 300 - *Gyrodinium* sp. : over 500 - *Karenia mikimotoi*: over 1,000 - Etc. : over 30,000 ○Diatom: over 50,000 ○Mixed blooms: over 40,000 cells (over 50%) of dinoflagellate
Red Tde Alert	HAB blooms and over radius 5km (79㎢) and fishery damages	○ Dinoflagellates: depends on cell size and toxicity - *Chattonella* spp : over 5,000 - *Cochlodinium polykrikoides* : over 1,000 - *Gyrodinium* sp. : over 2,000 - *Karenia mikimotoi*: over 3,000 - Etc. : over 50,000 ○Diatom : over 100,000 ○Mixed blooms : over 80,000 cells (over 50%) of dinoflagellate
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㎍/100g for PSP. So, NFRDI notifies fisherman not to harvest the shellfish when the toxin level exceeds over 80㎍/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 saguineum, Cochlodinium polykrikoides, Prorocentrum minimum, P. dentatum, Ceratium furca, Heterosigma akashiwo* and *Noctiluca scintillans* 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		
Akashiwo sanguinea	○	-
Cochlodinium polykrikoides	○	-
Prorocentrum dentatum	○	-
Prorocentrum minimum	○	-
Ceratium furca	○	-
Raphidophyceae		
Heterosigma akashiwo	○	-
Noctilucaceae		-
Noctiluca scintillans	○	-

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)

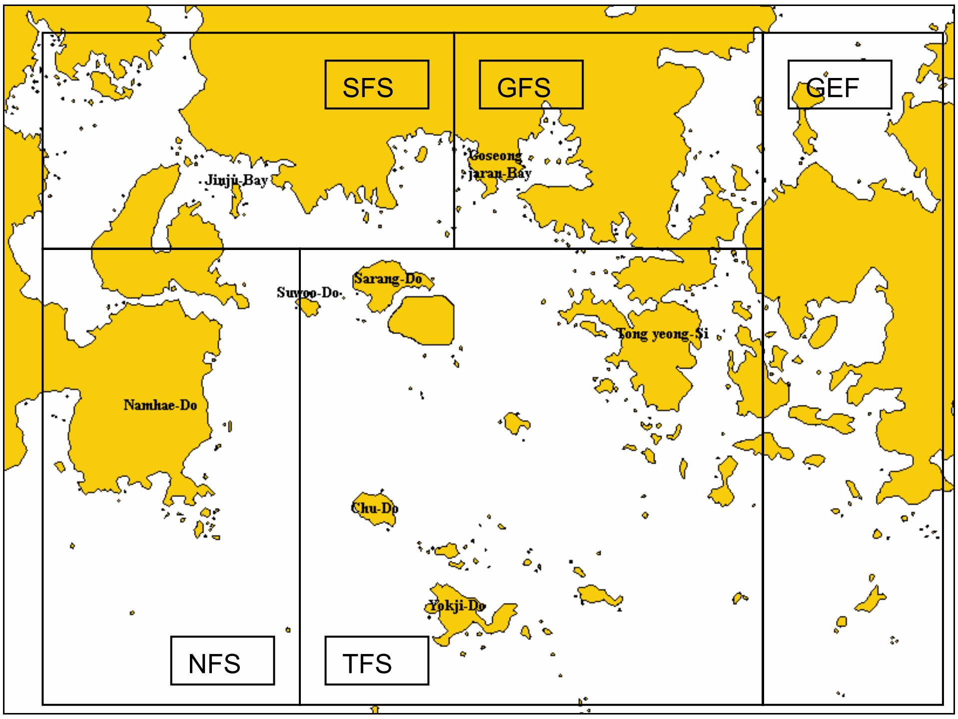


Figure 2. Monitor sea area in the case study of southeastern coast of Korea

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 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		7-8/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 1995-2008

From year 1995-2008, a total of 838 HAB events were recorded, in which 209 events(24.9%) induced fishery damage in Korea. Especially, a total of 174 HAB events were recorded, in which 52 events(29.9%) 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*. 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.

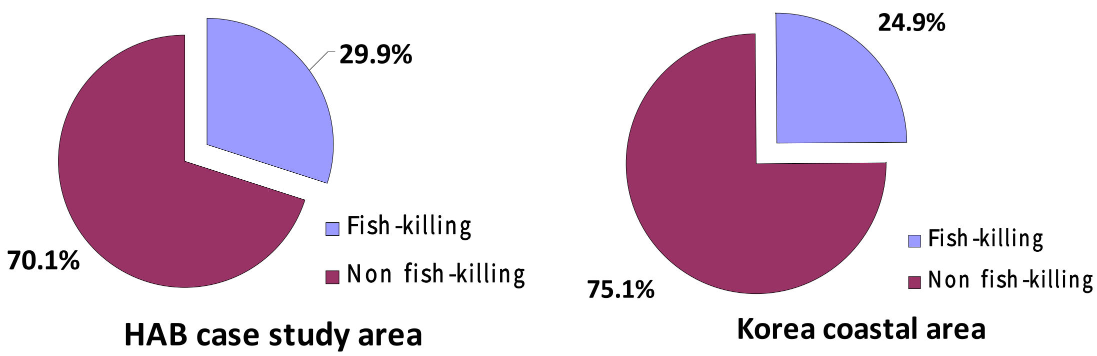


Figure 3. Percentage of fish-killing and non fish-killing red tides in Korea(1995-2008).

