Report of HAB Case Studies on Coastal Waters of Qingdao and Dalian in China

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Contents

1. Introduction

1.1. Objective

The objective of conducting the HAB case study in coastal areas of Qingdao and Dalian 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 cause 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

In case of Qindao, target area covers east coastal waters 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 . Meanwhile, Dalian coastal water is also focused as a target area in this report, location of this area is from 38º43'~40º10'N and 120º58'~123º31'E. Locations of target areas in this report are proposed as followed together (fig1).

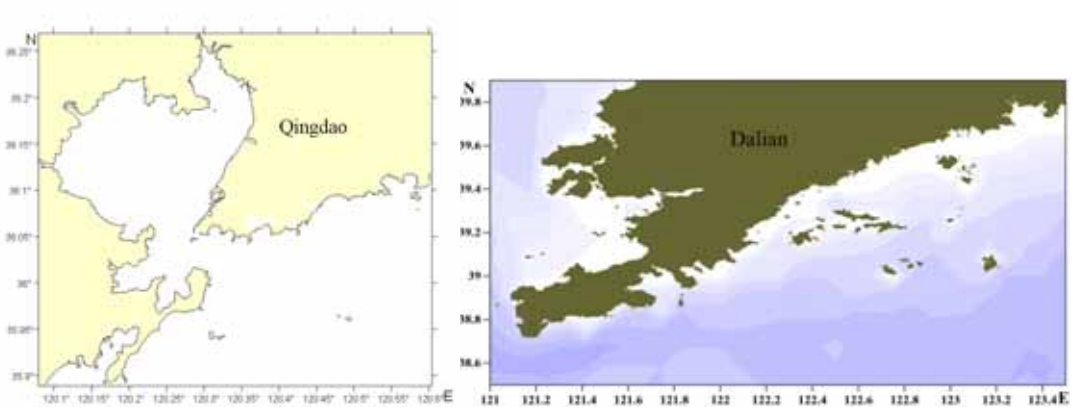


Figure 1 Proposed target sea area for the case study in China

1.3.2. Environmental/geographical characteristics

Qingdao target waters is surrounded by continents 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 northern temperate zone, the target 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 Qingdao target waters 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 Qingdao target waters. 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.

Meanwhile, Dalian coastal waters locates opposite with Shandong Peninsula, facing North Yellow Sea in southeast and Bohai Sea in Northwest, consisting Dalian Bay surroundings, Zhuanghe waters and South coastal waters of Dalian. Total area of this area would be more than 29001.4km^2, with a coastal line as long as 1906 km which represent 73% total coastal length of Liaoning Province. Average depth of Dalian coastal water is 18m.

Major rivers discharging directly into Qingdao target waters include Biliu, Fuzhou, Zhuanghe, Yingna, Dasha, Shizui, Liguancun, Dengsha rivers and etc. With a number of 152 rivers in total, most of them are seasonal, have peak runoff in summer and minimum discharge in winter.

Dalian is also a littoral city with a population of approximately 6,130,000 and a population density of about 464 people/ 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 Qingdao case study.

Similarly, National Marine Environmental Monitoring Centre (NMEMC) executed routine HAB monitoring framwork in Zhangzi Island coastal waters since 2003, either, aiming to provide water quality and HAB related information for cultural fishery in such area. With this purpose, NMEMC issued “Environmental condition information for fishery culture in HAB monitoring area of Zhangzi Island coastal waters” regularly. That’s also a necessary data source reported in Dalian case study.

Besides, many research programs on HABs are conducted in Jiaozhou Bay because it is a typical bay in North China sea. For the same reason, several studies on Dalian coastal waters are also conducted. Related data on HAB events are also used in this report.

2.2. Warning standards against HAB events

In order to prevent damage from HAB events, monitoring organizations in target areas have established HAB warning standards for major causative species in both Qingdao and Dalian 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 emergency strategies, such as spraying modified clay, moving fish cage, etc..

Table 1 HAB warning standards of dominant causative species

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
Chattonella marina	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 and Dalian coastal waters are basically non-toxin plankton and zooplankton, therefore, in this case study, the following 7 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	
Chaetoceros affinis	Yes	
Chattonella marina	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.

