Report of updated HAB case study in the south coast of Korea

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Contents

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: 127°30′ 11″ - 128°56′ 60″ , latitude: 34°35′ 43″ - 34°57′ 54″) is located in the eastern part of South Sea, Korea, which faces the East China Sea. The target area neighboring Goseong-jaran Bay and Jinju Bay is an important culture ground for finfish cage culture and shellfish bottom culture (Fig. 1). In addition to this existing target sea area, whole South coast (longitude: 126° 41′ 14″ - 128° 59′ 14″ , latitude: 33° 55′ 85″ - 35° 22′ 25″) was included as newly added sea area for which trend of HAB events, HAB season and causative species were analyzed.

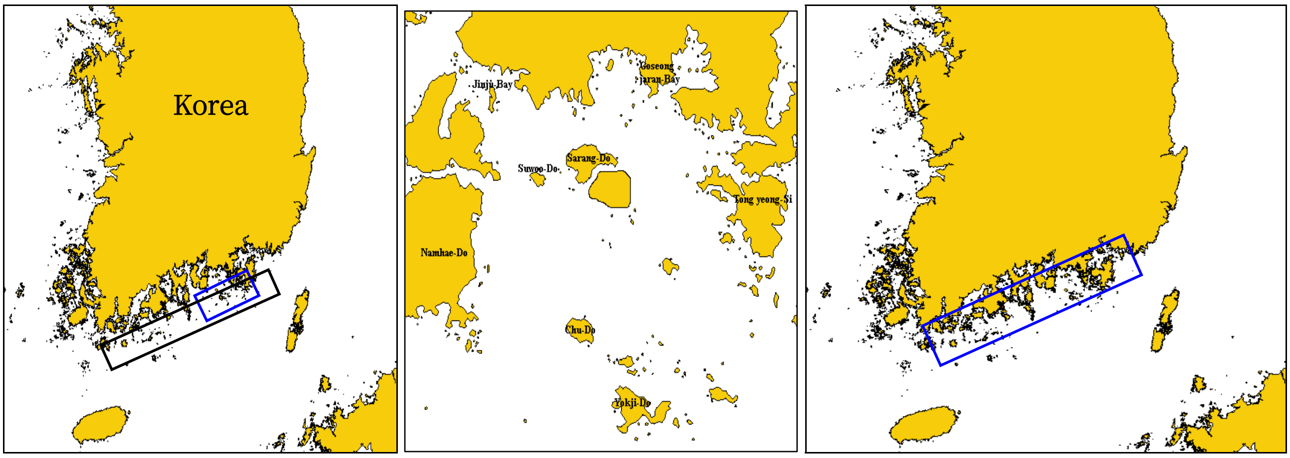


Figure 1. Target areas for the case study of Korea (middle, existing area; right, newly added area)

1.3.2. Environmental/geographical characteristics

The existing target sea area neighbors Tongyeong-Si, Namhae-Si and Goseong-Si. Its southern part facing offshore is directly affected by Tsushima warm current and has a long irregular coast line allowing relatively low wave against typhoon. Therefore, fisheries industry including fish farming has been well developed in this area. However, *Cochlodinium polykrikoides* blooms with huge fish kills have occurred in this area almost every year since 1995.

2. Methodology used in the case study of South coast of Korea

2.1. Methodology used in the case study

HABs and dominant causative species are regularly monitored by NFRDI from March to November. Also, local fisheries extension service stations are responsible for HAB monitoring and reporting to NFRDI for the designated areas where there were frequent HABs in the past. However, once HAB initiate, all relevant agency conducts their daily base HAB monitoring using vessel and helicopter. National Maritime Police Agency (NMPA) is another agency responsible for HABs monitoring by helicopter. NFRDI is major HAB monitoring research institute for the early detection of HAB and forecasting of HAB spreading over Korean coasts, particularly, from June to September when fish killing Cochlodinium species appear.

All the collected data obtained from field survey, meteorology and satellite by NOAA and MODIS are sent to HAB operation center under NFRDI. HAB operation center disseminates daily base HAB information to fisherman and HAB related agency for their appropriate measure.

2.2. Warning/action standards against HAB events

HABs monitoring network covering whole Korean coast was established for minimization of fisheries impact. To give previous attention to fisherman and aquaculturist, 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, NFRDI and local government recommend fisherman to stop feeding, and supply liquid oxygen and/or disperse 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 (12-79㎢) 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 Tide 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 regardless of cell densities in case fisheries damages are anticipated.

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

NFRDI runs routine shellfish toxin monitoring program over 100 stations around shellfish aquaculture farm. PSP toxin safety limit established by the government is 80㎍/100g meat. NFRDI notifies fisherman not to harvest the shellfish when the toxin level exceeds over this level.

The information on HAB causative species, cell densities and affected areas monitored by NFRDI and/or fisheries extension service stations is disseminated to fisherman and HAB relevant 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 the major HAB causative dinoflagellates in the case study area. However, there was no any HAB event made by PSP toxin producing *Alexandrium* spp. in the case study area.

C. polykrikoides, major fish killing HAB causative organism in Korea, exclusively formed monospecific bloom with high cell density in the summer season mainly from August to September. *Chattonella* spp. well known as major fish killing species, particularly, in Japan, there was no any fish killing events in Korea although the species made blooms from time to time in the case study areas. The major target HAB species in the case study area are listed in Table 2.

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

NFRDI is primarily in charge of HABs routine monitoring mainly from March to November to prevent fishery damage. In addition to NFRDI, local fisheries extension service stations under local government are responsible for HAB monitoring mainly targeting on potential HAB areas where there have been frequent HABs in the past. Monitoring areas are shown in Table 3 and Figure 2.

Table 3. Monitoring organization and monitored sea areas

Monitoring organization	Monitoring area
National Fisheries Research and Development Institute (NFRDI) - Southeast Sea Fisheries Research Institute - Southwest Sea Fisheries Research Institute	South coast covering inshore and offshore Southeastern area Southwestern area
Local government - Fisheries station under Gyeongnam province: Tonyeong (TFS), Sacheon (SFS), Goseong (GFS), Geoje (GEF), Namhae(NFS) - Fisheries station under Jeonam province: Wando (WFS), Yeosoo(YFS), Goheung (GFS), Jangheung (JFS), Kangjin (KFS)	South coast targeted on potential HAB areas in inshore Southeastern area (inshore) southwestern area (inshore)

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

Figure 2. Monitoring area by fisheries station (top, southeast region; bottom, southwest region)

3.2. Monitoring parameters

In the south coast of Korea, the following four types of HAB related surveys are conducted: regular HABs monitoring, monitoring on potential HABs areas, specific monitoring on Cochlodinium bloom during summer season and monitoring on shellfish poisoning by either NFRDI or fisheries service stations. Regular HABs monitoring are carried out over 90 stations monthly basis from March to November by NFRDI to investigate the status of water quality and dominant species of phytoplankton. Most of the coastal environmental parameters are monitored simultaneously. Monitoring on potential HABs areas is conducted by fishery service station when water discoloration by HAB events occurs. Monitoring on Cochlodinium bloom in south coast is conducted before, during and after blooms usually from June to October. This monitoring primarily aims at early prediction and warning of Cohchlodinium blooms based on scientific data collected from the field survey. Monitoring on shellfish poisoning is regularly conducted over 40 sites of shellfish culture farms to check the abundance of toxin producing species in the adjacent waters and toxins (PSP, DSP, ASP) within the shellfish meat.

The data used in this case study mainly originated from the monitoring data on potential HABs areas including HAB causative species, cell density, affected area, fisheries damage, water temperature and salinity. Table 4 shows the objectives and monitoring parameters of 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 HABs monitoring	To investigate the status of dominant phytoplankton species and water quality	- HAB species - Cell density - Water color	- Water temp. - Salinity - DO - Transparency - Nutrients - Chl.a	none		9/year (March – November)
Monitoring on potential HABs areas	To check HAB causative species and affected area	- HAB species (dominant/causative) -Cell density -Bloom area -Water color	-Water temp. -Salinity	-Weather -coverage by cloud -Wind direction/ speed		Immediately after water discoloration is reported
Specific monitoring on Cochlodinium	To forecast and warning of Cochlodinium blooms	-HAB species (abundance/succession) -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 (every the other week)
Regular monitoring on shellfish poisoning	To check abundance of toxin producing species and toxin content in the shellfish meat	-Toxic species (PSP, ASP, DSP) -Cell density -Water color	-Water temp. -Salinity -DO		Toxicity in the shellfish	1/month Every week once toxin is detected (usually 30/year)

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 clearing house in NFRDI. Table 5 shows the monitoring parameters that will be referred in the HABs case study. HAB causative species, cell density, bloom affected area and water quality are monitored for the early warning and prediction of HABs. Once *C. polykrikoides* initiates its blooms, it gradually develops into plume like patch and becomes larger around plume. Movement and spreading of the patch to the coast and neighboring areas is usually affected by tidal current and wind. We investigated all the parameter such as water quality and meteorology data over HABs affected areas of south coast. The data collected from HABs monitoring is used for prediction, warning and mitigation of HABs to minimize fisheries impact.