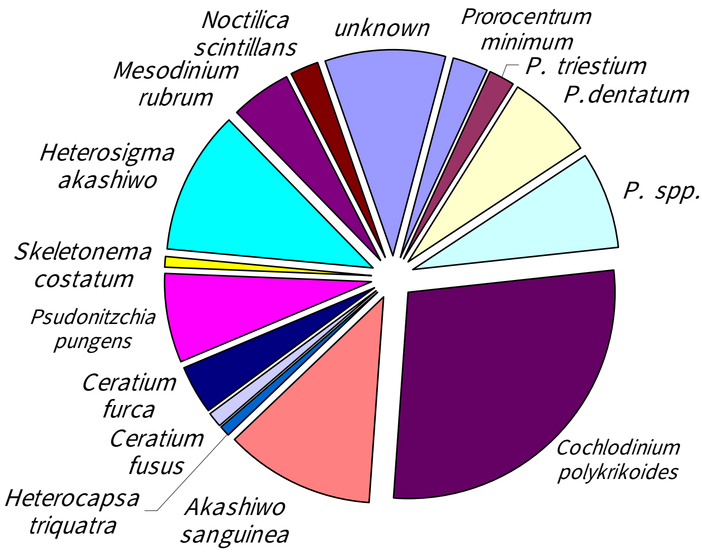


Figure 4. Percentage of HAB species in the southeastern coast of Korea(1995-2008).

4.2. Yearly trends of HAB events

During the 13 years between 1995 and 2008, a total of 174 HAB events were recorded, in which 52 events induced fishery damage in HABs case study area(Figure 5). Since 2005, non fish-killing red tide occurrences have been decreased, and it occurred only 0-2 times during 2005-2008. Total frequency of HABs has decreased in general. Particularly, only the non fish-killing algal blooms occurred in 2008 in the study areas and no fish mortality/economic losses were reported.

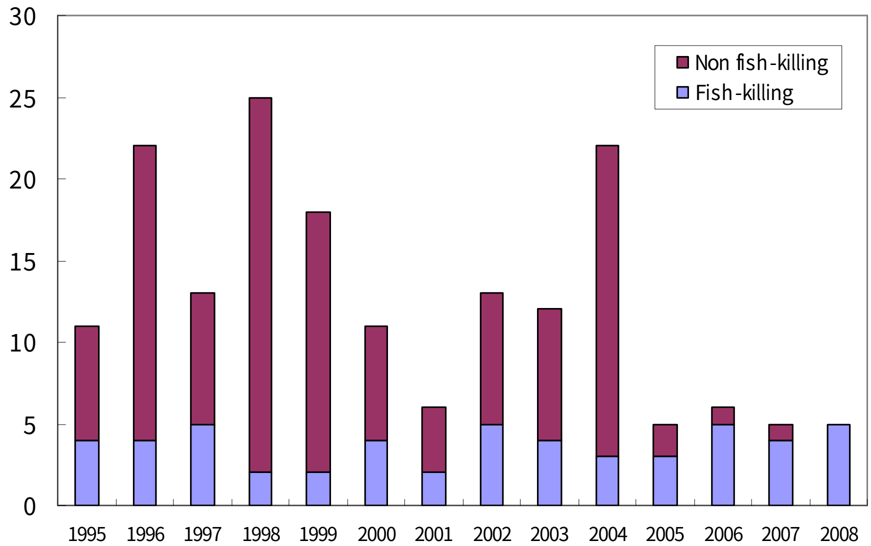


Figure 5. Number of HAB events in case study area (1995-2008)

4.3. Yearly trends of HAB season

According to the HAB data from 1995-2008, the highest peak season was high temperature season from June to September, of total fish-killing red tide occurrences, 59.6% 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.

