Report of HAB Case Studies in the Coastal Area of Qingdao Region

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1. Introduction

1.1. Objective

The objective of conducting the HAB case study in the coastal area of Qingdao region is to establish the most effective and least laborious way for sharing among 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, both red-tide and toxin-producing planktons will be referred as HAB species.

1.2. Definitions and rules used in the HAB case study

Harmful algal blooms (HABs) were called red tides in the past years because of the intense (often reddish) discoloration of seawater by pigments in the algae involved. However, the term red tide is too general: it includes dense accumulation of phytoplankton species which can visibly discolor seawater but have no harmful effects, and it excludes many other blooms which cause negative effects at very low density without any associated water discoloration. In spite of the name, red tides are often not red, and are seldom associated with tides, and in some cases exert no negative effects.

"Harmful algal blooms" (or HABs) is the term now used widely to describe blooms which have negative effects. They take many forms and have equally diverse effects, but they are always toxic or harmful. These effects involve different toxins produced by the algae, killing fish and other marine animals, as well as having more general environmental effects.

Traditionally, Chinese are used to the term "red tides" to describe any marine phytoplankton blooms that either causes water discolorations or results in harmful and toxic events. For scientific communities in China, HABs is widely used. HABs in this report, therefore, encompass both harmful or toxic blooms and harmless red tides.

1.3. Overview of the target sea area

1.3.1. Location and boundary

The target sea area covers the eastern part of Qingdao coastal area and a semi-enclosed interior gulf of Qingdao named Jiaozhou Bay, which jointed with the North Yellow Sea. The location of the target area is from 35º35'~37º09'N and 119º30'~121º00'E (Fig.1).

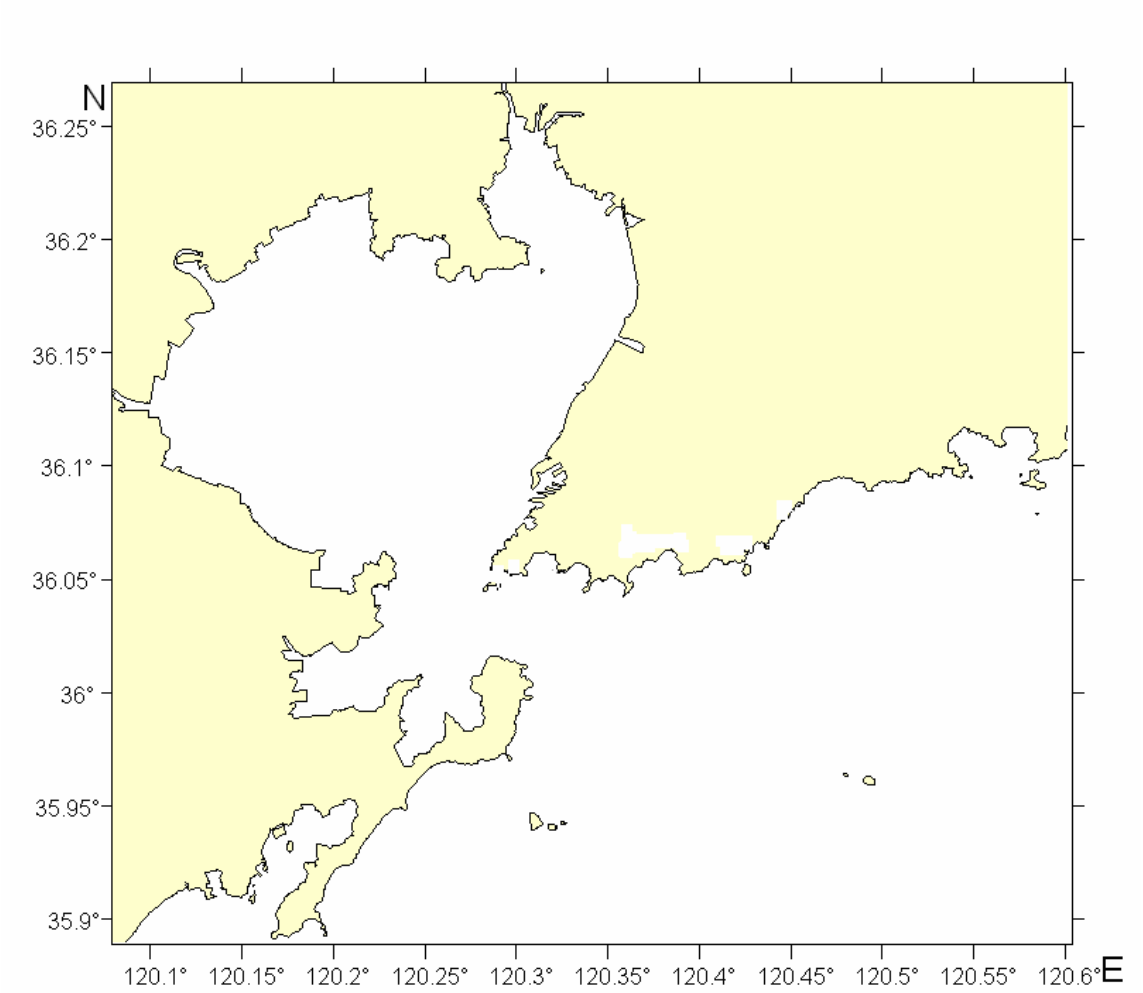


Figure 1 Proposed target sea area for the case study in China

1.3.2. Environmental/geographical characteristics

The target sea area is surrounded by the continent in northwest and faces North Yellow Sea in southeast, which includes waters of Jiaozhou Bay (390km^2) and east coastal waters of Qingdao (140km^2). With an average water depth of 7m and a maximum depth of 64m, most parts of Jiaozhou Bay are shallower than 5m. Located in the northern temperate zone, the target sea area is neither extremely hot in summer nor severely cold in winter. The multi-year mean air temperature is 13□, the sediment depth is about 662 mm and the seawater salinity is between 30.54~33.29.

Major rivers discharging directly into the target sea area include Haipo, Moshui, Licun, Dagu, 26 rivers in total. Haipo, Moshui, Licun, Dagu Rivers around Jiaozhou Bay have important effects on both salinity and hydrography of the target sea area. All rivers have peak runoff in summer and minimum discharge in winter.

Qingdao is a littoral city with a population of approximately 8,300,000 and a population density of about 1517people/km^2.

2. Methodology used in the case study in the Qingdao Coastal Waters

2.1. Methodology used in the case study

Red tide monitoring programs in China is conducted by State Oceanic Administration (SOA). The monitoring program started from late 1980s, and the monitoring network is still under construction. SOA has issued "Annual Report of Chinese Marine Environmental Quality" since 1990, in which the data on HABs case is reported. The HAB event in this report is based on two ways, one is seawater color change found by fisherman or air remote sensing, which is then identified. The other is based on regular monitoring by SOA. That is one of data sources in our HAB case study of Qingdao Coastal Waters.

In order to ensure the coastal water quality of Qingdao for the Sailing Regatta of 2008 Olympic game, HAB monitoring and routine sea quality monitoring programs are conducted by North China Sea Environment Monitoring Centre (NCSEMC) which authorized by SOA in recent years. NCSEMC has issued "Monitoring and warning report of HAB events in costal waters of Qingdao" daily during the July and August since 2005. That is another data source reported in the case study.

Besides, many research programs on HABs are conducted in Jiaozhou Bay because it is a typical bay in North China sea. Related data on HABs event is also used in the report.

2.2. Warning standards against HAB events

In order to prevent damage from HABs, monitoring organizations in the target sea area have established HAB warning standards for major causative species in Qingdao coastal waters by using related international standards as references (Table 1). In general, the standard of warning and action is similar in all cases — If exceeded, it will be reported to local government followed by actualization of certain countermeasurements, such as spraying modified clay, moving fish cage, etc..