Table 5. Monitoring parameters referred in the HAB case study

	Monitoring parameter	Survey type
HAB	- HAB species (causative/dominant species) - Cell density - Bloom area	Monitoring on potential HABs areas Specific monitoring on Cochlodinium
Water quality	- Water temperature - Salinity - DO	Monitoring on potential HABs areas
Others	- Water quality : transparency,nutrients, Chl.a - Meteorology: Weather, Cloud coverage, Wind direction/speed, current flow, precipitation, solar irradiance, typhoon	Regular HABs monitoring Specific monitoring on Cochlodinium

4. Status of HAB events

4.1. Status of HAB events in year 1995-2009

A total of 873 HAB events of which 209 events (23.9%) led to fish-kills occurred in whole Korean coasts in year 1995-2009. A total of 179 HAB events of which 52 events (29.1%) were responsible for fish kills occurred in the case study area at the same period (Fig. 3).

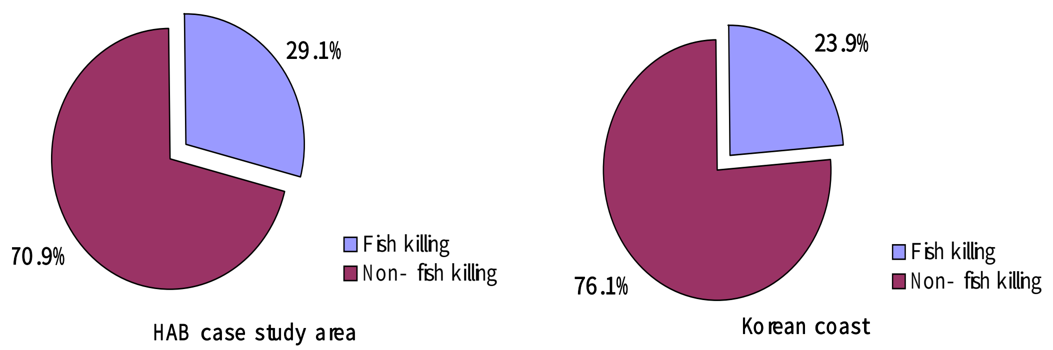


Figure 3. HAB Ratio between fish-killing and non fish-killing species (1995-2009).

The most frequent HAB causative species were *C. polykrikoides, Heterosigma akashiwo, Prorocentrum dentatum, Akashiwo sanguinea***.** The major fish-killing HAB causative species for last 15 years was *C. polykrikoides* with occupying about 23% of HAB events in the south coast (Fig. 4). In year 2009, there were 35 HAB events in total in south coast without any HAB event by fish-killing *C. polykrikoides*.

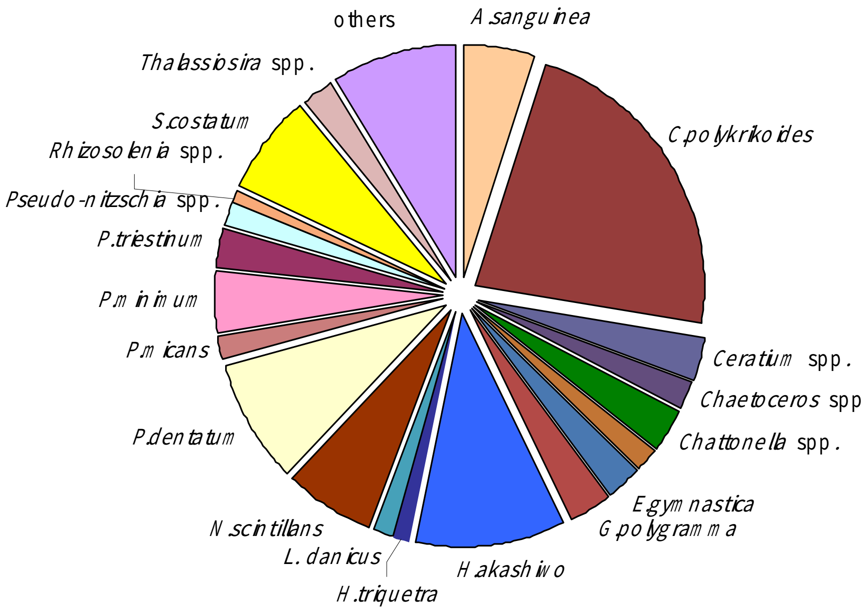


Figure 4. HAB causative species in Korean coast (1995-2009).

4.2. Yearly trends of HAB events

For the last 15 years from 1995 to 2009, 179 HAB events occurred in HABs case study area (Figure 5). Number of HAB event from 1995 to 2004 ranged 6-25 events a year with showing maximal number in 1998 mostly caused by fish-killing *C. polykrikoides* blooms. However, the number has sharply decreased since 2005 with showing less than 6 events a year in the case study area. Overall, there has been transition in the HAB causative species by showing a sharp decrease of fish killing *C. polykrikoides* blooms in south coast in recent years. In addition, there has not been any fish kill in south coast since 2008, and blooms by fish killing species in 2009 in the case study area was not reported.

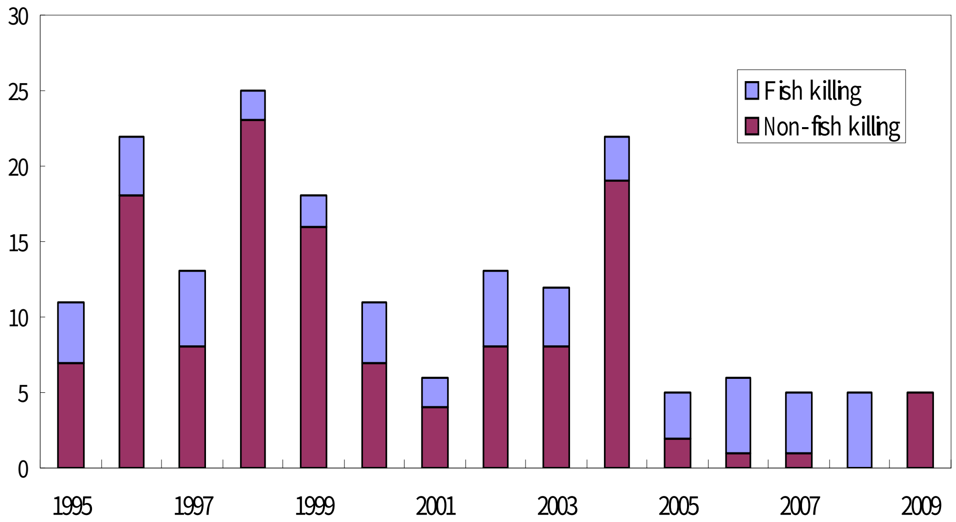


Figure 5. Number of HAB events in the case study area (1995-2009).

4.3. Yearly trends of HAB season

According to the HAB data in 1995-2009, more than 80% of HAB events occurred in high water temperature season from June to September in south coast (Fig. 5). The most frequent HAB month was in August, the highest water temperature season ranging normally 22-30℃, with showing more than 32% of HAB events. However, HAB events were relatively low in low water temperature season from October to May. There was no any significant seasonal trend between years. Meanwhile, the major fish killing HAB species in August was *C. polykrikoides* occupying 51.7% of the blooms. Also, another fish killing species, *Chattonella* spp. has made blooms in west coast from July to August since 2007.