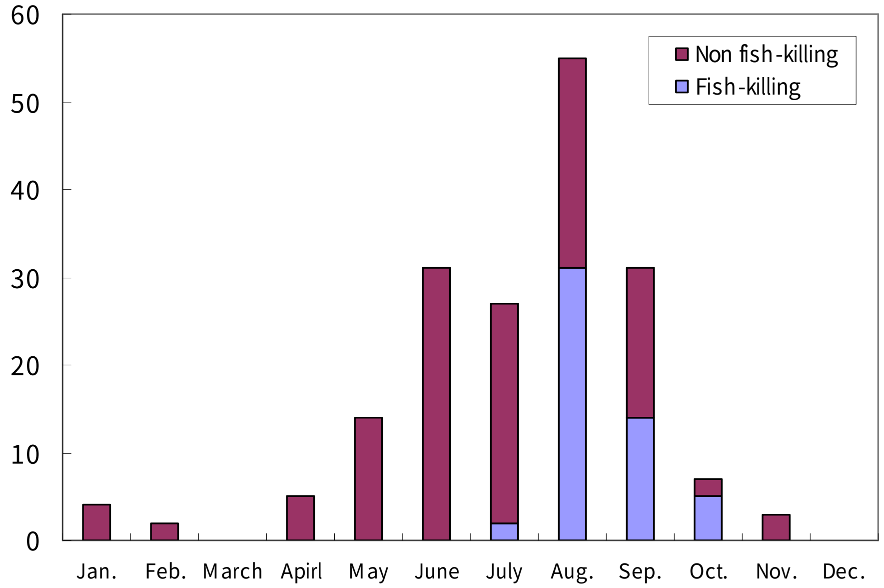


Figure 6. Number of HAB events by month in the southeastern coast of Korea(1995-2008)

4.4. **Yearly trends of causative species**

Table 6 shows the HAB species that were recorded in the southeastern coast of Korea between 1995-2008 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* ma blooms.

Table 6. HAB species recorded and their frequency of occurrences in the case study area of Korea(1995-2008)

Genus and Species	1995-1997	1998-2000	2001-2003	2004-2006	2007-2008	Total
Dinophyceae						
Prorocentrum minimum	2	3				5
P. triestium	1	1	2			4
P. dentatum	2		3	8		13
P. spp.		8	5	1		14
Cochlodinium polykrikoides	13	8	11	11	9	52
Akashiwo sanguinea	6	8	4	3	1	22
Heterocapsa triquatra	1	1				2

Ceratium fusus	1		1			2
Ceratium furca	1	6				7
Bacillariophyceae						
Pseudo-nitzchia pungens	2		3	8		13
Skeletonema costatum	1	1				2
Diatoms	1					1
Raphidophyceae						
Chattonella antiqua						
C. marina						
Heterosigma akashiwo	4	11	3	3	0	21
Others						
Mesodinium rubrum	1	3		5		9
Noctilica scintillans		3		1		4
Others	1	11	1	5		18
Total	37	64	33	45	10	189

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 2008 are shown in Appendix. Of a total of 43 HAB events in 2008, 28 events were *C. polykrikoides* blooms. For the case study area, 5 HAB events were recorded as *C. polykrikoides* blooms. However, there was no economic loss in 2008 and it was the first year of non-fish kills since 1995.

5.2. Period of HAB events

A total of 43 HAB events were recorded, in which 28 events(65.1%) induced fishery damage in Korea, 2008. Especially, all HAB events (5 events) were induced by *C. polykrikoides* in the case study area(Fig.7).

According to the HAB data in 2008, it occurred from April to September, HAB occurred during July to October, and 96% of HABs occurred in August and September (Fig. 8). The blooms in this case study area mostly occurred in August and September but it is the first year no fishery damage from 2005.

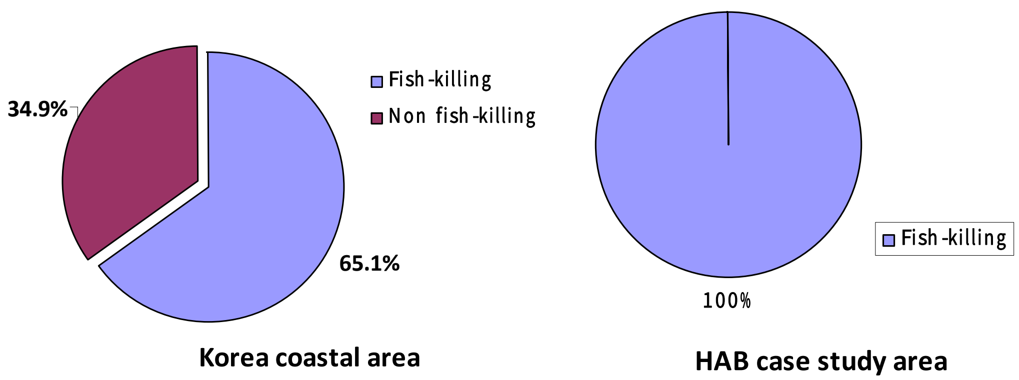


Figure 7. Percentage of fish-killing and non fish-killing red tides in Korea(2008).

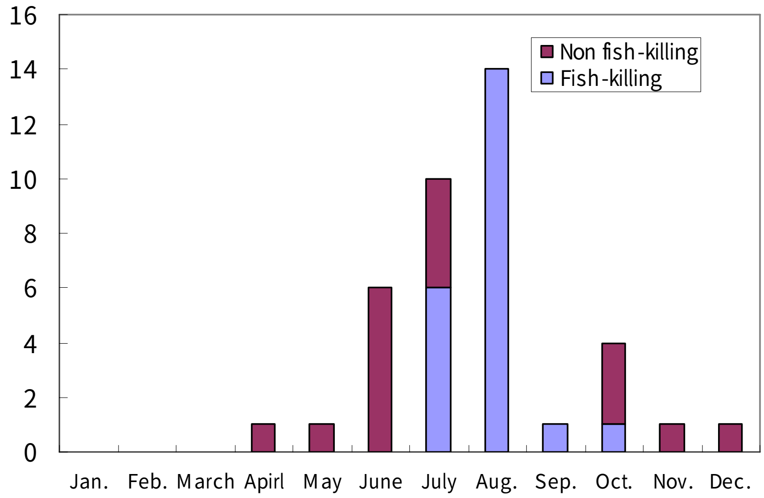


Figure 8. Number of HAB events by month in the southeastern coast of Korea (2008)