Table 1 HAB warning standards of Qingdao City

Name	Standards(cells/L)	Toxin
Mesodinium rubrum	$5x10^5$	No
Noctiluca scintillans	$5x10^4$	No
Skeletonema costatum	$5x10^6$	No
Heterosigma akashiwo	$5x10^7$	No
Eucamipa zoodianus	10^5	No
Alexandrium tamarense	10^6	Yes(PSP)

In China, harvested shellfish are monitored to check the presence of any algal toxins. Safety limits are established by the Government, which are 80μg STXeq/100g of meat for PSP and less than detection limit by means of mouse bioassay (0.05 MU/g) for DSP.

2.3. Target HAB species

The causative HAB species in Qingdao coastal waters are basically non-toxin plankton and zooplankton, therefore, in this case study, the following 5 species of HAB are referred as 'target HAB species'.

Table 2 Target HAB species in this case study

Name	Red tide causative species	Toxin-producting plankton
Mesodinium rubrum	Yes	
Noctiluca scintillans	Yes	
Skeletonema costatum	Yes	
Heterosigma akashiwo	Yes	
Eucamipa zoodianus	Yes	

3. Monitoring framework and parameters of HAB

3.1. Monitoring framework

As mentioned above, North China Sea Environmental Monitoring Centre (NCSEMC) conducts HAB monitoring in recent years to prevent HABs in Qingdao coastal waters. There're 43 monitoring stations set up in the target sea area, distributed among Jaozhou Bay、Huiquan Bay、Tuandao Bay、Taipingjiao Bay、Fushan Bay、Maidao Bay、Shazikou Bay and adjacent coastal waters. The boundaries and locations of the monitoring stations are presented on Figure 2.

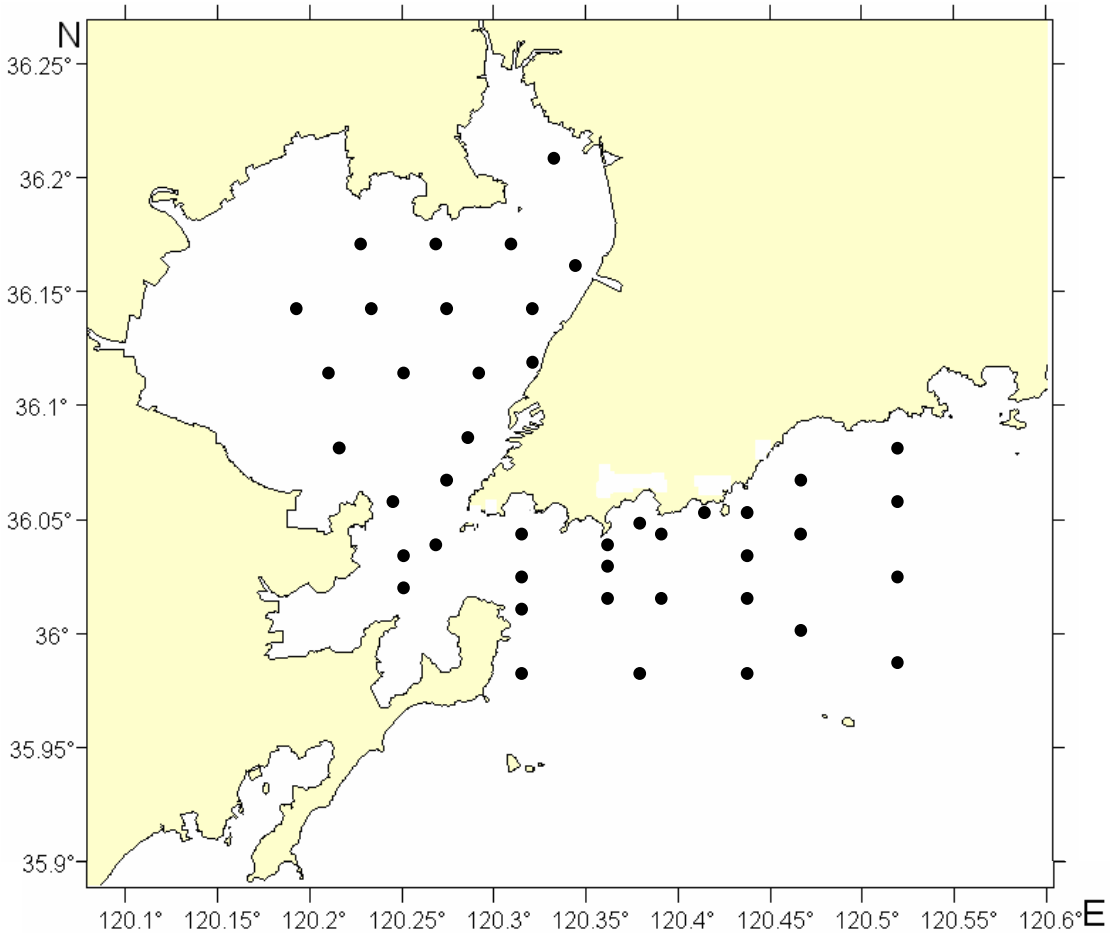


Figure 2 . Monitoring framework in Qingdao target sea area

3.2. Monitoring parameters

In the coastal waters of Qingdao, the following two types of HAB related surveys are conducted: post-HAB survey and regular HAB monitoring survey. Post-HAB survey is conducted when discoloration of water bas been observed and HAB event has occurred. Regular HAB monitoring survey is conducted regularly at fixed locations, irrespective of any HAB events.

This case study will focus mainly on results of the post-HAB survey, which monitors HAB causative species, cell density, affected area, water temperature, salinity and DO. Meanwhile, regular HAB monitoring results such as nutrients、wind speed/direction、weather condition and other water quality as well as meteorological parameters will be used for further discussions.

3.3. Data and information used

Information on HAB events will be mainly collected from following sources:

Reports published by organizations that conduct HAB monitoring in the target sea area

Monitoring and warning report of HAB events in costal waters of Qingdao (2005-2008)

Annual Report of China Marine Environment (2003-2008)

Annual Report of Marine Environment of Shandong Province (2006)

Annual Report of Offshore Water Environment of China.(2001-2008)

Annual Report of Marine Environment of Qingdao.(2004-2005)

Published references and data

Results from related research projects

Personal communication

Table 3 shows monitoring parameters that will be referred in the HAB case study

Table 3 Monitoring parameters referred in the HAB case study

	Monitoring parameter	Survey type
HAB	- HAB species (dominant/causative spp.) - Cell density - Bloom area	Post-HAB survey
Water quality	- Water temp. - Salinity - DO	Post-HAB Survey
Others	- Water quality Transparency, Nutrients - Meteorology Weather, Wind, direction/speed	Regular HAB monitoring survey

4. Status of HAB events

The target sea area, Jiaozhou Bay and eastern part of Qingdao coastal waters, is one of HABs occurrence areas in North Yellow Sea. Therefore this chapter will emphasize records in the past ten or more years of HAB status in Qingdao coastal waters as the epitome of North Yellow Sea.

4.1. Status of HAB events in the past decades or so

As summerized in table 4, 40 HAB events have been recorded by SOA in North Yellow Sea since 1990, in which, 27 HAB events occurred in Qingdao coastal waters. Therefore, Qingdao coastal waters is the typical “target sea area” to study the HAB events occurred in North Yellow Sea.