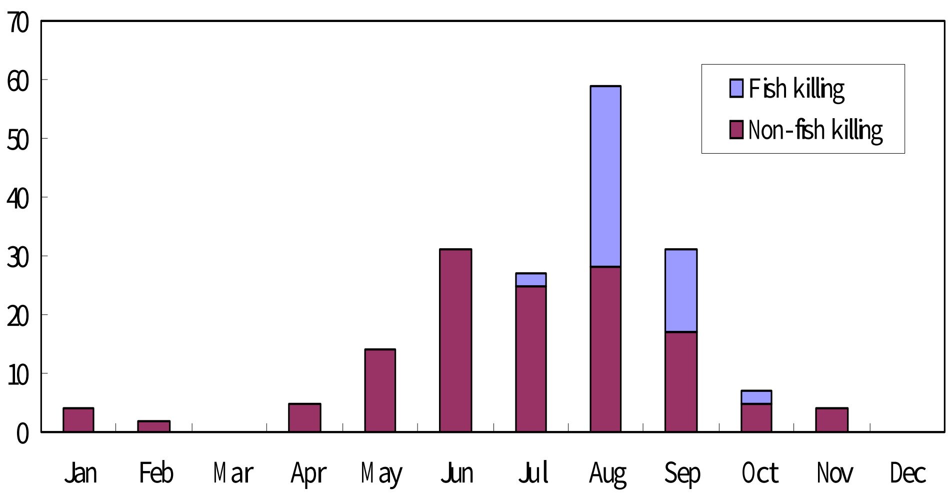


Figure 6. Number of monthly HAB events in south coast (1995-2009)

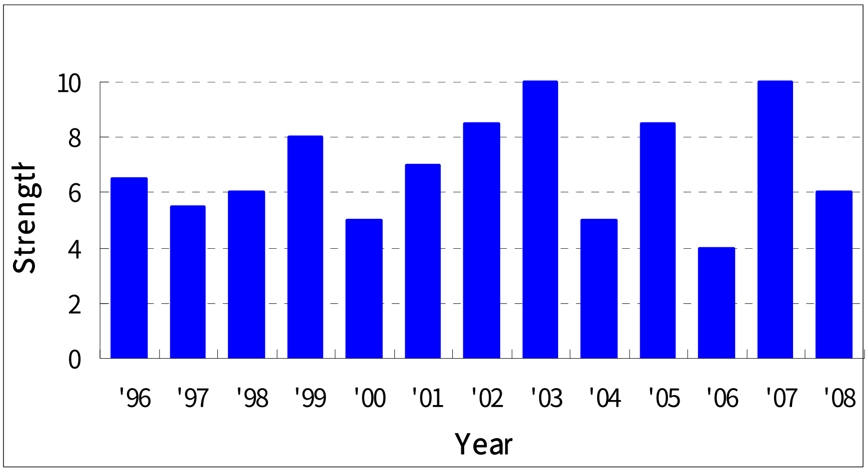


Figure 7. The variation of bloom strength of *C. polykrikoides* in south coast during 1996-2008 (Bloom strength was calculated based on maximal cell density, bloom scale and duration).

4.4. **Yearly trends of causative species**

Table 6 shows the number of HAB events by causative species in the case study area during 1995-2009. A total of 194 events by HAB species were recorded. The most frequent HAB species were dinoflagellates such as *Cochlodinium polykrikoides, Akashiwo sanguinea, Heterosigma akashiwo, Noctiluca scintillans* and *Prorocentrum* spp. HABs by dinoflagellates were much more frequent than by diatoms. Only *C. polykrikoides* among other causative species was responsible for fish killing. Number of blooms by *C. polykrikoides* in the case study area showed 3-6 events a year until 2008. However, there was no bloom by *C. polykrikoides* in year 2009. Moreover, bloom strength by the species has sharply decreased since 2008 (Fig, 7).

Table 6. Number of HAB events by causative species in the case study area (1995-2009)

Causative Species	1995-1997	1998-2000	2001-2003	2004-2006	2007-2008	2009	Total
Dinophyceae							
Alexandrium fraterculus						1	1
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				1	8
Gonyaulax polygramma						1	1
Bacillariophyceae							
Pseudo-nitzchia pungens	2		3	8			13
Skeletonema costatum	1	1					2
Raphidophyceae							
Heterosigma akashiwo	4	11	3	3	0		21

Others							
Mesodinium rubrum	1	3		5			9
Noctilica scintillans		3		1			4
Others	2	11	1	5		2	21
Total	37	64	33	45	10	5	194

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

5.1. Number of HAB events

Records of HAB events in 2008-2009 are shown in Appendix. A total of 43 HAB events among which 28 events were caused by *C. polykrikoides* occurred in south coast in 2008; 35 HAB events without any *C. polykrikoides* bloom occurred in south coast in 2009. Meanwhile, 5 HAB events only caused by *C. polykrikoides* occurred in the case study area in 2008; 5 HAB events without any *C. polykrikoides* bloom occurred in the case study area in 2009. There was no fisheries damage both in 2008 and 2009, which was the first year of no fish kills since 1995. There was no remarkable change in annual nutritional level for recent three years based on the data obtained from regular environmental monitoring for totally six survey stations in Tongyoung, Namhae and Yeosoo sea area where there had been frequent *C. polykrikoides* bloom during high water temperature season in south coast (Table. 13). However, there were some fluctuations in monthly nutritional levels mainly caused by either discharge of heavy rainfall from land or strong extension of kuroshio warm currents to the Korean coasts.

5.2. Period of HAB events

According to the HAB data during 2008-2009, HABs occurred from April to December in south coast. More than 63% of HAB occurred both in July (22.7%) and August (40.9%). *C. polykrikoides* was the major HAB causative species in those periods. HAB was very low during low water temperature season from November to May when water temperature shows below 17 ℃ in the area (Fig. 8). Interestingly, there was only one HAB event in September in 2008 and 2009, which was extremely low number compared to ordinary years. The low HAB event in September was closely related to *C. polykrikoides* blooms which showed sharp decrease in HAB events and early termination of blooms within August in 2008. In addition, there was no *C. polykrikoides* bloom in 2009 extraordinarily.

In 2008-2009, 50% (5 events of 10 HAB events in total) of HAB was caused by fish killing *C. polykrikoides* in the case study area. Meanwhile, 59% of HAB was caused by fish killing *C. polykrikoides* and *Chatonella* spp. in whole Korean coasts (Fig. 9). High ratio of HAB events by fish killing species in the case study area during 2008-2009 were attributed to *C. polykrikoides* blooms in 2008 when only *C. polykrikoides* made blooms without any non-fish killing species blooms.

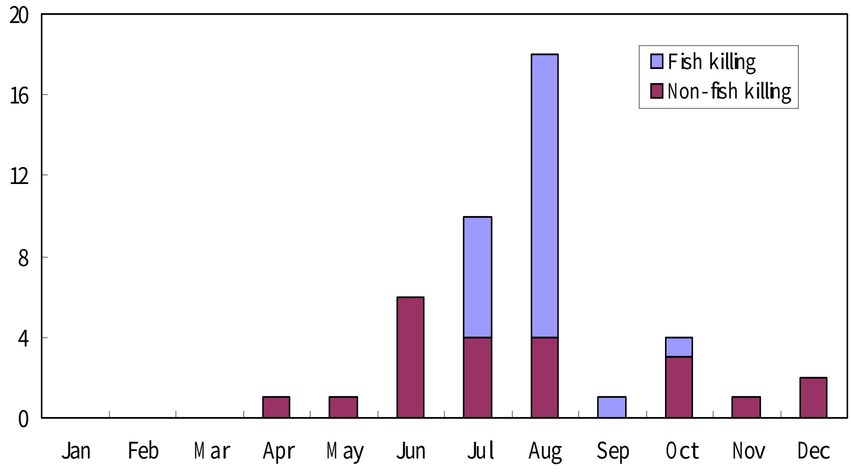


Figure 8. Number of monthly HAB events in south coast (2008-2009)

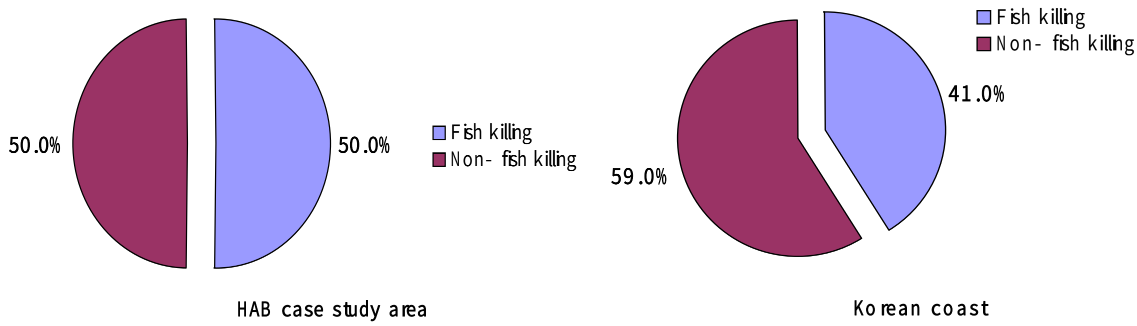


Figure 9. HAB ratio between fish-killing and non fish-killing species in Korea (2008-2009).