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 24-50 days recorded in the southeastern coast of Korea in 2008(Table 7). High density blooms lasted for a long time since blooms were dispersed to other areas through wind or current. While the bloom lasted till its extinction in Namhae since the first occurrence on 4th August, blooms reoccurred in Tongyeong, Goeje, and Goseong in the mid-September after the end of August. And, there was a low density of *C. polykrikoides* blooms lasted for a long period in 2008.

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

	Duration	Organism
Yeosu	43	*C. polykrikoides*
Namhae	50	"
Tongyeong	45	"
Geoje	40	
Goseong	24	
Taean(West Sea)	7	*Chattonella* 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 2008. 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 2008, *C. polykrikoides* blooms were only recorded in Namhae, Tongyeong, Goseong, Geoje, and Jinju Bay. In 2007, the number of HAB event was low but the blooms dispersed to other areas and high density blooms resulted in numerous fishery damages. On the other hand, there was no fishery damage in 2008 although a low density of *C. polykrikoides* blooms lasted for a long period.

Table 8. Number of HAB events by area

Year	Sea area		No. of events	Causative species
	Sub-area	Spot		
2007	Tongyeong	Tongyeong Dosan	1	*Akashiwo sangunea*
	Tongyeong-Namhae	Namhae Mizo	1	*Cochlodinium polykrikoides*
		Tongyeong Sarang Suyou-do	1	
		Goseong Bay	1	
		Jinju bay	1	
		Upper Sarang-do	1	
	Total		6	
2008	Namhae	Namhae Mizo	1	*Cochlodinium polykrikoides*
	Tongyeong - Goseong	Tongyeong Sanyang Ogok-do	1	
		Tongyeong Sarang chu-do	1	
		Goseong Bay	1	
		Jinju bay	1	
	total		5	

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

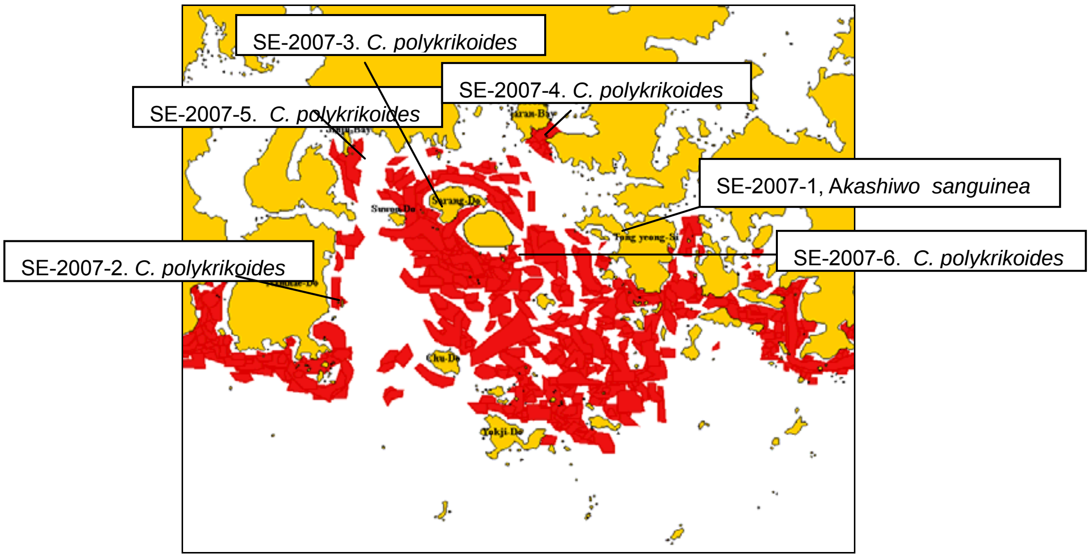


Figure 9-1. Location of HAB events in 2007(event no. and causative species)