Table 4 Situation of HAB events in North Yellow Sea, China

Event No.	Location	Approximate Area suffered(Km^2)	Duration (DD/MM/YY)	Causative species	Max Cell Density(Cells/L)	Damage	
						Fishery damage (Chinese Yuan)	Human Health
1	Jiaozhou Bay, Qingdao	2	26/06/1990	*Mesodinium rubrum*	/	/	
2	Changhai country, Liaoning	/	1990	/		2.5 million due to death scallops	
3	Jiaozhou Bay, Qingdao	/	04/1992	/	/	/	
4	East Qingdao	/	12/05/1992	/	/	/	
5	Jiaozhou Bay, Qingdao	/	08/1992	/	/	/	
6	Dalian Bay, Dalian	40	11/08/1993	/	/	/	
7	Jiaozhou Bay, Qingdao	/	08/1997	*Skeletonema costatum*	/	/	
8	Jiaozhou Bay, Qingdao	10	03/07/1998-08/07/1998	*Skeletonema costatum*	$4.5x10^6$	/	
9	Jiaozhou Bay, Qingdao		08/06/1999-15/06/1999	*Eucampia zodiacus*	$2.3x10^6$	/	
10	Jiaozhou Bay, Qingdao	26	23/07/1999-24/07/1999	*Skeletonema costatum*, *Eucampia zodiacus*	/	/	
11	Fushan Bay, Qingdao	60	26/07/1999	*Mesodinium rubrum*	/	/	
12	Dalian Bay, Dalian		07/1999	*Exuviaella marina*	$8.1x10^6$	/	DSP detected
13	Dalian Bay, Dalian	100	17/07/1999-21/07/1999	*Noctiluca scintinllans*	/	/	
14	Penglai, Shandong	680	17/07/1999	*Noctiluca scintinllans*	/	/	
15	Shidao, Shandong	160	06/08/1999	/	/	/	
16	Zhuanghe, Liaoning	827	02/08/2000	/	/	15 million	
17	Jiaozhou Bay, Qingdao	92	20/07/2000-23/07/2000	*Noctiluca scintinllans*	/	/	
18	Dandong, Liaoning		24/05/2001	/	/	/	
19	Fushan Bay, Qingdao		04/04/2001	*Noctiluca scintinllands*	/	/	

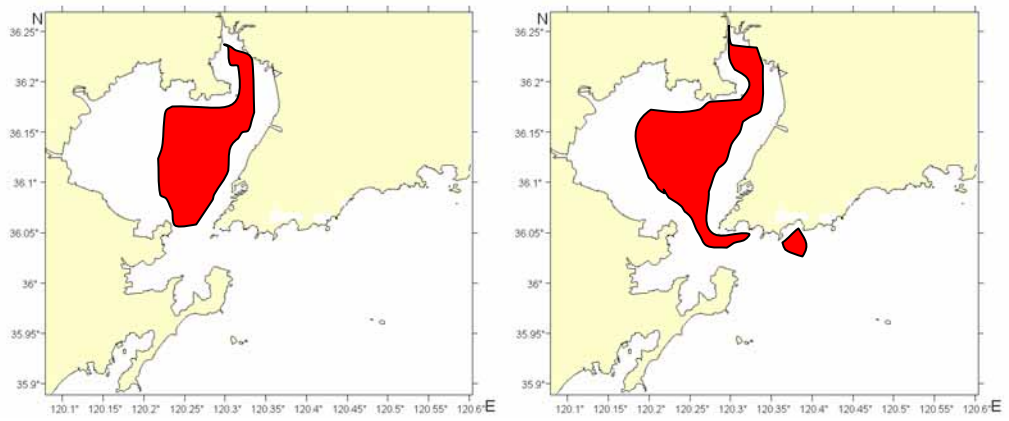
20	Jiaozhou Bay, Qingdao	5	11/06/2001-12/06/2001	*Noctiluca scintillands*	/	/	
21	Jiaozhou Bay, Qingdao	9.8	07/07/2001-13/07/2001	*Mesodinium rubrum*	/	/	
22	The coast of Jiangsu	1000	20/06/2001	*Skeletonema costatum*	/	/	
23	Yalujiang Estuary, North Yellow Sea	110	24/08/2001-14/09/2001	*Eucampia zoodiacus, Chaetocerus socialis*	/	/	
24	Fushan Bay, Qingdao	60	28/06/2002-02/07/2002	*Mesodinium rubrum*	/	/	
25	Dandong Waters, Liaoning	30	06/2003	/	/	/	
26	Jiaozhou Bay,Qingdao	200	07/2003	*Coscinodiscus asteromphalus*	/	/	
27	East Qingdao	450	04/07/2003-10/07/2003	*Mesodinium rubrum*	/	/	
28	Jiaozhou Bay, Qingdao		02/2004	*Guinaradia delicatula*	/	/	
29	Jiaozhou Bay, Qingdao	70	09/02/2004-28/02/2004	*Rhizosolenia delicatula*	/	/	
30	Jiaozhou Bay, Qingdao	70	22/03/2004-25/03/2004	*Thalassiosira nordenskÖldii*	/	/	
31	Jiaozhou Bay, Qingdao		07/2004	*Coscinodiscus asteromphalus*	/	/	
32	Fushan Bay, Qingdao	50	10/08/2004	*Mesodinium rubrum*	/	/	
33	Jinshatan, Dalian		06/09/2004	*Chattonella antiqua*	/	/	
34	Jinshatan, Dalian		25/09/2004	*Alexandrium catenella*	/	/	
35	Lingshan Bay, Qingdao	80	12/06/2005-17/06/2005	*Heterosigma akashiwo*	$9.54x10^7$	/	
36	Shazikou Bay, Qingdao	70	07/06/2007-10/06/2007	*Heterosigma akashiwo*	$5.31x10^7$	/	
37	East Qingdao	15	20/08/2007-23/08/2007	*Skeletonema costatum*	$1.11x10^7$	/	
38	Shazikou Bay, Qingdao	8	25/09/2007-28/09/2007	*Gonyaulax spinifera*	/	/	
39	Jiaozhou Bay, Qingdao	5	28/06/2008-29/06/2008	*Heterocapsa sp.*	$3.28x10^6$	/	
40	South Qingdao	86	07/08/2008-08/08/2008	*Chattonella antiqua*	$5.2x10^5$	/	

From year 1997-2008, a total of 22 HAB events were recorded in Qingdao coastal waters. Most frequently observed HAB species were *Skeletonema costatum* and *Mesodinium rubrum*, which constituted almost half of all recorded events.

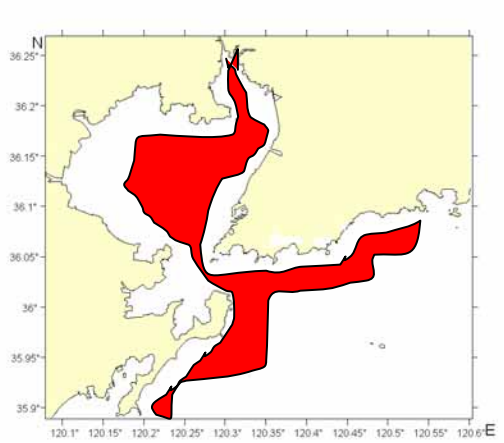
Table 5 Yearly Trends of HAB enents

HAB event	HAB area	Causative species	Squares
08/1997	Centre of Jiaozhou Bay	*Skeletonema costatum*	small
03/07/1998-08/07/1998	North-east part of Jiaozhou Bay	*Skeletonema costatum*	10km^2
06/1999	North-east part of Jiaozhou Bay	*Eucampia zodiacus*	Small
23/07/1999-24/07/1999	Jiaozhou Bay	*Skeletonema costatum, Eucampia zodiacus*	26km^2
26/07/1999	Fushan Bay	*Mesodinium rubrum*	60km^2
20/07/2000	Centre of Jiaozhou Bay	*Noctiluca scintinllans*	92km^2
04/04/2001	Fushan Bay	*Noctiluca scintinllands*	small
11/06/2001-12/06/2001	Jiaozhou Bay	*Noctiluca scintillands*	5km^2
07/07/2001-13/07/2001	Mouth of Jiaozhou Bay	*Mesodinium rubrum*	9.8km^2
28/06/2002-02/07/2002	Fushan Bay	*Mesodinium rubrum*	60km^2
04/07/2003-10/07/2003	Tuandao Bay、Huiquan Bay、Taipingjiao Bay、Fushan Bay	*Mesodinium rubrum*	450km^2
02/2004	North-east part of Jiaozhou Bay	*Guinaradia delicatula*	Small
09/02/2004-28/02/2004	East part of Jiaozhou Bay	*Rhizosolenia delicatula*	70km^2
22/03/2004-25/03/2004	North-east part of Jiaozhou Bay	*Thalassiosira nordenskÖldii*	70km^2
07/2004	North part of Jiaozhou Bay	*Coscinodiscus asteromphalus*	Small
10/08/2004	Fushan Bay	*Mesodinium rubrum*	50km^2
12/06/2005-17/06/2005	Lingshan Bay	*Heterosigma akashiwo*	80km^2
07/06/2007-10/06/2007	Shazikou Bay	*Heterosigma akashiwo*	70km^2
20/08/2007-23/08/2007	Eastern costal waters	*Skeletonema costatum*	15 km^2
25/09/2007-28/09/2007	Shazikou Bay	*Gonyaulax spinifera*	8km^2
28/06/2008-29/06/2008	Jiaozhou Bay	*Heterocapsa sp.*	5 km^2
07/08/2008-08/08/2008	Southern costal waters	*Chattonella antiqua*	86 km^2

According to table 5, the HAB area expanded obviously in recent years. Jiaozhou bay was the major HABs area of Qingdao coastal waters during the whole 90s, however, Fushan bay became to be another main HAB area from early years of 21st century. Moreover, the HAB area expanded much seriously in recent 4-5years, which was from the western part (Lingshan Bay) to the eastern part (Shazikou Bay) of Qingdao coastal waters as shown in figure 3.