5.3. Duration of HAB events

Duration of HAB events was 5-50 days in the case study area from 2008 to 2009 (Table 7). The duration showed a big difference depending on causative species: 22-50 days in *C. polykrikoides* and 5-11 days in other dinoflagellates. The duration of fish killing dinoflagellate, *C. polykrikoides* blooming in mostly offshore was much longer than non-fish killing dinoflatellates whose HAB boundary usually restricted to inshore area. Longer HAB duration of *C. polykrikoides* than any other dinoflagellates was estimated to be related to loner duration of available nutrients in the offshore where nutrient is consistently supplied by currents. Moreover, patches of *C. polykrikoides* spread to neighboring areas by wind or currents where available nutrients are abundant. However, sea water circulation in embayment where most of the dinoflatellates make bloom is not good as offshore, which leads to early termination of HAB after shortage of nutrient pool. There was no any remarkable trend in HAB duration along with years.

Table 7. Duration of HAB events in the case study areas (2008-2009)

Year	Organism	Duration	Location
2008	*Cochlodinium polykrikoides*	Jul. 30 – Sept. 11 (43 days)	Yeosu

	Cochlodinium polykrikoides	Aug. 4 - Sept. 23 (50 days)	Namhae
	Cochlodinium polykrikoides	Aug. 8 - Sept 22 (45 days)	Tongyeong
	Cochlodinium polykrikoides	Aug. 16 - Sept 25 (40 days)	Geoje
	Cochlodinium polykrikoides	Aug. 29 - Sept. 20 (22 days)	Goseong
2009	*Ceratium furca*	Aug. 3 - Aug. 6 (4 days)	Goseong
	Alexandrium fraterculus	Aug. 10 - Aug. 20 (11 days)	Namhae
	Gonyaulax polygramma	Aug. 10 - Aug. 14 (5 days)	Tongyeong
	Scrippsiella trochoidea	Aug. 23 - Aug. 27 (5 days)	Geoje
	Gymnodinium sp.	Oct. 31 - Nov. 10 (11 days)	Namhae

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

5.4. Location of HAB events

Table 8 shows location of HAB events in the case study area from 2007-2009. Figures 10-1 through Figure 10-4 shows the spatial distributions of HAB affected areas from 2007 to 2009. In 2007, *C. polykrikoides* blooms were dominant affecting most of the case study area including Tongyeong Sarang-do, Goseong bay and Jinju Bay (Fig. 10-1). There was huge amount of fisheries damage (11.5 billion Korean wons) by *C. polykrikoides* blooms in Korean coasts in 2007 with showing highly dense bloom although the number of bloom events was relatively low compared to ordinary years. Excluding *C. polykrikoides* blooms in 2007, there was only one HAB event by *Akashiwo sangunea* in Dosan sea area within the case study area. In 2008, all of the HAB events in the case study were caused by *C. polykrikoides* in Namhae Mizo, Tongyeong Sarang-do/Ogok-do, Goseong bay, Jinju Bay and Geoje Chilcheondo (Fig. 10-2 and Fig. 10-3). In whole Korean coasts, the number of HAB events by *C. polykrikoides* in 2008 was the same as in 2007.However, the maximum cell density in 2008 (7,300 cells/ml) was much lower than that of 2007 (32,500 cells/ml). There was no fish kills in 2008. In 2009, there were five HAB events by only non-fish killing dinoflagellates in Namhae Nam-myeon/ Sandong, Tongyoung Tae-do, Goseong Donghae and Geoje Chilcheon-do (Fig. 10-4). There was no any *C. polykrikoides* blooms and fish kills in 2009.

Table 8. Location of HAB events in the case study area

Year	Sea area		No. of events	Causative species
	Sub-area	Spot		
2007	Tongyeong	Dosan	1	*Akashiwo sangunea*
	Tongyeong-Namhae	Mizo	1	*Cochlodinium polykrikoides*
		Sarang suyou-do	1	
		Goseong Bay	1	
		Jinju bay	1	
		Upper Sarang-do	1	
	Total		6	
2008	Namhae	Mizo	1	*Cochlodinium polykrikoides*
	Tongyeong - Goseong	Sanyang ogok-do	1	
		Sarang chu-do	1	
		Goseong Bay	1	
		Jinju bay	1	
	Total		5	
2009	Namhae	Nam-myeon	1	*Alexandrium fraterculus*
		Sandong eunjeom	1	*Gymnodinium* sp.
	Tongyeong - Goseong	Tongyeong Tae-do	1	*Gonyaulax polygramma*
		Goseong Donghae-myeon	1	*Ceratium furca*
	Geoje	Chilcheon-do	1	*Scrippsiella trochoidea*

	Total	5	

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

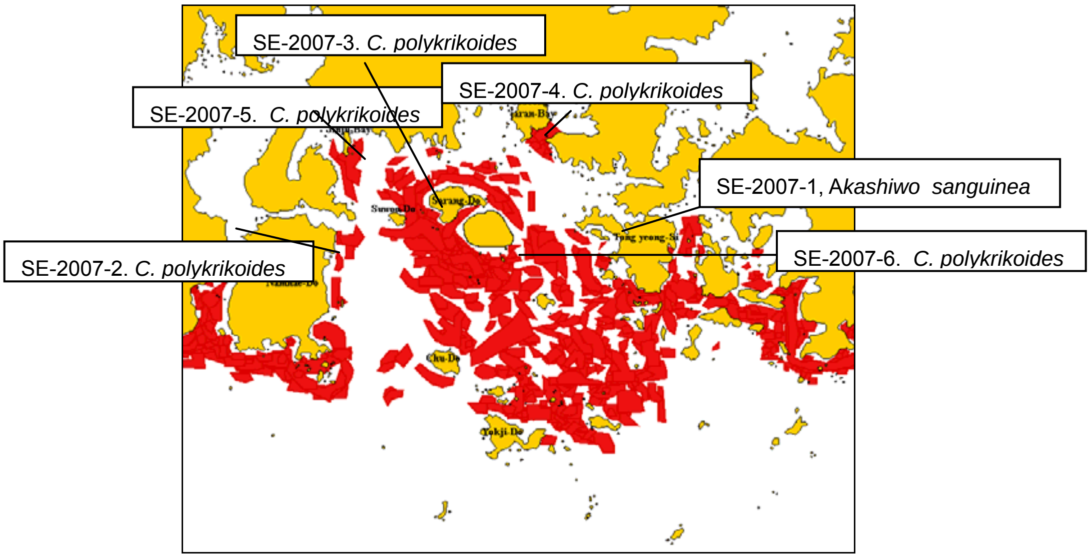


Figure 10-1. Spatial distribution of HABs in 2007(red area indicates HAB affected dimension).