Note : Red one is dispersal area of HAB

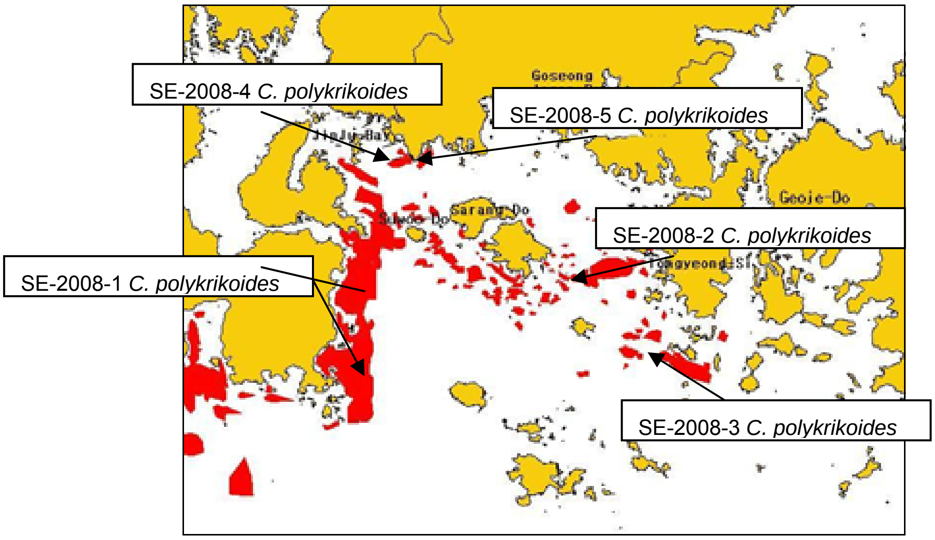


Figure 9-2. Location of HAB events in 2008(event no. and causative species)

Note : Red one is dispersal area of HAB

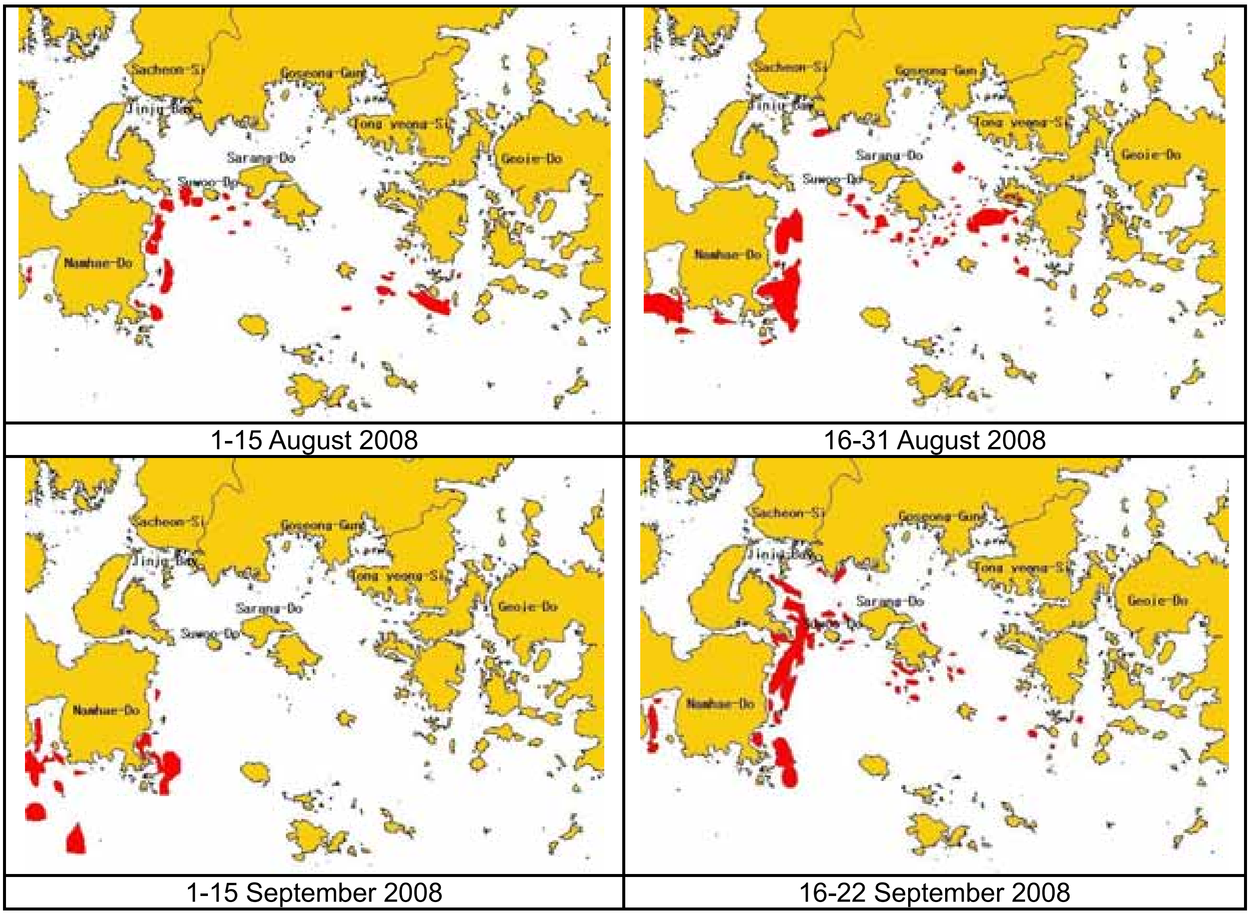


Figure 2. Cumulative location of HAB events for half a month (red ones show the location of HAB event)

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 *C. polykrikoides*. After HAB occurrence in Namhae, it expended to Tongyeong, Geoje, and Goseong, and then became extinct on 22th September.