Meanwhile, National Marine Environmental Monitoring Centre (NMEMC) conducts HAB monitoring since 2003 in Zhangzi Island coastal waters to protect culture fishery in this area. Annual monitoring framework is from May to September, based on data monitorred, pH index、DO index、Nutrient Quality Index (NQI)、HAB risk index and comprehensive risk index of environment are proposed after comprehensive assessments.

The boundaries and locations of the monitoring stations are presented on Figure 2.

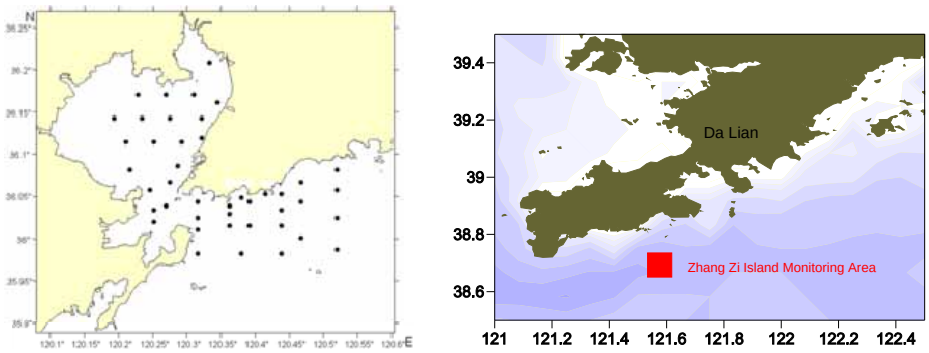


Figure 2 . Monitoring framework in target areas of Qingdao and Dalian

3.2. Monitoring parameters

In Qingdao coastal waters, 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 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.

In case of Dalian coastal waters, monitoring parameters would be reflected in form of cultural suitability of target waters which is decided by several different indices. At the mean time, explanations and criterion of each index would be introduced in this report, either.

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 (2005-2009)
Annual Report of China Marine Environment (2003-2009)
Annual Report of Marine Environment of Shandong Province (2006)
Annual Report of Marine Environment of Liaoning Province (2005-2009)
Annual Report of Offshore Water Environment of China.(2001-2009)
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

As target areas, Qingdao coastal waters, including Jiaozhou Bay as well as east coastal waters and Dalian waters, are both HAB occurrence areas in North Yellow Sea. Therefore this chapter will emphasize records in the past ten or more years of HAB status in such areas as the epitome of North Yellow Sea.

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

As summerized in table 4, 50 HAB events have been recorded by SOA in North Yellow Sea since 1990, in which, 29 HAB events occurred in Qingdao coastal waters and 13 HAB events occurred in Dalian coastal waters. Therefore, Qingdao and Dalian coastal waters are typical “target areas” to study 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 waters, Dalian	/	1990	/		20 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 waters, Dalian	827	02/08/2000	/	/	120 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 marina*	/	/	
34	Jinshatan, Dalian		25/09/2004	*Alexandrium catenella*	/	/	