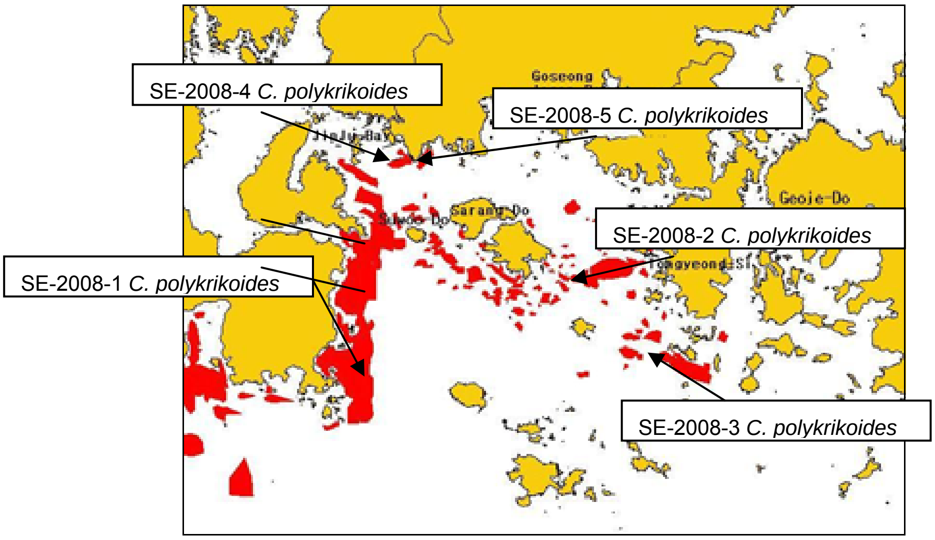
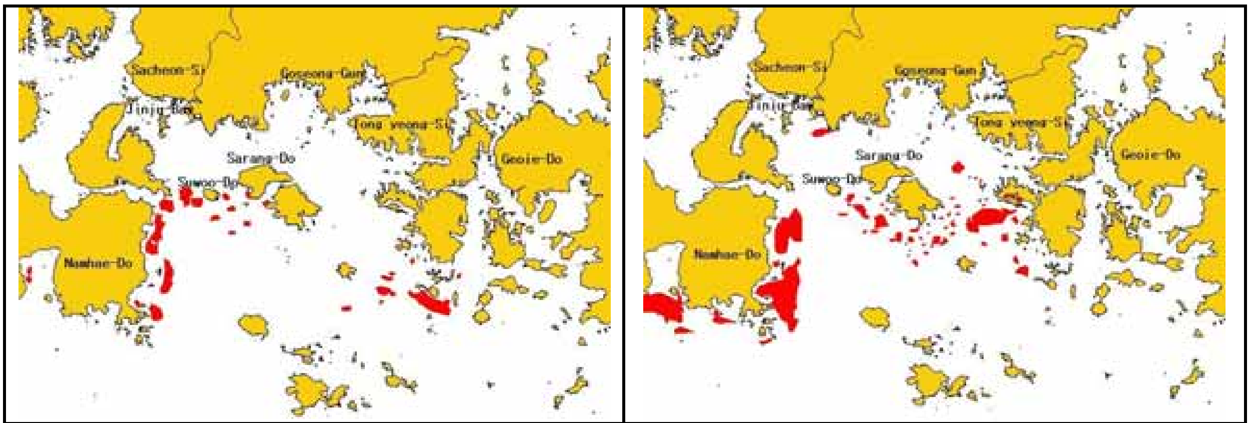
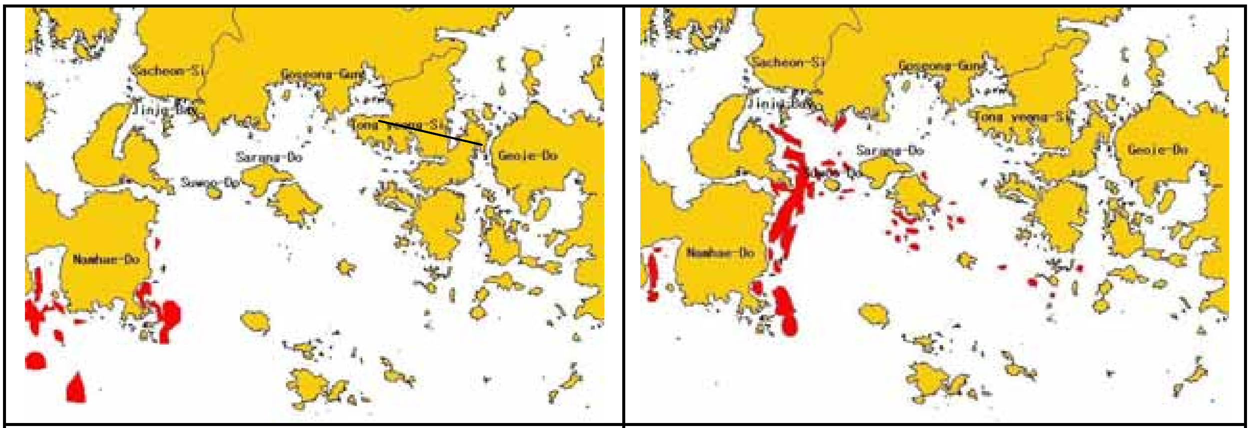


Figure 10-2. Cumulative spatial distribution of HABs in 2008 (red area indicates HAB affected dimension).



1-15 August 2008	16-31 August 2008



1-15 September 2008	16-22 September 2008

Figure 10-3. Changes of HAB affected areas in every half a month (red area indicates HAB affected dimension).

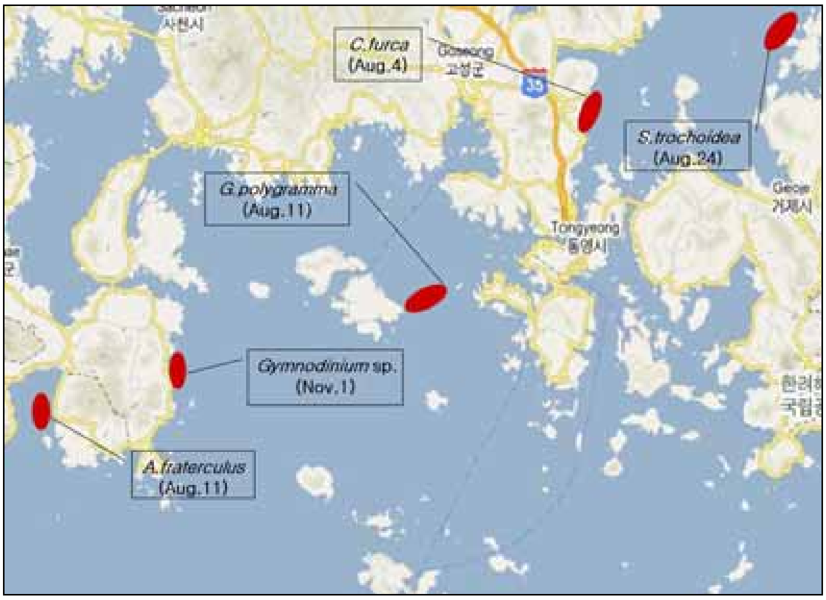


Figure 10-4. Spatial distribution of HABs in 2009 (red area indicates HAB affected dimension)

5.5. Causative species

Six species were responsible for HABs in the case study area from 2008 to 2009 (Table 8). In 2008, *C. polykrikoides* was the only HAB causative species in the case study area. In 2009, five dinoflagellates such as *Alexandrium fraterculus, Gonyaulax polygramma, Ceratium furca, Scrippsiella trochoidea* and *Gymnodinium* sp. was HAB causative species without bloom by *C. polykrikoides.*

The reason why there was no bloom by *C. polykrikoides* was assumed to be related to unusual oceanographic characteristics in 2009. The vegetative cells of *C. polykrikoides* appeared in the offshore of south coast from late June to early July likewise ordinary years. However, salinity level sharply decreased from late July through August when the species usually shows rapid growth (Table 12). Low salinity in south coast in that period was estimated to be related to the heavy rainfall with typhoon in July in Korean Peninsula and/or strong approach of low saline water mass from the East China Sea to Korean coast. Considering that of *C. polykrikoides* is stenohaline species that shows very low growth below 30-31 of salinity level, the low salinity in south coast in August of 2009 might suppress the growth of the species. Thus, there were several blooms by other dinoflagellates which are more competitive than *C. polykrikoides* in low salinity near inshore areas during this period. However, it was too late for *C. polykrikoides* to resume its growth in October when the salinity recovered to normal level of around 33. Meanwhile, based on nutrient data from specific monitoring on Cochlodinium in south coast, the nutrient level from July to August in 2009 was slightly higher than that of 2007 and 2008 (Table 12).

5.6. Maximum density of each HAB event

Table 9 shows the maximum density of each HAB event in the case study from 2008 to 2009. The maximum cell density of HAB event only caused by *C. polykrikoides* in 2008 was 5,600 cells/ml, which was much lower than that in previous year (32,500 cells/ml). The low density of *C. polykrikoides* bloom in 2008 was closely related to no fish kills in the year although duration of the bloom was longer than previous year. In 2009, the maximum cell densities of HAB events caused by different type of dinoflagellates were 2,000 cells/ml in *Ceratium furca*, 6,000 cells/ml in *Alexandrium fraterculus*, 950 cells/ml in *Gonyaulax polygramma,* 15,000 cells/ml in *Scrippsiella trochoidea* and 1,800 cells/ml in *Gymnodinium* sp. Overall, HAB affected area in 2009 was much smaller than that in 2008. Larger HAB affected area in 2008 was attributed to causative species, *C. polykrikoides* which makes blooms in both offshore and offshore with frequent spreading to neighboring areas by currents. However, HAB area by the dinoflagellates occurred in 2009 was mostly restricted to the embayment where water circulation and spreading of blooms are least affected.