Table 9. HAB species recorded in the southeastern coast of Korea in 2008

Genus and Species	2006 onwards	Total
Dinophyceae		
<u>*Cochlodinium polykrikoides*</u>	5	5
Total	5	5

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, 2008. Within these HAB events, maximum densities peaked on 4th September at 32,500 cells/mL in Namhaedo and dominant species was *C. polykrikoides* in 2007. Maximum density was 7,300 cells/mL in Geoje on 2th September 2008. Particularly, in 2008, a low density bloom lasted longer than the other years.

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^2)
2008	SE-2008-1	*C. polykrikoides*	5,600	40.
2008	SE-2008-2	*C. polykrikoides*	2,650	60
2008	SE-2008-3	*C. polykrikoides*	2,500	60
2008	SE-2008-4	*C. polykrikoides*	4,000	3
2008	SE-2008-5	*C. polykrikoides*	5,000	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. However, no fisheries damage occurred in 2008 because a low density bloom of *C. polykrikoides* occurred in fish farm areas in 2008 and the blooms did not last long.

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	*C. polykrikoides*	Rockfish, Parrot fish etc.	Rockfish, 2, Parrot fish 1 , etc. 1.9	7,337
Aug, 2007	SE-2006-2	Namhae-Do	Namhae-Do Mizo	*C. polykrikoides*	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*, *Akashiwo sanguinea, Noctiluca scintillans* blooms were dominant in Bay While *A. sanguinea* and *C. polykrikoides* blooms occurred in eastern part of South Sea. *C. polykrikoides* blooms occurred over 50 days. High density blooms lasted for long time since blooms were dispersed to other areas through wind or current. The bloom started in the end of July and became extinct on 26th September. The bloom period was the third longest since 1995 but the cell density was the second lowest. Additionally, the bloom area was limited in one region. Therefore no fisheries damage occurred.

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
2008	SE-2008-1	8.4-9.23	Namhae	21.0-26.9	30.5-32.9
2008	SE-2008-2	8.8-9.22	Tongyeong Sanyang	22.2-27.0	29.0-32.3
2008	SE-2008-3	8.16-9.25	Tongyeong Sarang	24.0-27.0	30.1-33.2
2008	SE-2008-4	8.29-9.5	Sacheon	24.9-27.0	30.0-32.8
2008	SE-2008-5	9.11-9.20	Goseong	26.5-27.0	30.9-33.2

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 (㎎/L)	NH_4-N (mg/L)	NO_2-N (mg/L)	NO_3-N (mg /L)	DIP (mg/L)	SIO2-SI (mg/L)	Chl-a (μg/L)	Trans-parency (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
Jul-08	Tongyeong	3	24.4	32.9	8.16	-	0.049	0.005	0.015	0.018	0.163	8.99	2.0
Jul-08		4	30.1	33.7	8.03	-	0.048	0.004	0.041	0.011	0.320	1.31	3.5
Jul-08	Goseong-Jaran Bay	5	28.7	32.6	7.94	-	0.044	0.005	0.037	0.035	0.790	1.73	3.5
Jul-08		6	28.2	32.6	8.07	-	0.041	0.006	0.052	0.005	0.290	0.32	7.0
Jul-08	Sachun	7	25.5	32.8	8.15	-	0.008	0.007	0.022	0.012	0.276	1.23	5.0
Jul-08	Jinju Bay	8	25.5	32.8	8.15	-	0.059	0.007	0.043	0.005	0.114	2.05	3.5
Jul-08		9	29.3	31.8	8.12	-	0.059	0.007	0.040	0.022	0.109	0.77	4.0
Jul-08	Tongyeong off shore	10	24.7	33.0	8.20	-	0.021	0.006	0.042	0.012	0.221	0.01	10.0
Jul-08		11	25.6	32.8	8.13	-	0.014	0.008	0.009	0.018	0.294	0.34	9.0
Jul-08		12	22.3	33.4	8.02	-	0.047	0.007	0.013	0.010	0.100	2.52	3.5
Aug-08	Tongyeong	3	23.7	35.4	7.99	7.97	0.006	0.002	0.008	0.011	0.269	4.59	2.0
Aug-08		4	29.3	33.1	8.09	8.97	0.020	0.005	0.013	0.033	0.086	1.58	5.5
Aug-08	Goseong-Jaran Bay	5	27.8	33.4	7.92	7.98	0.021	0.008	0.012	0.040	0.996	2.79	3.0
Aug-08		6	28.0	33.0	8.02	7.34	0.027	0.008	0.011	0.023	0.432	1.13	5.0
Aug-08	Sachun	7	22.3	33.3	8.16	8.20	0.030	0.005	0.020	0.012	0.202	2.54	5.0
Aug-08	Jinju Bay	8	25.1	32.8	7.95	8.81	0.015	0.010	0.016	0.022	0.337	4.96	2.0
Aug-08		9	26.3	32.8	8.04	9.21	0.011	0.008	0.012	0.005	0.100	3.81	2.0
Aug-08	Tongyeong off shore	10	23.6	33.2	8.21	8.65	0.017	0.005	0.005	0.009	0.174	1.02	5.0
Aug-08		11	23.5	33.3	7.66	8.05	0.027	0.004	0.002	0.023	0.328	2.02	4.0
Aug-08		12	21.6	33.8	8.03	7.71	0.019	0.008	0.023	0.022	0.125	3.75	3.0
Sep-08	Tongyeong	3	25.5	32.1	8.13	-	0.011	0.003	0.024	0.007	0.109	4.65	2.5
Sep-08		4	26.7	32.8	7.99	-	0.010	0.002	0.029	0.005	0.291	5.32	2.0
Sep-08	Goseong-Jaran Bay	5	27.2	33.0	7.97	-	0.006	0.001	0.052	0.010	0.109	2.40	1.5
Sep-08		6	26.4	32.2	8.07	-	0.008	0.002	0.034	0.000	0.080	1.12	5.0
Sep-08	Sachun	7	25.8	32.2	8.13	-	0.007	0.004	0.037	0.005	0.064	1.22	6.0
Sep-08	Jinju Bay	8	27.0	32.5	8.11	-	0.010	0.002	0.043	0.003	0.048	4.45	2.0
Sep-08		9	26.5	32.4	8.08	-	0.008	0.002	0.045	0.007	0.035	2.30	2.0
Sep-08	Tongyeong off shore	10	25.0	31.9	8.16	-	0.012	0.001	0.035	0.000	0.172	0.21	11.0
Sep-08		11	25.6	32.2	8.10	-	0.008	0.002	0.033	0.003	0.060	2.93	4.5
Sep-08		12	24.9	32.3	8.14	-	0.007	0.004	0.038	0.019	0.096	2.58	5.0