Main HAB area during 90s　　Main HAB area during early 21st centery



Main HAB area in recent years

Figure 3 HABs area expansion of Qingdao coastal waters

4.2. Yearly trends of HAB events

During 12 years between 1997 and 2008, a total of 22 HAB events were recorded. The frequency of HAB events has increased significantly in recent years than before.

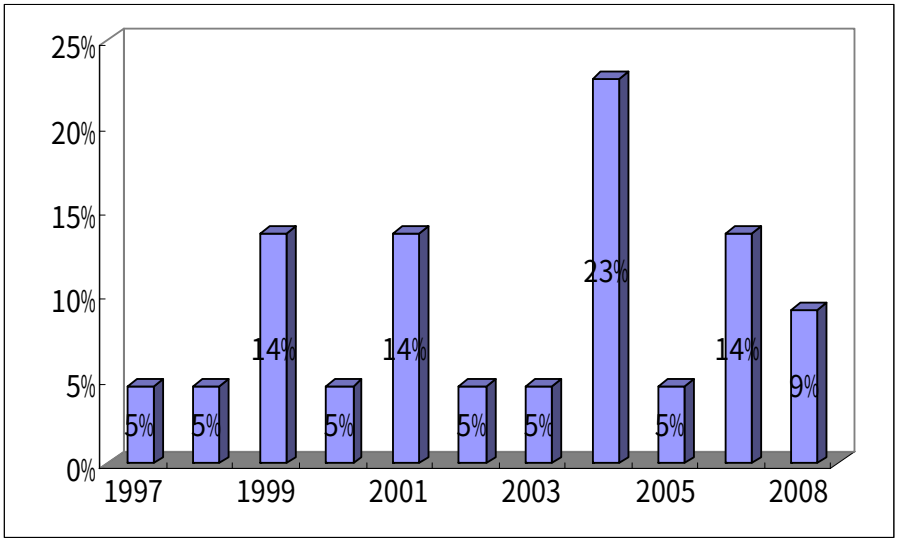


Figure 4 Yearly trend of HAB events in the target area

According to figure 4, over half of HAB events recorded occurred in recent 5 years, especially in 2004, in which 5 HAB events have occurred—accounted for about 23% of total.

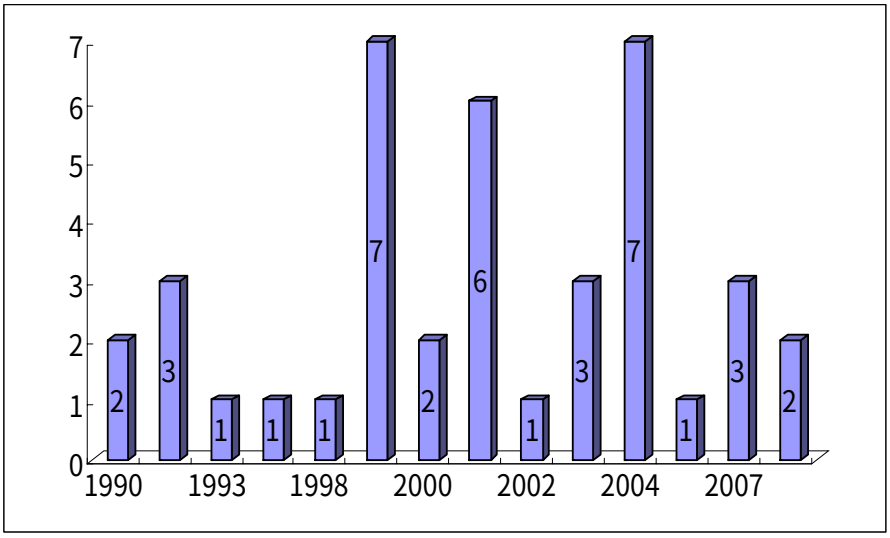


Figure 5 Yearly trend of HAB events in North Yellow Sea

For the North Yellow Sea region, the same conclusion could be obtained that the frequency of HAB events has increased significantly in recent years than before. Figure 5 shows the yearly trend of HAB events in North Yellow Sea from 1990 to 2008. There're 40 events recorded and 13 among them occurred in recent 5 years. The trend of HABs occurrence seemed smooth and annual average was just 2 from 1990 to 1998. HABs events dramatically increased from 1999 and then appeared a peak value of HABs occurrence in every 2 or 3 years.

4.3. Yearly trends of HAB season

According to the HAB data from 1997-2008, over 80% of HAB events occurred during June-September (Figure 6). June、July and August are considered to be most frequent months of HAB occurrence. Of these 4 months, June and July are considered to be dominant durations of HAB events, with over half of total HAB events occurring in the 2 months.

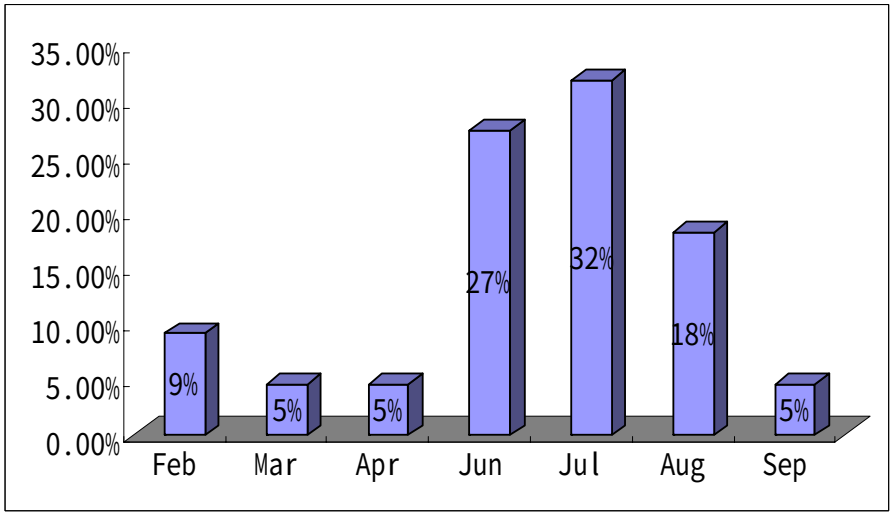


Figure 6 Seasonal trend of HAB events in the target area

The record of North Yellow Sea indicates the same situation. Only less than 20% HAB events occurred during the year except for June to September, with not even a single HAB event recorded during the months of October to December and January. July is also believed to be the dominant durations of HAB events in the whole year, followed by June and August (Figure 7).