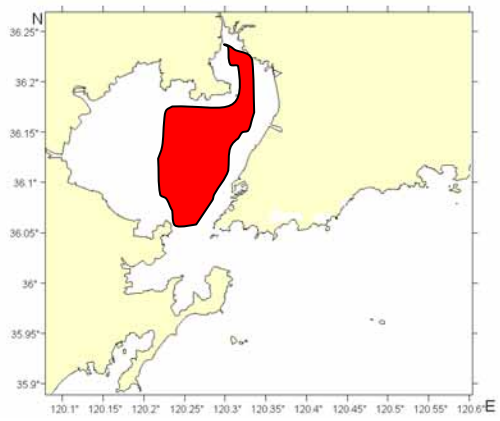
35	Lingshan Bay, Qingdao	80	12/06/2005-17/06/2005	*Heterosigma akashiwo*	$9.54x10^7$	/	
36	Caotun Waters, Dalian	small	25/06/05	*Noctiluca scintinllands*			
37	Zhuanghe Waters, Dalian	16	26/08/05~03/09/05	*Chaetoceros affinis*			
38	Zhuanghe Waters, Dalian	16	29/08/05~02/09/05	*Chaetoceros affinis*			
39	Shazikou Bay, Qingdao	70	07/06/2007-10/06/2007	*Heterosigma akashiwo*	$5.31x10^7$	/	
40	East Qingdao	15	20/08/2007-23/08/2007	*Skeletonema costatum*	$1.11x10^7$	/	
41	Zhuanghe Waters, Dalian	20	08/05/06	*Noctiluca scintinllands*			
42	Fushan Bay, Qingdao	5	08/2006	*Mesodinium rubrum*			
43	Shazikou Bay, Qingdao	8	25/09/2007-28/09/2007	*Gonyaulax spinifera*	/	/	
44	Dalian Bay, Dalian	108	27/02/08	*Thalassiosira nordenskioldi, Skeletonema costatum*			
45	Jiaozhou Bay, Qingdao	5	28/06/2008-29/06/2008	*Heterocapsa sp.,*	$3.28x10^6$	/	
46	Xinghai Bay, Dalian	5	08/08	*Chattonella marina*			
47	South Qingdao	86	07/08/2008-08/08/2008	*Chattonella antiqua*	$5.2x10^5$	/	
48	Fushan Bay, Qingdao	10	26/08/2008	*Noctiluca scintinllands*	$3.2\ x10^5$		
49	The coast of Rizhao	580	07/05/2009-12/05/2009	*Noctiluca scintinllands*	/	/	
50	The coast of Haiyang	550	26/05/2009-01/06/2009	*Noctiluca scintinllands*	/	/	

From year 1997-2008, a total of 24 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.

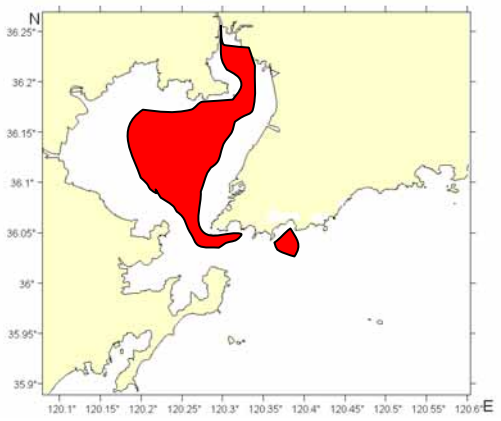
Table 5 Yearly trends of HAB enents in Qingdao

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,*	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、	*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*	70km^2
07/2004	North part of Jiaozhou Bay	*Coscinodiscus*	Small
10/08/2004	Fushan Bay	*Mesodinium rubrum*	50km^2
12/06/2005-17/06/2005	Lingshan Bay	*Heterosigma akashiwo*	80km^2
08/2006	Fushan Bay	*Mesodinium rubrum*	5 km^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
26/08/2008	Fushan Bay	*Noctiluca scintinllands*	10 km^2

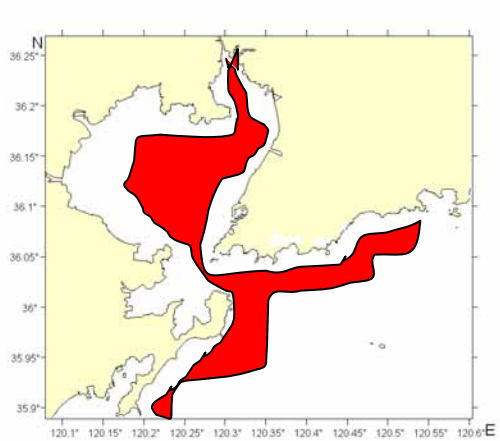
According to table 5, HAB affected areas in Qingdao expanded obviously in recent years. Jiaozhou Bay was the major HAB affected area of Qingdao coastal waters during whole 90s, however, Fushan bay became to be another main HAB affected area from early years of 21st century. Moreover, HAB affected areas expanded much seriously in recent 5-6 years, which were 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

Meanwhile, There are 13 HAB recorded events occurred in Dalian waters since 1990. During these cases, dominant causative species *Noctiluca scintinllans, Chaetoceros affinis* and *Chattonella marina,* caused over half of all recorded events.