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

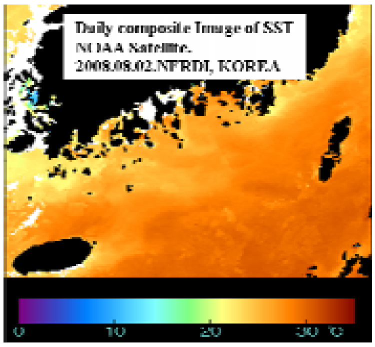
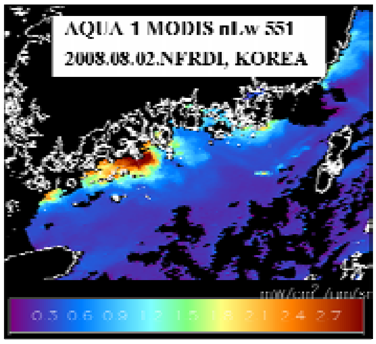
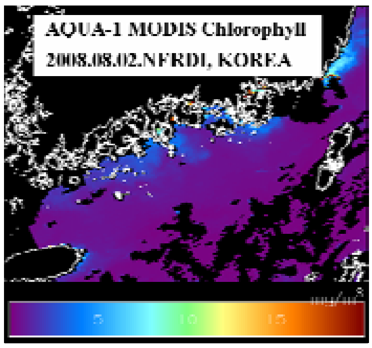
Organization	Name of system	Monitoring Parameters	Data Set available					
			Sensor	Period of data	Unit of data set	Resolution	Product data level	Processing algorithm
NASA	Ocean Color Web	Chlorophyll a	CZCS (SeaStar)	1978.11-1986.6	Daily, 8-Day, Monthly, Seasonal, Annual	4 km	Level 3	OC4 Chl-a algorithm
						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	1 km	Level 2	
					Daily, 8 Day, Monthly, Seasonal, Annual	9 km	Level 3	
					Daily, 8 Day, Monthly, Seasonal, Annual	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
2008	SE-2008-1	2008. 8. 2	South Sea of Korea (Sea surface temperature image)	
2008	SE-2008-1	2008. 8. 2	South Sea of Korea (nLw 551 image)	
2008	SE-2008-1	2008. 8. 2	South Sea of Korea (chlorophyll-a image)	