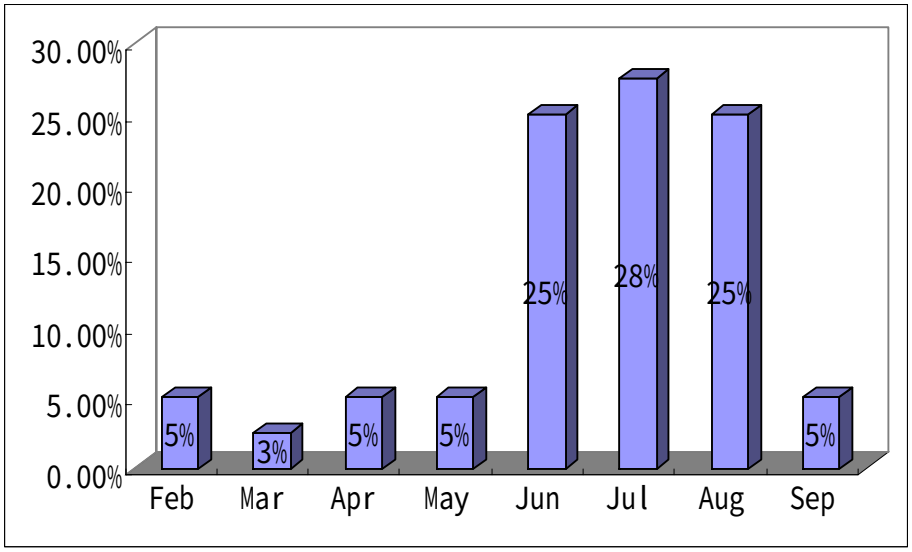


Figure 7 Seasonal trend of HAB events in the yellow sea

4.4. Yearly trends of causative species

Table 6 shows HAB species recorded in the Qingdao coastal area during 1997-2008 and their frequency of occurrences. A total of 12 HAB species were recorded and most frequent species were *Skeletonema costatum* and *Mesodinium rubrum*. In general, most species belonged to diatoms.

Table 6 Yearly trends of causative species

Specie name	1997	1998	1999	2000	2001	2002	2003	2004	2005	2007	2008	total
Diatom	1	1	3					4		1		10
Skeletonema costatum	1	1	1							1		4
Eucampia zodiacus			2									2
Guinaradia delicatula								1				1
Rhizosolenia delicatula								1				1
Thalassiosira nordenskÖldii								1				1
Coscinodiscus asteromphalus								1				1
Dinoflagellate				1	2					1		4
Noctiluca scintinllans				1	2							3
Gonyaulax spinifera										1		1
Zooplankton			1		1	1	1	1				5
Mesodinium rubrum			1		1	1	1	1				5
Raphidophyceae									1	1	2	4
Heterosigma akashiwo									1	1		2
Heterocapsa sp.											1	1
Chattonella antiqua											1	1

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

5.1. Number of HAB events

Records of HAB events in 2005-2008 are chosen to illustrate the status of recent HAB events. A total of 6 HAB events in the target sea area were recorded in the period (table 7).

Table 7 HAB events occurred in recent years

HAB event	HAB area	Causative species	Maximum Density(cells/L)
12/06/2005-17/06/2005	Lingshan Bay	*Heterosigma akashiwo*	$9.54x10^7$
07/06/2007-10/06/2007	Shazikou Bay	*Heterosigma akashiwo*	$5.31x10^7$
20/08/2007-23/08/2007	Eastern costal waters	*Skeletonema costatum*	$1.11x10^7$
25/09/2007-28/09/2007	Shazikou Bay	*Gonyaulax spinifera*	/
28/06/2008-29/06/2008	Jiaozhou Bay	*Heterocapsa sp.*	$3.28x10^6$
07/08/2008-08/08/2008	Southern costal waters	*Chattonella antiqua*	$5.2x10^5$

Besides the HAB events, there were 4 records of high biomass, in which the maximum density of causative species closed to the warning levels (table 8). Most frequently observed HAB species were *Heterosigma akashiwo* and *Skeletonema costatum* respectively.

Table 8 High biomass events closed to warning levels in recent years

Event	Area	Causative species	Maximum Density(cells/L)	Warning Standards(cells/L)
12/06/2005	Fushan Bay	*Skeletonema costatum*	$3.6x10^5$	$5x10^6$
05/07/2006-09/07/2006	Fushan Bay	*Mesodinium rubrum*	$5.6x10^4$	$5x10^5$
23/08/2006-24/08/2006	Fushan Bay	*Chaetoceros socialis*	$2.6x10^5$	10^6
08/08/2008-09/08/2008	Western area of Fushan Bay	*Thalassiosira sp.*	$4.22x10^6$	10^7

5.2. Period of HAB events

As shown in the figure 8, June and August are most possible periods of HAB events and high biomass events that approach the warning level in the target sea area. Summer and early autumn are most possible seasons.

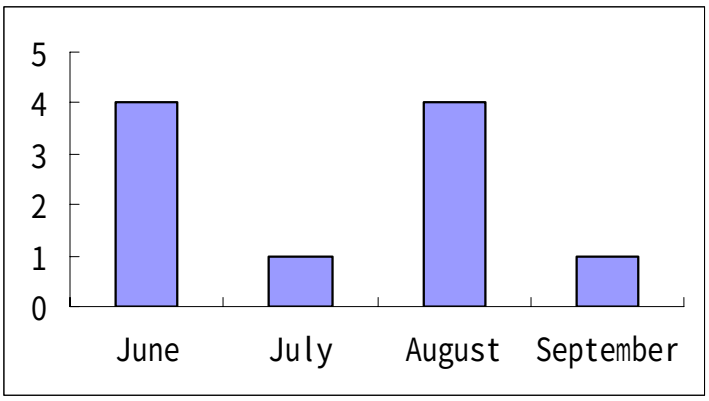


Figure 8 Period of HAB events

5.3. Duration of HAB events

Table 9 shows the number of HAB events and high biomass events by duration (number of days) in 2005-2008. A total of 10 events occurred during the period, in which 1 event lasted for 5 days, 1 event was 4 days, 3 events were 3 days, 3events were 2 days and 2 events were just 1 day. The longest HAB duration was 5 days by *Heterosigma akashiwo*, which occurred in Lingshan Bay with an area of 80 km^2 during June. Therefore, we could say that HABs events in the target area are smaller and the duration of each event is shorter.

Table 9 Durations of HAB events in recent years

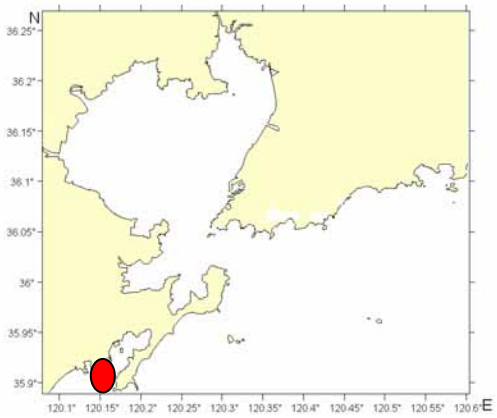
HAB event	Duration	Causative species
12/06/2005-17/06/2005	5 days	*Heterosigma akashiwo*
12/06/2005	1 day	*Skeletonema costatum*
05/07/2006-09/07/2006	4 days	*Mesodinium rubrum*
23/08/2006-24/08/2006	1 day	*Chaetoceros socialis*
07/06/2007-10/06/2007	3 days	*Heterosigma akashiwo*
20/08/2007-23/08/2007	3 days	*Skeletonema costatum*
25/09/2007-28/09/2007	3 days	*Gonyaulax spinifera*
28/06/2008-29/06/2008	2days	*Heterocapsa sp.*
07/08/2008-08/08/2008	2days	*Chattonella antiqua*
08/08/2008-09/08/2008	2days	*Thalassiosira sp.*

5.4. Location of HAB events

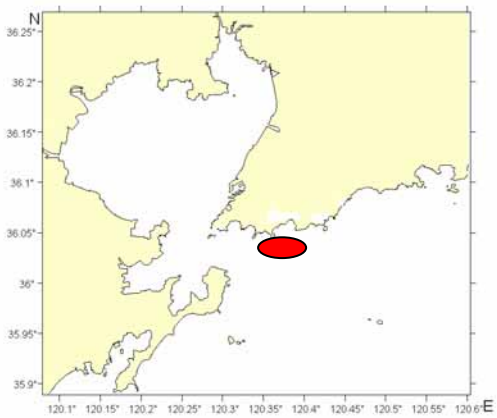
The location of above HABs and high biomass events in the target sea areas is shown as table 10 and figure 9. Events often occured in Fushan bay and Shazikou bay during the period. Eutrophication and weak water exchange in the two bays are considered to be major reasons. Both two bays are small semi-enclosed gulves and water exchange is weak. There is a major living waste-water discharge near Fushan bay, which often results in the eutrophication of nearby waters. Shazikou bay is surrounded by many culture fishery places and fishery ports, and as a result, the water there is believed to suffer from serious eutrophication.