Table 6 Yearly trends of HAB events in Dalian

HAB event	HAB area	Causative species	Squares
1990	Changhai waters, Dalian	/	/
11/08/1993	Dalian Bay, Dalian	/	40 km^2
07/1999	Dalian Bay, Dalian	*Exuviaella marina*	/
17/07/1999-21/07/1999	Dalian Bay, Dalian	*Noctiluca scintinllans*	100km^2
02/08/2000	Zhuanghe waters, Dalian	/	827km^2
06/09/2004	Jinshatan, Dalian	*Chattonella marina*	/
25/09/2004	Jinshatan, Dalian	*Alexandrium catenella*	/
25/06/05	Caotun Waters, Dalian	*Noctiluca scintinllands*	/
26/08/05~03/09/05	Zhuanghe Waters, Dalian	*Chaetoceros affinis*	16 km^2

29/08/05~02/09/05	Zhuanghe Waters, Dalian	*Chaetoceros affinis*	16 km^2
08/05/06	Zhuanghe Waters, Dalian	*Noctiluca scintinllands*	20 km^2
27/02/08	Dalian Bay, Dalian	*Thalassiosira nordenskioldi, Skeletonema costatum*	108km^2
08/08	Xinghai Bay, Dalian	*Chattonella marina*	5km^2

As shown in table 6, Dalian bay and its surrounding were main HAB affected areas before 2000. However, Zhuanghe waters became to another essential HAB affected area recently. Therefore, Dalian bay and its surrounding as well as Zhuanghe waters are believed to be typical HAB affected areas in Dalian coastal waters even though it's hard to declare expansion of HAB affected areas precisely due to insufficient records in Dalian target waters rather than in Qingdao target waters.

4.2. Yearly trends of HAB events

During 12 years between 1997 and 2008, a total of 24 HAB events were recorded in Qingdao coastal waters. Meanwhile.13 HAB events were recorded since 1990 in Dalian coastal waters. The frequency of HAB events has increased significantly in recent years than before.

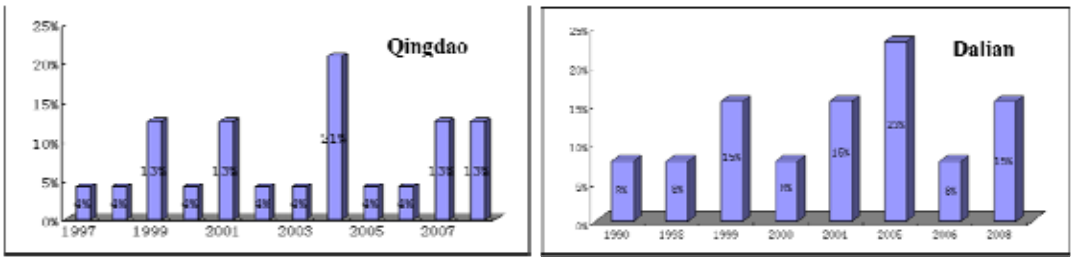


Figure 4 Yearly trend of HAB events in target areas

According to figure 4, over half of HAB recorded events occurred in recent 6 years in Qingdao coastal waters,, especially in 2004, in which 5 HAB events have occurred—accounted for about 21% of total. The same trend also exists in Dalian coastal waters, over 60% HAB recorded events occurred in recent 6 years. Especially 2005, 3 events occurred in this year, with a 23% frequency of total events. .