Table 9. Maximum density of HAB events in the case study area (2008-2009)

Year	Event No.	Causative species	Maximum density (cells/mL)	Affected area (km^2)
2008	SE-2008-1	*Cochlodinium polykrikoides*	5,600	40.
2008	SE-2008-2	*Cochlodinium polykrikoides*	2,650	60
2008	SE-2008-3	*Cochlodinium polykrikoides*	2,500	60
2008	SE-2008-4	*Cochlodinium polykrikoides*	4,000	3
2008	SE-2008-5	*Cochlodinium polykrikoides*	5,000	2
2009	2009-1	*Ceratium furca*	2,000	0.8
2009	2009-2	*Alexandrium fraterculus*	6,000	2
2009	2009-3	*Gonyaulax polygramma*	950	3
2009	2009-4	*Scrippsiella trochoidea*	15,000	2
2009	2009-5	*Gymnodinium* sp.	1,800	0.5

5.7. Status of HAB induced fisheries damage

Table 10 shows the fisheries damage caused by HAB in south coast, 2007. Large fishery damages by *C. polykrikoides* blooms occurred mostly in August, 2007 when it showed highly dense blooms. Approximately 10 million U.S. dollars of losses with 7 million individuals of fish kills (Rockfish, parrot fish etc.) occurred in finfish cage culture farms in south coast. However, there was no fisheries damage in 2008. Because the density of *C. polykrikoides* blooms was low (max. cell density: 5,600 cells/ml) compared to 2007 (max. cell density: 32,500 cells/ml). There was no bloom by *C. polykrikoides* in 2009 in Korean coasts.

Table 109. Fisheries damage by HABs in south coast in 2007

Month/ Year	Event No.	Sub-area	Spot	Causative Species	Fisheries damage		
					Fish species	Quantity (million ind.)	Economic loss (million won)
Aug. 2007	SE-2006-3	Tongyeong	Sarang-do	*Cochlodinium polykrikoides*	Rockfish, Parrot fish etc.	Rockfish, 2, Parrot fish 1 , etc. 1.9	7,337
Aug, 2007	SE-2006-2	Namhae	Namhae Mizo	*Cochlodinium polykrikoides*	Sea bream, Sea bass, Rockfish, parrot fish	Rockfish, 0.69, Sea bream 0.39, Parrot fish 0.15, Sea bass 0.61, Sea bastes 0.15	3,664

Source: National Fisheries research and Development Institute

5.8. Status of target species

In 2007, the major target species, fish killing *C. polykrikoides,* made highly dense blooms, the second highest cell density and 11.5 billion of huge fish kills, the second biggest fish kills since 1995. However, in 2008, scale and cell density of *C. polykrikoides* blooms sharply decreased without any fish kills. In 2009, *C. polykrikoides* did not make any bloom in whole Korean coast. Hence, it is assumed that the strength of *C. polykrikoides* blooms in Korean coasts has been decreasing recently although there was unusual oceanographic characteristic in 2009 affected on the suppression of cell growth. Overall, HABs by both fish killing species and non-fish killing species have been decreasing year by year since 2007. However, shellfish toxin producing species such as *Alexandrium* spp., *Dinophysis* spp. and *Psuedo-nitzschia* spp. still frequently appear and/or sometimes intoxicate shellfish in the case study area although they seldom show high density to form blooms (Fig. 11). Thus, NFRDI in Korea runs regular monitoring program targeted on shellfish poisoning in addition to HABs.

Figure 1110. Shellfish harvest banning areas in south coast due to PSP toxin (red color, harvest closure area; red circle, higher than limitation level; blue circle, less than limitation level).

*Source: Information on shellfish poisoning from NFRDI website (www.nfrdi.re.kr)

5.9. Environmental monitoring results during HAB events

Table 11 shows environmental conditions during HABs in the case study areas from 2007 through 2009. Water temperatures and salinities during *C. polykrikoides* blooms in 2007 and 2008 ranged 21.0-29.4 ℃ and 29.0-34.0, respectively. In 2009, water temperatures and salinities during HABs events showed 19.0-26.5 and 28.9-32.9, respectively. Overall, salinity in 2009 was lower than in 2007 and 2008, which was estimated to be caused by heavy rainfall and low saline water from offshore during summer season in 2009. Low salinity recovered in the south coast from late September in 2009.

Table 11. Environmental data during HABs monitoring in the case study area (2007-2009)

Year	Event No.	Duration	Spot	Water temp.(℃)	Salinity
2007	SE-2007-1	JUL 24 - JUL 30	Tongyeong	22.4-24.5	32.0-33.2
2007	SE-2007-2	AUG 6 - SEP 15	Namhae	23.3-29.4	28.3-32.0
2007	SE-2007-3	AUG 9 – SEP 12	Tongyeong	24.0-27.6	30.2-34.0
2007	SE-2007-4	AUG 11 – SEP 1	Goseong	26.0-29.5	30.3-32.3
2007	SE-2007-5	SEP 3 – SEP 9	Sacheon	22.1-25.6	30.1-32.8
2007	SE-2007-6	OCT 19 – OCT 29	Tongyeong	22.5-23.8	32.8-33.2
2008	SE-2008-1	AUG 4 – SEP 23	Namhae	21.0-26.9	30.5-32.9
2008	SE-2008-2	AUG 8 – SEP 22	Tongyeong Sanyang	22.2-27.0	29.0-32.3
2008	SE-2008-3	AUG 16 – SEP 25	Tongyeong Sarang	24.0-27.0	30.1-33.2
2008	SE-2008-4	AUG 29 – SEP 5	Sacheon	24.9-27.0	30.0-32.8
2008	SE-2008-5	SEPT 11 – SEP 20	Goseong	26.5-27.0	30.9-33.2
2009	2009-1	AUG 3 – AUG 6	Goseong	24.0-25.2	28.9-30.6
2009	2009-2	AUG 10 – AUG 20	Namhae	24.1-26.5	29.3-30.9
2009	2009-3	AUG 10 – AUG 14	Tongyeong	24.2-24.9	30.3-31.4
2009	2009-4	AUG 23 – AUG 27	Geoje	24.7-25.5	29.1-30.6
2009	2009-5	OCT 31 – NOV 10	Namhae	19.0-19.6	31.8-32.9

5.10. Water quality parameters of regular HAB monitoring survey

Table 12 shows water quality obtained from specific monitoring on Coclodinium in south coast from July to September in 2007-2009. DIN level in 2007, 2008 and 2009 ranged 0.024-0.252, 0.003-0.071 and 0.040-0.421, respectively. Also, DIP level in 2007, 2008 and 2009 was 0.003-0.054, 0.001-0.040 and 0.001-0.036, respectively. Although yearly nutrient level showed relatively big fluctuations, however, it was estimated to be related to heavy rainfall or typhoon before survey. Considering the mean value of nutrient in each year, the difference among three years was not so big. It was estimated that decrease and/or no bloom events by *C. polykrikoides* in south cost since 2008 was not directly related to the variation of water quality.

Table 1211. Water quality data obtained from regular HAB monitoring in south coast (2007-2009)