Table 10 Locations of HAB events in recent years

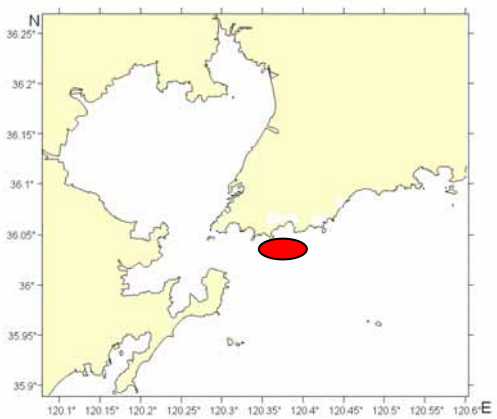
HAB event	HAB area	Causative species
12/06/2005-17/06/2005	Lingshan Bay	*Heterosigma akashiwo*
12/06/2005	Fushan Bay	*Skeletonema costatum*
05/07/2006-09/07/2006	Fushan Bay	*Mesodinium rubrum*
23/08/2006-24/08/2006	Fushan Bay	*Chaetoceros socialis*
07/06/2007-10/06/2007	Shazikou Bay	*Heterosigma akashiwo*
20/08/2007-23/08/2007	East costal waters	*Skeletonema costatum*
25/09/2007-28/09/2007	Shazikou Bay	*Gonyaulax spinifera*
28/06/2008-29/06/2008	Jiaozhou Bay	*Heterocapsa sp.*
07/08/2008-08/08/2008	Southern costal waters	*Chattonella antiqua*
08/08/2008-09/08/2008	Western area of Fushan Bay	*Thalassiosira sp.*



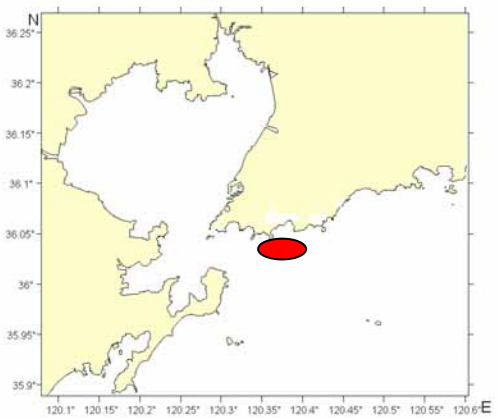
June,2005



June,2005



July,2006



August,2006

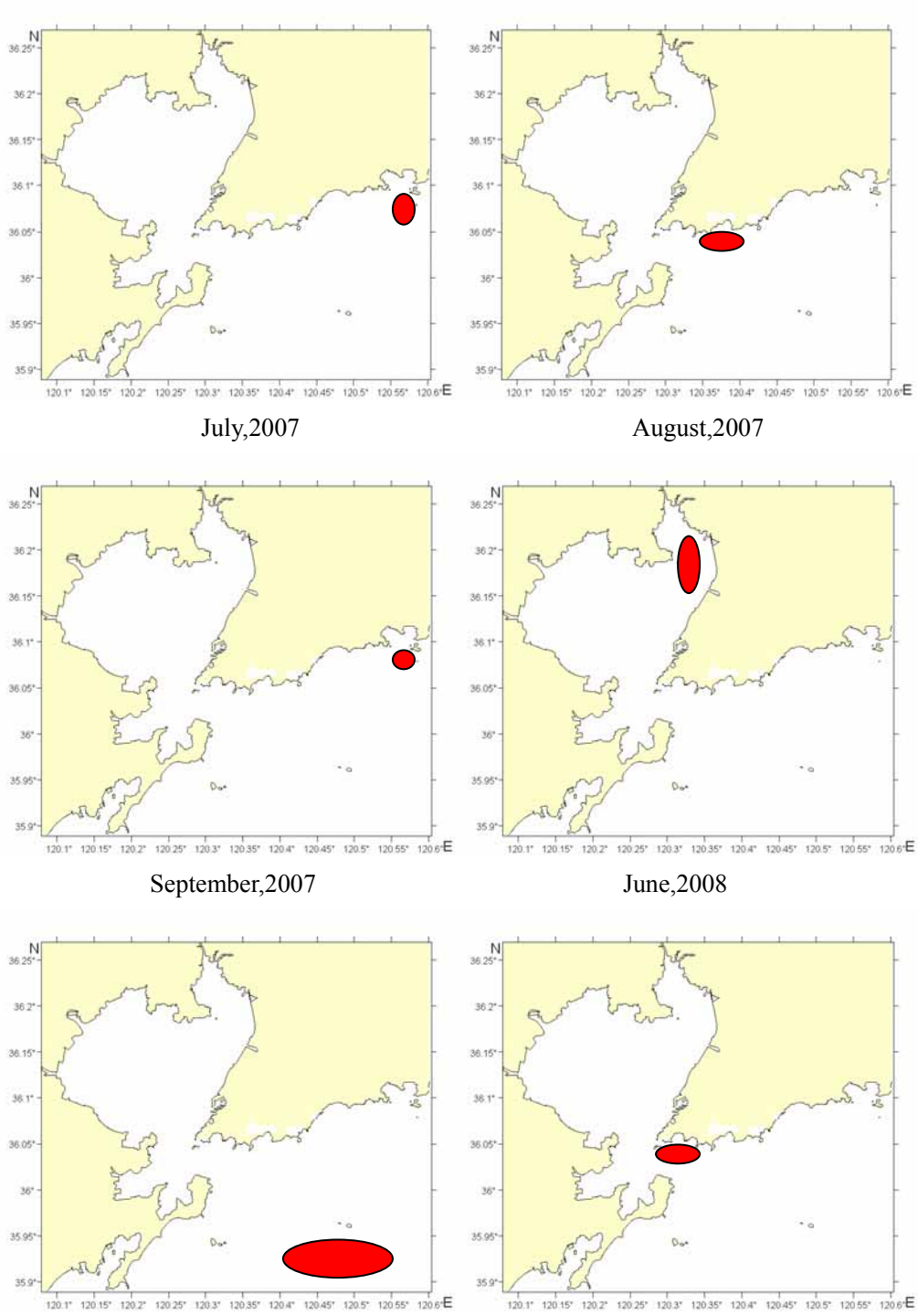


Figure 9 Locations of HAB events in recent years

Comparison with historical records, Jiaozhou Bay is believed to be another source of HAB events, especially in the northeastern part because of its weak seawater exchange ability and great pollution. However, more attentions were attracted to the eastern part of Qingdao coastal waters from 2005 to 2008 due to where is 2008 Olympic sailing competition waters. Therefore, more data on the HABs from 2005 to 2008 in the eastern part of Qingdao coastal waters were available. As a result, this chapter will discuss the status of recent HAB events and results of

environmental monitoring mostly based on the data on the eastern part of Qingdao coastal waters.

5.5. Causative species

As shown in the table 11, there were 8 causative species of HAB events and most frequent species were *Heterosigma akashiwo* and *Skeletonema costatum*, 2 times respectively.

Table 11 Causative species of HAB events in recent years

HAB event	Causative species	Causative genus
12/06/2005-17/06/2005	*Heterosigma akashiwo*	Raphidophyceae
12/06/2005	*Skeletonema costatum*	Diatom
05/07/2006-09/07/2006	*Mesodinium rubrum*	Micro-zooplankton
23/08/2006-24/08/2006	*Chaetoceros socialis*	Diatom
07/06/2007-10/06/2007	*Heterosigma akashiwo*	Raphidophyceae
20/08/2007-23/08/2007	*Skeletonema costatum*	Diatom
25/09/2007-28/09/2007	*Gonyaulax spinifera*	Dinoflagellate
28/06/2008-29/06/2008	*Heterocapsa sp.*	Raphidophyceae
07/08/2008-08/08/2008	*Chattonella antiqua*	Raphidophyceae
08/08/2008-09/08/2008	*Thalassiosira sp.*	Diatom

According to monitoring results during 2004~2006 conducted by NCSEMC, diatoms are dominant species of the community in the target sea area. 86 species of diatoms were tested out of 108 species in total, and the percentage was 79.63%. *Skeletonema costatum* was the most common specie of diatoms. Besides *Skeletonema costatum*, *Mesodinium rubrum* and *Heterosigma akashiwo* are the other important species that occurred during HAB events and have caused HABs to occur more and more frequently in the target area.