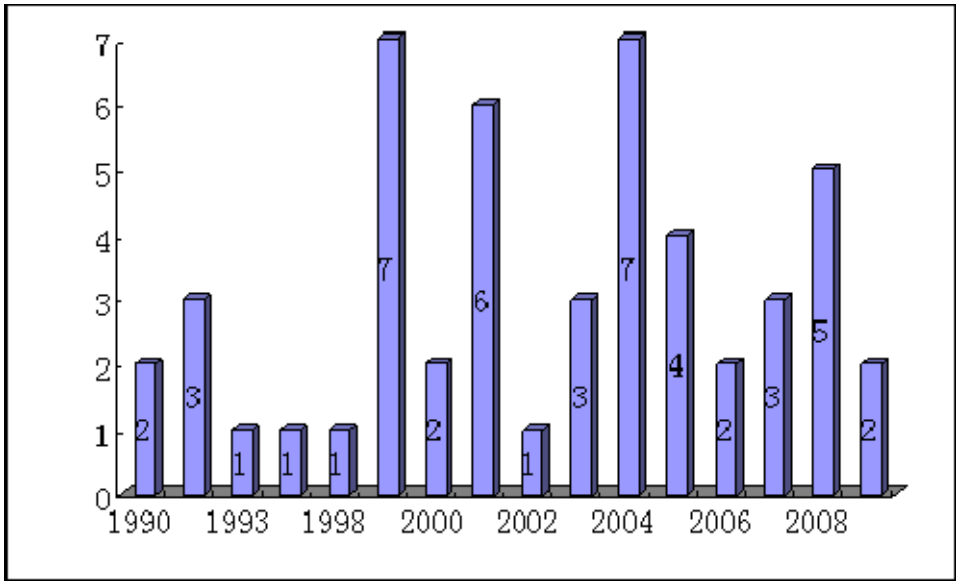


Figure 5 Yearly trend of HAB events in North Yellow Sea

For North Yellow Sea region, the same conclusion could be noticed 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 2009. There're 50 events recorded and 23 among them occurred in recent 6 years. The trend of HAB occurrences seemed smooth and annual average was just 2 from 1990 to 1998. However, Number of events dramatically increased from 1999 and then appeared a peak value, representing high frequency of HAB occurrence in every 2 or 3 years.

4.3. Yearly trends of HAB season

According to HAB records in Qingdao coastal waters from 1997-2008, almost 80% of events occurred during June-August (Figure 6). As a result, June、July and August are considered to be most frequent months of HAB occurrence in Qingdao. At the same time, based on total HAB records in Dalian coastal waters, approximate 75% of HAB events occurred inJuly, August and September. Therefore, these 3 months are considered to be most frequent months of HAB occurrences in Dalian.

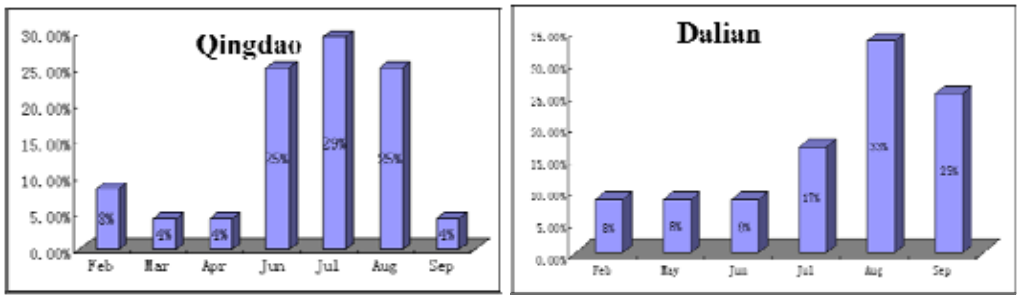


Figure 6 Seasonal trend of HAB events in target areas

Records of North Yellow Sea indicate the same situation. Only 20% HAB events occurred during the whole year besides June to September, with not even a single HAB event recorded during the months from October to December and January. August is believed to be the dominant duration of HAB events in the whole year, followed by July and June (Figure 7).