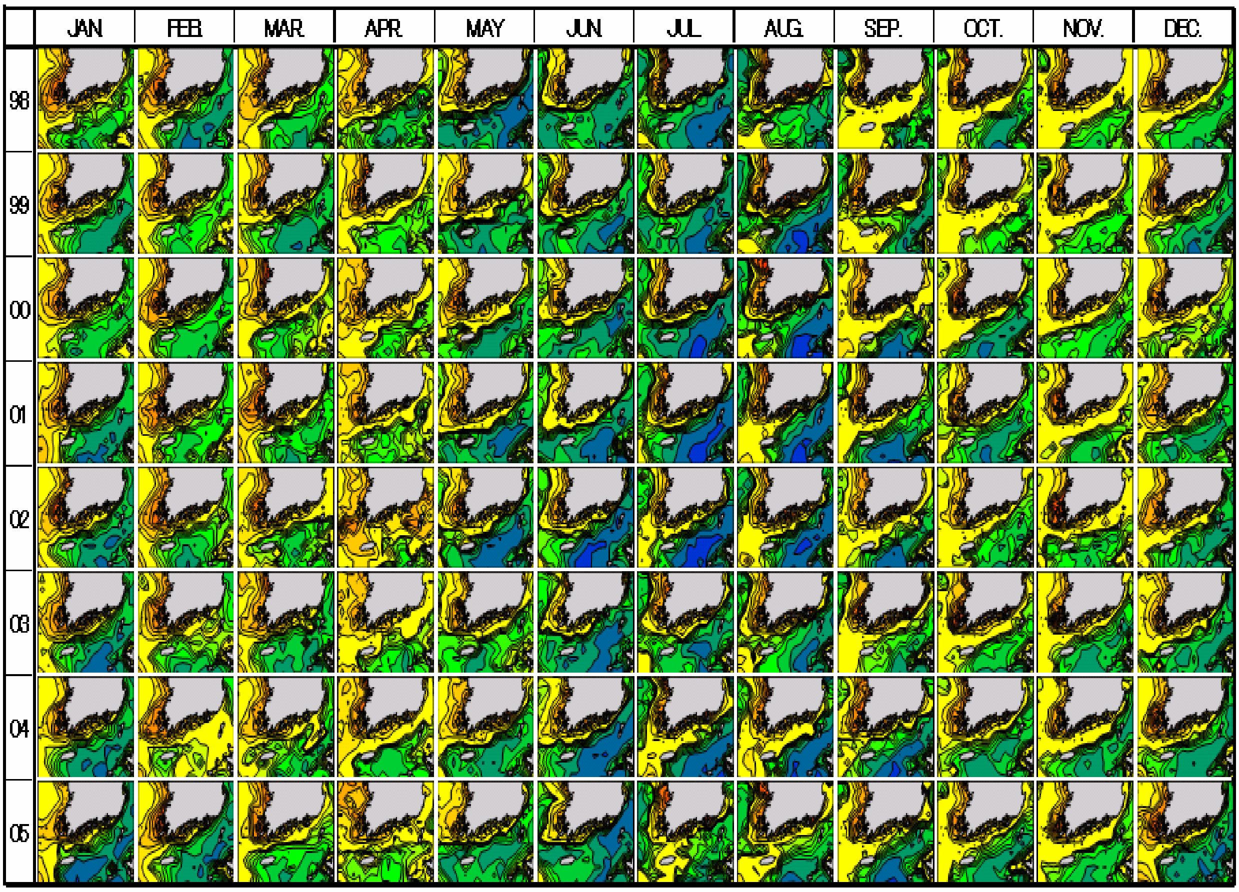


Figure 6. Monthly average SeaWiFS Chl-a imagies in the South Sea of Korea from 1998 to 2005.

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 2008, *C. polykrikoides* blooms lasted for a long time in Korean waters, and the cell densities of harmful algae were mostly below 3,000cells/mL. The maximum cell density was 7,300cell/mL in Geoje and there was no fisheries damage since 1995. It may be due to development of cold water mass in the early stage of bloom, increase in solar radiation intensity, no physical disturbance (Typhoon, strong wind etc.), lack of nutrients due to strong thermal stratification. Additionally, lack of nutrients due to low rainfall delayed the expansion and growth of the blooms The increase in solar radiation intensity due to the late hot weather resulted in reoccurrences of harmful algal blooms and the bloom became extinct by temperature decrease.

Herein, information on the causative agent and environmental parameters 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.

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Appendix

Records of HAB events in the southeastern coast of Korea in 2007, 2008.

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	*Akashiwo sanguinea*	500				22.4-24.5	32.0-33.2	No info.
SE	2007	2	2007	8	6	2007	9	15	42	Namhae	Namhae Mizo	*C. polykrikoides*	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	*C. polykrikoides*	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	*C. polykrikoides*	4,000	-	-	-	26.0-29.5	30.3-32.3	3
SE	2007	5	2007	9	3	2007	9	9	6	Tongyeong	Jinju bay	*C. polykrikoides*	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	*C. polykrikoides*	2,130	-	-	-	22.5-23.8	32.8-33.2	2
SE	2008	1	2008	8	4	2008	9	23	50	Namhae	Tongyeong Dosan	*C.polykrikoides*	5,600	-	-	-	21.0-26.9	30.5-32.9	40.
SE	2008	2	2008	8	8	2008	9	22	45	Tongyeong	Namhae Mizo	*C.polykrikoides*	2,650	-	-	-	22.2-27.0	29.0-32.3	60
SE	2008	3	2008	9	16	2008	9	25	40	Tongyeong	Tongyeong Sarang Suyou-do	*C. polykrikoides*	2,500	-	-	-	24.0-27.0	30.1-33.2	60
SE	2008	4	2008	8	29	2008	9	5	7	Tongyeong	Goseong Bay	*C. polykrikoides*	4,000	-	-	-	24.9-27.0	30.0-32.8	3
SE	2008	5	2008	9	11	2008	9	20	9	Tongyeong	Jinju bay	*C. polykrikoides*	5,000	-	-	-	26.5-27.0	30.9-33.2	2