Survey date	Spot	Survey point	Water temp. (℃)	Salinity	NH_4-N (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)	DIN (mg/L)	DIP (mg/L)	SIO_2-Si (mg/L)	Chl-a (µg/L)	Trans parency (m)
Jul-07	Tongyeong	T5	22.12	32.56	0.001	0.001	0.044	0.046	0.003	0.061	3.61	4
Jul-07		T7	21.75	32.82	0.003	0.001	0.050	0.054	0.007	0.112	2.01	5
Jul-07	Namhae	T10	20.48	33.31	0.008	0.003	0.196	0.206	0.002	0.216	5.38	5
Jul-07		T12	20.78	33.47	0.008	0.002	0.085	0.095	0.012	0.190	1.03	5.5
Jul-07	Yeosu	Y3	19.88	33.65	0.003	0.004	0.045	0.051	0.005	0.492	2.61	2
Jul-07		Y6	20.17	33.59	0.033	0.004	0.068	0.105	0.008	0.343	3.87	3
Aug-07	Tongyeong	T5	23.92	32.45	0.009	0.001	0.085	0.094	0.025	0.029	2.82	4
Aug-07		T7	24.50	21.23	0.007	0.001	0.075	0.082	0.008	0.030	3.67	7
Aug-07	Namhae	T10	25.56	30.79	0.004	0.013	0.235	0.252	0.030	0.518	11.03	1.5
Aug-07		T12	28.37	32.81	0.007	0.018	0.047	0.073	0.054	0.325	7.11	2.5
Aug-07	Yeosu	Y3	26.52	32.79	0.003	0.023	0.131	0.158	0.018	0.584	1.81	3
Aug-07		Y6	25.86	33.18	0.007	0.013	0.024	0.043	0.017	0.390	1.69	3.3
Sep-07	Tongyeong	T5	24.11	31.55	0.012	0.008	0.018	0.038	0.017	0.240	16.72	4.5
Sep-07		T7	24.28	31.90	0.014	0.009	0.045	0.069	0.020	0.665	2.54	8
Sep-07	Namhae	T10	22.57	28.53	0.027	0.019	0.451	0.497	0.033	1.334	0.44	5
Sep-07		T12	25.10	31.43	0.012	0.005	0.007	0.024	0.011	0.141	1.22	1.5
Sep-07	Yeosu	Y3	24.29	31.54	0.016	0.006	0.015	0.036	0.012	0.158	1.25	2.5
Sep-07		Y6	24.60	30.47	0.011	0.010	0.007	0.028	0.004	0.150	1.91	10
Jul-08	Tongyeong	T5	21.36	32.33	0.018	0.004	0.001	0.022	0.028	-	3.13	3
Jul-08		T7	21.50	32.78	0.015	0.002	0.003	0.021	0.020	-	1.12	5
Jul-08	Namhae	T10	23.40	32.28	0.037	0.001	0.003	0.041	0.021	-	2.22	4
Jul-08		T12	22.63	32.43	0.015	0.003	0.007	0.025	0.002	-	0.83	4
Jul-08	Yeosu	Y3	24.20	32.22	0.002	0.001	0.002	0.005	0.002	0.632	3.96	2.5
Jul-08		Y6	25.70	32.70	0.001	0.001	0.001	0.003	0.002	0.353	1.31	3
Aug-08	Tongyeong	T5	23.32	33.10	0.010	0.008	0.001	0.018	0.018	0.157	1.22	5
Aug-08		T7	23.91	33.05	0.030	0.005	0.007	0.042	0.002	0.199	0.80	6
Aug-08	Namhae	T10	24.18	32.64	0.008	0.013	0.001	0.019	0.040	0.225	2.02	4
Aug-08		T12	25.01	33.04	0.012	0.006	0.004	0.022	0.002	0.380	2.32	5
Aug-08	Yeosu	Y3	24.81	32.89	0.003	0.001	0.001	0.005	0.003	0.414	3.96	3.5
Aug-08		Y6	23.98	33.06	0.002	0.001	0.001	0.004	0.001	0.235	1.13	5
Sep-08	Tongyeong	T5	25.10	32.09	0.014	0.003	0.024	0.041	0.003	0.200	0.49	12.0
Sep-08		T7	25.41	31.76	0.013	0.005	0.017	0.035	0.001	0.169	0.39	16.0
Sep-08	Namhae	T10	25.51	31.96	0.013	0.003	0.021	0.037	0.017	0.208	1.09	4.0
Sep-08		T12	25.24	31.59	0.037	0.004	0.031	0.071	0.034	0.182	0.17	14.0
Sep-08	Yeosu	Y3	25.21	32.14	0.004	0.002	0.004	0.010	0.002	0.099	2.18	3
Sep-08		Y6	25.03	31.88	0.004	0.001	0.006	0.012	0.001	0.098	0.50	10.5
Jul-09	Tongyeong	T5	21.24	31.74	0.012	0.003	0.082	0.096	0.021	0.189	2.99	9

Jul-09		T7	21.10	32.47	0.019	0.001	0.034	0.054	0.022	0.114	3.46	8
Jul-09	Namhae	T10	22.47	26.76	0.060	0.008	0.353	0.421	0.017	0.751	2.22	4
Jul-09		T12	19.34	33.15	0.016	0.001	0.078	0.096	0.036	0.250	4.47	4
Jul-09	Yeosu	Y3	20.65	32.95	0.019	0.008	0.136	0.162	0.020	0.434	2.38	0.9
Jul-09		Y6	21.23	32.90	0.023	0.008	0.205	0.236	0.025	0.506	1.72	0.8
Aug-09	Tongyeong	T5	24.54	30.61	0.010	0.001	0.029	0.040	0.003	0.204	1.37	10
Aug-09		T7	24.15	30.54	0.026	0.003	0.028	0.058	0.006	0.196	1.85	9
Aug-09	Namhae	T10	24.29	27.54	0.024	0.008	0.058	0.089	0.005	0.050	1.06	17
Aug-09		T12	24.48	30.61	0.020	0.003	0.040	0.064	0.005	0.154	1.25	7
Aug-09	Yeosu	Y3	24.09	30.66	0.043	0.003	0.113	0.159	0.007	0.292	2.46	3
Aug-09		Y6	23.98	30.61	0.023	0.003	0.162	0.188	0.005	0.223	1.75	4.5
Sep-09	Tongyeong	T5	24.21	31.42	0.024	0.001	0.079	0.104	0.012	0.076	3.30	4.5
Sep-09		T7	24.30	31.33	0.021	0.003	0.076	0.100	0.007	0.070	4.14	5.5
Sep-09	Namhae	T10	25.02	30.31	0.016	0.003	0.037	0.056	0.001	0.097	6.73	3
Sep-09		T12	24.60	31.71	0.018	0.001	0.064	0.084	0.004	0.122	2.10	7
Sep-09	Yeosu	Y3	24.70	31.67	0.024	0.002	0.071	0.097	0.004	0.118	3.40	2
Sep-09		Y6	24.91	31.46	0.017	0.003	0.076	0.095	0.004	0.112	3.42	2.5

Source: Data from specific monitoring on Cochlodinium by National Fisheries research and Development Institute

5.11. Meteorological observation parameters

In addition to field survey data, NFRDI collects meteorological data such as wind direction, wind speed, solar irradiance, amount of precipitation, typhoon, tidal difference, etc mostly from KMA (Korean Meteorological Administration) for the prediction of HABs. Wind and current greatly affect on the spreading of HABs to eastward, particularily, in case of *C. polykrikoides* blooms in Korea. In addition, meteorological condition (e.g. long period of rainy season and heavy rainfall), also, plays an important role in the early termination of blooms by stenohaline species like *C. polykrikoides* and in species succession from stenohaline to euryhaline species including diatoms.

6. Eutrophication monitoring with satellite image

6.1. Framework of Satellite image monitoring

NFRDI receives satellite image which are applicable for the HABs case study as follows:

- Available images: SST images (NOAA series), ocean color (chlorophyll-a and suspended sediment) images (SeaWiFS) and MODIS
- 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 x 1 km, 4 x 4 km and 9 x 9 km

NFRDI has received NOAA/AVHRR satellite data since 1989, which is opened to the public through NFRDI webpage. MODIS data has been available since May 2001. Also, SeaWiFS data with LAC (local area coverage) spatial resolution has been supported by KEOC (Korea Earth Observation Center) since 1999. OCM (Ocean Color Monitor) of IRS-P4 Chl-a concentration data had been received from May 2001 to October 2004.

6.2. Parameters of satellite image monitoring

Table 14 shows information on the remote sensing data available in NFRDI. Chlorophyll-a and SST data among other parameters are available for the HAB case study.