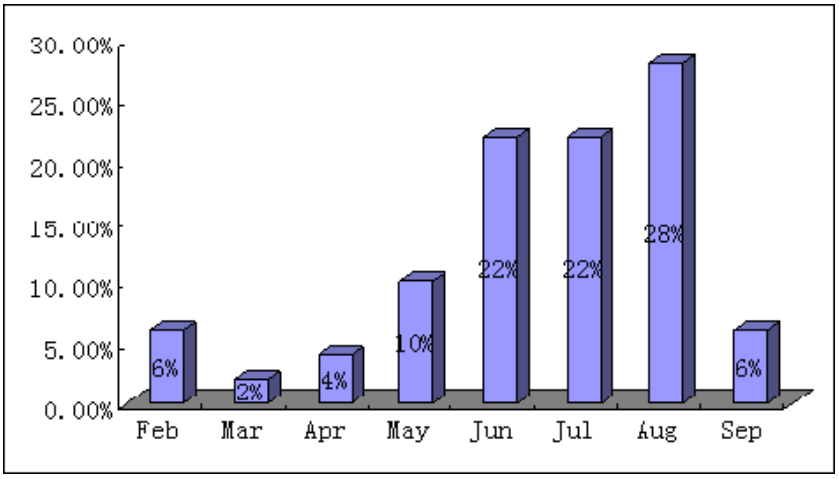


Figure 7 Seasonal trend of HAB events in North Yellow Sea

4.4. Yearly trends of causative species

Table 7 shows HAB species recorded in Dalian coastal waters since 1999 and their frequency of occurrences. A total of 7 HAB species were recorded and the most frequent species was *Noctiluca scintinllans,* followed by *Chattonella marina* and *Chaetoceros affinis*. In general, dinoflagellate as well as diatom species take equivalently crucial parts of all causative species.

Table 7 Yearly trends of causative species in Dalian coastal waters

Specie name	1999	2004	2005	2006	2008	total
Diatom			2		2	4
Skeletonema costatum					1	1
Chaetoceros affinis			2			2
Thalassiosira nordenskÖldii					1	1
Dinoflagellate	2	1	1	1		5
Noctiluca scintinllans	1		1	1		3
Exuviaella marina	1					1
Alexandrium catenella		1				1
Raphidophyceae		1			1	2
Chattonella marina		1			1	2

Table 8 shows HAB species recorded in Qingdao coastal area during 1997-2008 and their frequency of occurrences. A total of 12 HAB species were recorded and most frequent species were *Mesodinium rubrum*、*Noctiluca scintinllans* and *Skeletonema costatum*. Differing from Dalian coastal waters, 40% of causative species in Qingdao coastal waters belongeds to diatoms, in addition, dinoflagellate、zooplankton and raphidophyceae species occupies nearly 20% of total causative species separately.

Table 8 Yearly trends of causative species in Qingdao coastal wasters

Specie name	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	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	1	5
Noctiluca scintinllans				1	2							1	4
Gonyaulax spinifera											1		1
Zooplankton			1		1	1	1	1					6
Mesodinium rubrum			1		1	1	1	1		1			6
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 status of recent HAB events for Qingdao coastal waters. A total of 8 HAB events in target area of Qingdao were recorded in this period (table 9).

Table 9 HAB events occurred recently in Qingdao coastal waters

HAB event	HAB area	Causative species	Maximum Density(cells/L)
12/06/2005-17/06/2005	Lingshan Bay	*Heterosigma akashiwo*	$9.54x10^7$
08/2006	Fushan Bay	*Mesodinium rubrum*	
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*	$5.2x10^5$
26/08/2008	Fushan Bay	*Noctiluca scintinllan*	$3.2\ x10^5$

Besides HAB events, there were also 4 records of high biomass events in Qingdao target waters, in which the maximum density of causative species in each event closed to the warning levels (table 10). Most frequently observed HAB species were *Heterosigma akashiwo* and *Skeletonema costatum* respectively.

Table 10. High biomass events closed to warning levels recently in Qingdao coastal waters

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

In case of Dalian coastal waters, HAB events during 2004 to 2008 are chosen to illustrate recent status of HAB events. During such period, 8 HAB events are recorded (table 11). Among these recent events, most frequently observed HAB species were *Noctiluca scintinllands, Chattonella marina* and *Chaetoceros affinis* respectively.

Table 11 HAB events occurred recently in Dalian coastal waters

HAB event	HAB area	Causative species	Maximum Density(cells/L)
06/09/2004	Jinshatan, Dalian	*Chattonella marina*	/
25/09/2004	Jinshatan, Dalian	*Alexandrium catenella*	/
25/06/05	Caotun Waters, Dalian	*Noctiluca scintinllands*	/
26/08/05~03/09/05	Zhuanghe Waters, Dalian	*Chaetoceros affinis*	/
29/08/05~02/09/05	Zhuanghe Waters, Dalian	*Chaetoceros affinis*	/
08/05/06	Zhuanghe Waters, Dalian	*Noctiluca scintinllands*	/
27/02/08	Dalian Bay, Dalian	*Thalassiosira nordenskioldi, Skeletonema costatum*	/
08/08	Xinghai Bay, Dalian	*Chattonella marina*	/

5.2. Period of HAB events

As shown in the figure 8, August is the most possible occurring period of HAB and high biomass that approach the warning level in Qingdao target waters, followed by June. Summer and early autumn are most possible occurring seasons. In case of Dalian target waters, september is the most possible occurring period of HAB events, followed by August.