5.6. Maximum density of each HAB event

Table 12 shows the maximum density of each HAB event that occurred in the target sea area during 2005-2008. Within these HAB events, the maximum density was recorded in June 2005 at Lingshan Bay, reaching $9.54x10^7$ cells/L.

Table12 Maximum density of each HAB event in recent years

HAB event	Causative species	Maximum density(cells/L)
12/06/2005-17/06/2005	*Heterosigma akashiwo*	$9.54x10^7$
07/06/2007-10/06/2007	*Heterosigma akashiwo*	$5.31x10^7$
20/08/2007-23/08/2007	*Skeletonema costatum*	$1.11x10^7$
25/09/2007-28/09/2007	*Gonyaulax spinifera*	/
28/06/2008-29/06/2008	*Heterocapsa sp.*	$3.28x10^6$
07/08/2008-08/08/2008	*Chattonella antiqua*	$5.2x10^5$

5.7. Status of HAB induced fishery damage

There were not official statistic data on fishery damage caused by HAB events in the target sea area. According to the estimate from the fishermen, the HAB event occurred in Lingshan Bay 2005 caused great fishery damage. This HAB event was caused by *Heterosigma akashiwo* and resulted in serious damage of culture and capture fishery. During this event, the total catch decreased significantly and most yellow croaker captured were dead totally.

5.8. Status of target species

According to the recent 12-year record of HAB events in table 5, major causative species are *Heterosigma akashiwo*, *Mesodinium rubrum* and *Skeletonema costatum*, with diatoms and zooplankton especially played a significant role. In some cases, although maximum density did not reach HABs level, density of *Mesodinium rubrum* and *Skeletonema costatum* frequently maintained at a high level. Therefore, the target species in Qingdao coastal waters should be diatoms, *Heterosigma akashiwo* and micro-zooplankton, especially *Mesodinium rubrum* and *Skeletonema costatum* (Table 13). A decreasing trend of the size of causative species is also present, and as such, some small micro-diatoms and micro-zooplankton are taking the place of macro-planktons such as *Noctiluca scintinllans*.

Table 13 status of target species of HAB and high biomass event in recent years

Specie name	2005	2006	2007	2008	total
Diatom					4
Skeletonema costatum	1		1		2
Chaetoceros socialis		1			1
Thalassiosira sp.				1	1
Dinoflagellate					1
Gonyaulax spinifera			1		1
Zooplankton					1
Mesodinium rubrum		1			1
Raphidophyceae					4
Heterosigma akashiwo	1		1		2
Heterocapsa sp.				1	1
Chattonella antiqua				1	1

5.9. Environmental monitoring results during HAB events in August of 2007

In August of 2007, there was a HAB event occurred in the target sea area as showed in Fig10. Environmental parameters were monitored during the HAB event of *Skeletonema costatum* occurred on 20-23 of August in 2007. Major monitored parameters included temperature、salinity、pH、DO as shown in Table 14. During the HAB event, water temperature ranged in22.68-25.32°C, salinity ranged in 27.928 - 29.599, pH ranged in 6.97- 8.2 and DO ranged in 6.66 - 7.81. As an example, the nutrients change in station 20 during the event on 20-23 of August in 2007 is showed in Table 15.

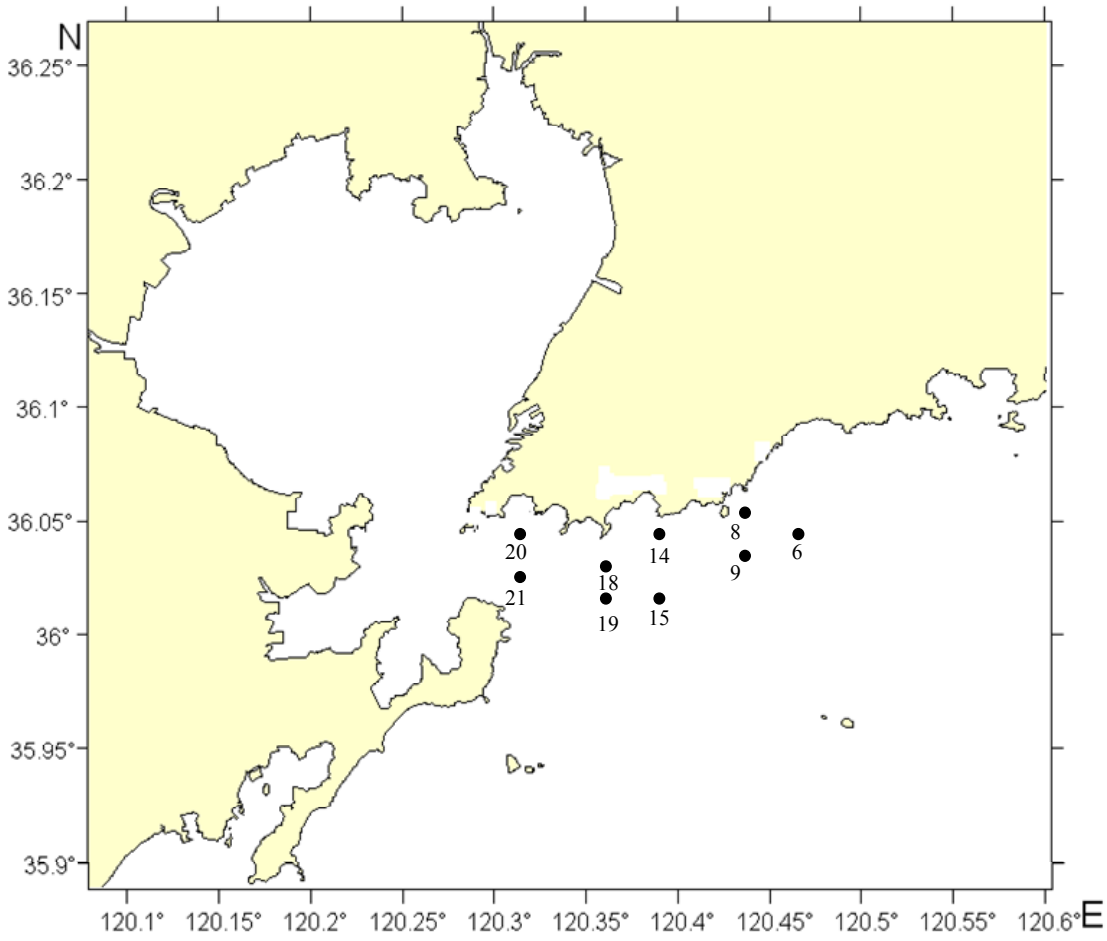


Figure 10 The location of monitoring stations during the HAB event in August of 2007

Table 14 Environmental monitoring results during HAB event in August of 2007

Station	Temperature(ºC)	Salinity	pH	DO(mg/L)
6	22.7~25.1	29.141~29.599	6.97~8.05	6.66~7.42
8	22.7~25.2	28.528~29.495	7.93~8.09	6.90~7.46
9	23.0~25.2	29.032~29.461	7.96~8.14	6.99~7.49
14	23.6~25.1	29.012~29.298	7.93~8.20	6.91~7.57
15	23.5~25.2	29.039~29.336	7.94~8.19	7.04~7.68
18	24.1~25.3	28.197~29.271	8.00~8.16	7.15~7.68
19	23.9~25.1	28.48~29.215	7.99~8.19	7.17~7.81
20	24.2~25.3	27.928~28.691	7.97~8.16	7.22~7.73
21	24.2~25.3	28.439~28.627	7.98~8.15	7.20~7.71

Table 15 Environmental monitoring results in station 20 during the HAB event

Date	Temperature(ºC)	Salinity	pH	DO(mg/L)
20th	24.9	28.310	8.13	7.22
21st	24.2	28.691	8.16	7.30
22nd	24.3	28.593	8.01	7.73
23rd	25.3	27.928	7.97	7.30

Because there was a continuous rainstorm before the HAB event, salinity was lower than the normal level and water temperature was also lower than the multi-year mean level. *Skeletonema costatum* is a specie that can grow in a wide range of salinity. As a result, the *Skeletonema costatum* became the dominant specie during this HAB event.