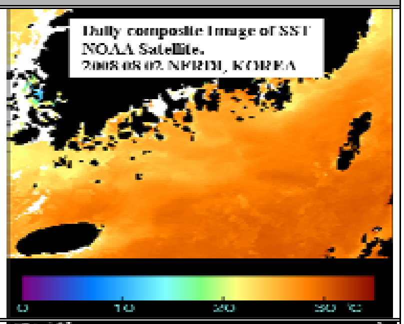
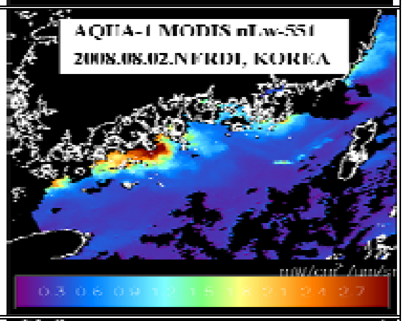
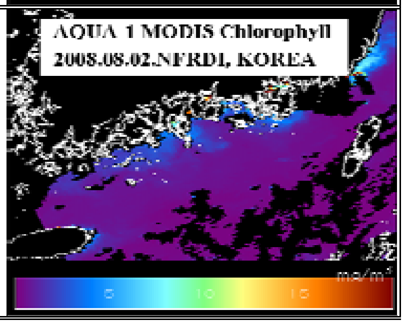
Table 12. Parameters of satellite data available for the HAB case study

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
NASA	Ocean Color Web	Chlorophyll a	CZCS (SeaStar)	1978.11-1986.6	Daily, Monthly, Seasonal, Annual	4 km	Level 3	OC4 Chl-a algorithm
						9 km		
			OCTS (ADEOS)	1996.8-1997.7	Daily, Monthly, Seasonal, Annual	9 km	Level 3	
			SeaWiFS (Orbview-2)	1997.9-2004.12	Daily	1 km	Level 2	
					Daily, Monthly, Seasonal, Annual	9 km	Level 3	
					Daily, Monthly, Seasonal, Annual	4 km	Level 13	
						9 km		

6.3. Results of satellite image monitoring

Remote sensing data of SST and Chlorophyl-a was applied for the detection of spatial distribution of HABs and surface water temperature in the case study area. The information on SST was useful in understanding distribution of surface sea water temperature in open sea, which is one of the helpful parameters for the prediction of HABs by *C. polykrikoides* which frequently makes huge scale bloom in offshore. However, in case of Chlorophyl-a remote sensing image, there was some limitation in practical application. In 2008, detection of HAB events by remote sensing Chlorophyl-a image was applicable, particularly, targeting on *C. polykrikoides* bloom which made large scale bloom as long as several tens of kilometers in 2008 (Table 15). However, in 2009, the bloom affected area in the case study area was very small ranging 0.5-3 km^2 in dimension which is partly beyond detection limit of Chlorophyl-a due to the resolution problem. Thus, detection of HAB events by Chlorophyl-a remote sensing image was not promising in 2009. In addition to resolution problems of chlorophyll-a remote sensing image in the practical application to HABs detection, there are limitations in identifying HAB species to be solved in future. Hence, in order to know the HAB causative species, it is essential to collect sample by field survey additionally at the moment. It was thought that application of remote sensing image to HABs detection is one of the useful tools. However, it needs more scientific knowledge to be solved for the practical field application.

Table 13. 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	Aug. 2, 2008	South Sea of Korea (Sea surface temperature image)	
2008	SE-2008-1	Aug. 2,2008	South Sea of Korea (nLw 551 image)	
2008	SE-2008-1	Aug. 2,2008	South Sea of Korea (chlorophyll-a image)	

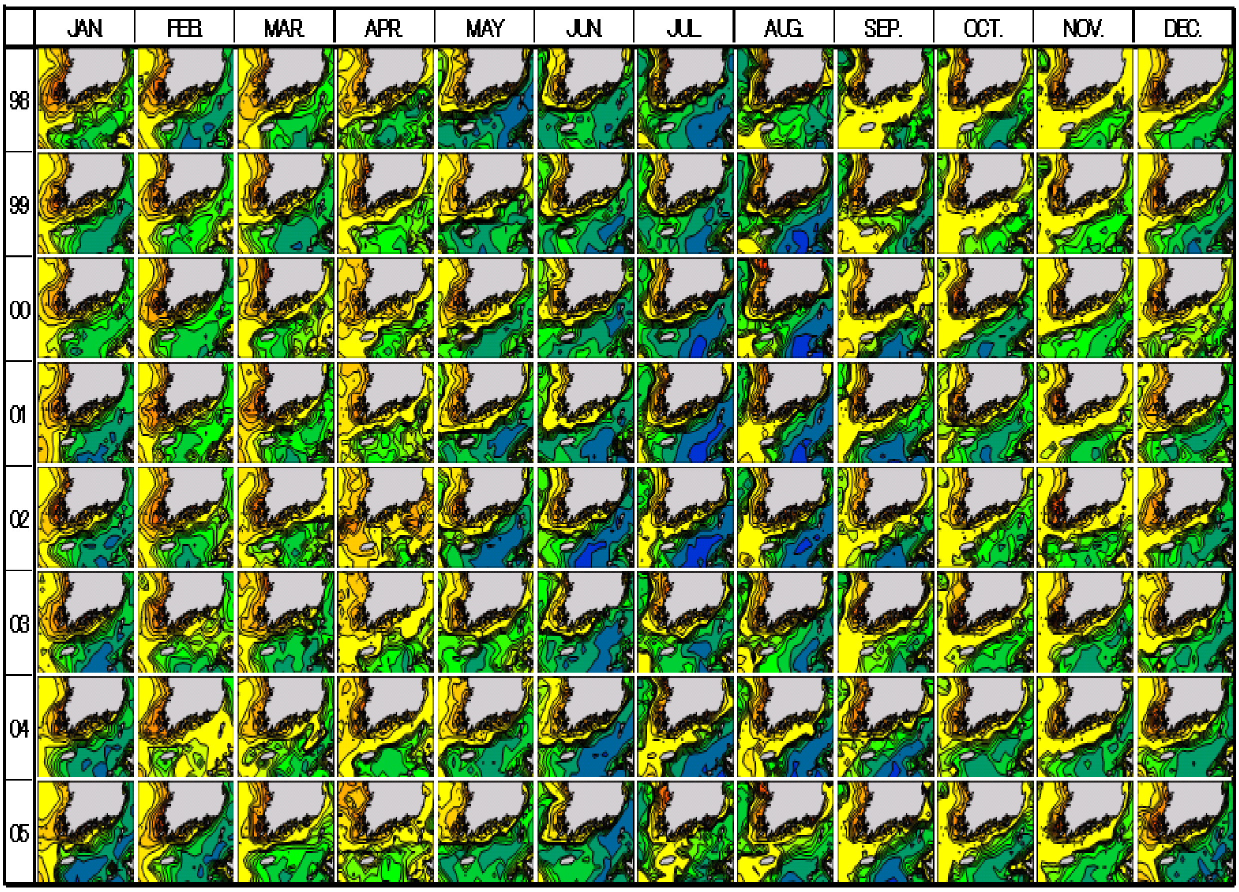


Figure 12. Monthly average SeaWiFS Chl-a imagies in the south coast of Korea from 1998 to 2005.

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* blooms have been the direct and severe impacts on the coastal aquaculture industries in Korea. 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 without fish kills in Korean coasts. Although the number of HAB events by *C. polykrikoides* was the same as in 2007, the maximum cell density was much lower than that of 2007 when there was huge fish kills. In 2009, there were five HAB events by non-fish killing dinoflagellates without *C. polykrikoides* blooms and fish kills. The main reason that there was no *C. polykrikoides* bloom was assumed to be related to unusual oceanographic characteristics in 2009. The vegetative cells of *C. polykrikoides* appeared in the offshore of south coast from late June to early July likewise ordinary years. However, salinity level sharply decreased from late July through August when the species usually shows rapid growth. Considering that of *C. polykrikoides* is stenohaline species that shows very low growth below 30-31 of salinity level, the low salinity in south coast in August of 2009 might suppress the growth of the species. It was estimated that decrease and/or no bloom events by *C. polykrikoides* since 2008 was not directly related to the variation of water quality in south coast of Korea.

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.

8. References

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Appendix

Records of HAB events in south coast of Korea in 2007-2009.

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	1.986	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.	4.9	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	8	Tongyeong	Jinju bay	*C. polykrikoides*	5,000	-	-	-	26.5-27.0	30.9-33.2	2
SE	2009	1	2009	8	4	2009	8		4	Goseong	Donghae-myeon	*C.furca*	2,000				24.0-25.2	28.9-30.6	0.8
SE	2009	2	2009	8	11	2009	8	19	11	Namhae	Nam-myeon	*Alex..fraterculus*	6,000				24.1-26.5	29.3-30.9	2
SE	2009	3	2009	8	11	2009	8	13	5	Tongyeong	Tae-do	*G.polygramma*	950				24.2-24.9	30.3-31.4	3
SE	2009	4	2009	8	24	2009	8	26	5	Geoje	Chilcheon-do	*S.trochoidea*	15,000				24.7-25.5	29.1-30.6	2
SE	2009	5	2009	11	1	2009	11	9	11	Namhae	Sandong eunjeom	*Gymnodinium*.sp.	1,800				19.0-19.6	31.8-32.9	0.5