5.10. Major nutrients status during the period of HAB event in August of 2007

Table 16 shows value ranges of major nutrients during the *Skeletonema costatum* HAB event occurred on 20-23 of August in 2007. Monitored major nutrients included nitrate, nitrite, ammonia, phosphate and silicate. As an example, the nutrients change in station 20 during the event on 20-23 of August in 2007 is showed in Table 17

Table 16 Major nutrient status during *Skeletonema costatum* HAB event **in August of 2007**

Station	SiO3-Si (μg/L)	PO4-P (μg/L)	NO2-N (μg/L)	NO3-N (μg/L)	NH4-N (μg/L)
6	338~470	2.25~6.3	31.5~38.9	71~198	17.6~76.4
8	242~430	1.35~3.6	29.3~41.4	84.6~261	23.2~200
9	308~448	0.9~3.6	27.1~32.3	83.6~171	13.5~82.1
14	290~308	0.9~4.95	26.5~29.2	94~132	24.1~52.9
15	282~378	1.35~5.4	26.1~31.7	56.4~138	23.8~69.9
18	253~326	2.25~4.95	30.5~44.3	122~265	32.7~59.6
19	242~326	2.25~4.5	25.2~35.9	57.4~185	16.7~59.9
20	271~326	1.8~5.4	31.5~38.5	174~222	33.6~52.6
21	245~319	2.25~4.05	33.4~45.3	110~277	6.4~52.9

Table 17 The nutrient changes in station 20 during the HAB event

Date	DO(mg/L)	SiO3-Si (μg/L)	PO4-P (μg/L)	NO2-N (μg/L)	NO3-N (μg/L)	NH4-N (μg/L)
20th	7.22	326	5.4	38.5	222	52.6
21st	7.30	297	4.5	34.7	200	33.6
22nd	7.73	301	3.15	31.5	174	46.8
23rd	7.30	271	1.8	35.1	198	37.3

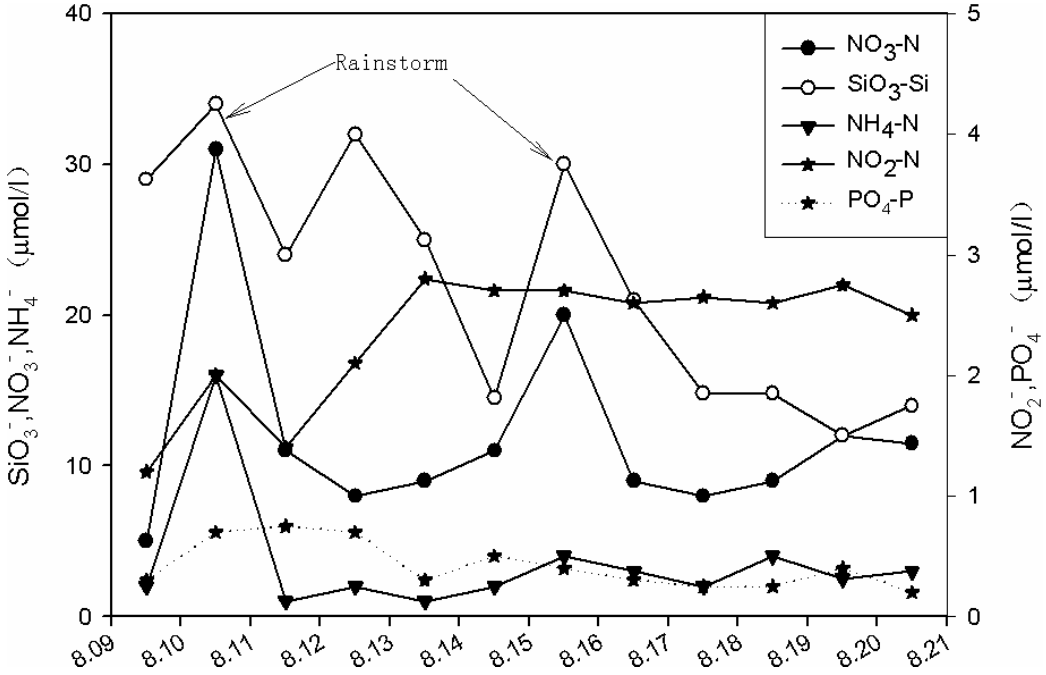


Figure 11 Nutrient changes in August of 2007

According to monitoring results by NCSEMC, there were several times of rainfall in Qingdao before the HABs event (Fig.11), especially on 10th ~11th of August the rainfall was over 240mm. The rainfall input terrestrial nutrients into the target sea area. As a result, the concentration of silicate increased over 10 times, along with significant improvements in concentrations of other nutrients. As shown in figure 7, concentrations of both silicate、nitrate and ammonium were over 30μmol/L, and the concentration of phosphate was over 0.6μmol/L. Therefore, sufficient nutrients and suitable environmental conditions resulted in the HABs event that lasted for 4 days.

5.11. Meteorological observation parameters

The meteorological data were recorded in table 18, 19 during the *Skeletonema costatum* HAB event in 2007. Major parameters included temperature、air pressure、wind speed、wind direction and so on.

Table 18 Meteorological observation parameters during HAB event

Station	Temperature (ºC)	Air pressure (hpa)	Wind speed(m/s)	Wind direction(º)				Weather condition
				20th	21th	22th	23th	
6	25.2~26.8	1000.4~1008.1	0~5.3	C	164	34	94	Sunny
8	25.2~26.8	1000.4~1008.1	0~5	C	144	34	94	Sunny
9	25.3~26.9	1000.4~1008.1	0~5.7	C	124	24	84	Sunny
14	25.5~26.9	1000.4~1008.1	0~5.7	C	144	34	84	Sunny
15	25.5~27.0	1000.4~1008.1	0~5.4	C	104	34	94	Sunny
18	25.9~26.8	1000.3~1008.1	1.5~5.7	164	134	24	84	Sunny
19	25.8~26.8	1000.3~1008.1	1.3~5.5	174	134	44	84	Sunny
20	26.2~26.9	1000.3~1008.1	1.9~4.2	184	124	34	94	Sunny
21	26.1~26.9	1000.3~1008.1	1.7~4.6	194	124	24	94	Sunny

Table 19 Meteorological observation parameters in station 20 during the HAB event

Date	Temperature (ºC)	Air pressure (hpa)	Wind speed(m/s)	Wind direction(º)	Weather condition
20th	26.6	1008.1	1.9	184	Sunny
21st	26.6	1006.9	3.5	124	Sunny
22nd	26.9	1007.8	3.9	34	Sunny
23rd	26.2	1000.3	4.2	94	Sunny

As shown in the table above, during the HAB event, the weather maintained sunny with no rain, which was favorable for plankton growth because of strong photosynthesis. The wind was mild, less than 5m/s in most cases, and in some spots only static wind existed. Slow wind speed is favorable for phytoplankton growth, without being disturbed by strong waves. In summary, the meteorological condition was also fit for *skeletonema costatum* blooming.

6. Conclusion

The target sea area in the report, Jiaozhou Bay and eastern part of Qingdao coastal waters, are some of the HAB occurrence areas in North Yellow Sea. The scale of HAB events increased significantly from less than 10km^2 in early 1990s to 50~70 km^2 on average in recent years. The major causative species include diatoms—mostly *Skeletonema costatum*, as well as zooplankton—mostly *Mesodinium rubrum* and also *Heterosigma akashiwo* in recent years. Duration HAB events, the maximum density of HAB organisms reached 9.34x10^{7}cells/L. Eutrophication is one of important reasons of HAB events in the target sea area. The concentration of nutrients in recent years has been present at a much higher level as compared to the early 1990s. Moreover the meteorological conditions in summer and early autumn are suitable for the growth of HAB organisms, especially after nutrient input caused by rainfall, with most HABs events occuring during this period.

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