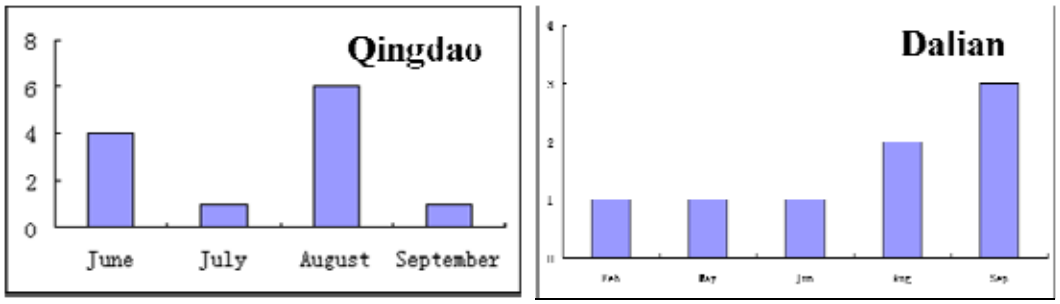


Figure 8 Periods of HAB events

5.3. Duration of HAB events

Table 12 shows status of HAB events and high biomass events in Qingdao coastal waters by duration (number of days) from 2005 to 2008. A total of 12 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 4 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 Qingdao target waters are smaller and the duration of each event is shorter than before.

Table 12 Durations of HAB events recently in Qingdao coastal waters

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*
08/2006	1 day	*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.*
26/08/2008	1 day	*Noctiluca scintinllan*

Table 13 shows status of HAB events in Dalian coastal waters by duration (number of days) from 2004 to 2008. A total of 8 events occurred during this period, most events were as short as 1 day solely, except for 2 events occurred during late august and early september in 2005, with *Chaetoceros affinis* as causative species similarly. As a result, durations of recent HAB events in Dalian coastal waters are short basically.

Table 13 Durations of HAB events recently in Dalian coastal waters

HAB event	Duration	Causative species
06/09/2004	1 day	*Chattonella marina*
25/09/2004	1 day	*Alexandrium catenella*
25/06/05	1 day	*Noctiluca scintinllands*
26/08/05~03/09/05	8 days	*Chaetoceros affinis*
29/08/05~02/09/05	5 days	*Chaetoceros affinis*
08/05/06	1 day	*Noctiluca scintinllands*
27/02/08	1 day	*Thalassiosira nordenskioldi*, *Skeletonema costatum*
08/08	1 day	*Chattonella marina*

5.4. Location of HAB events

Locations of all HAB and high biomass event above in target areas of Qingdao and Dalian are described in table 14, table 15 and respectively marked in figure 9. In Qingdao, events often occur in Fushan bay and Shazikou bay during the period. Eutrophication and weak water exchange in two bays are considered to be major reasons. Both two bays are small semi-enclosed gulves and water exchanges are weak. There is a major living waste-water discharge near Fushan bay, which often results in eutrophication of nearby waters. Shazikou bay is surrounded by many cultural fishery places and fishery ports, as a result, waters there are believed to suffer from serious eutrophication, either. In Dalian, events often occur in Dalian

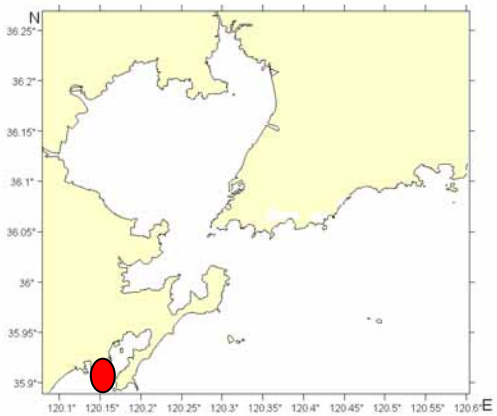
bay as well as its surrounding and Zhuanghe coastal waters during the period. Eutrophication which is caused by cultural fishery is supposed to be the major reason.

Table 14 Locations of HAB events recently in Qingdao coastal waters

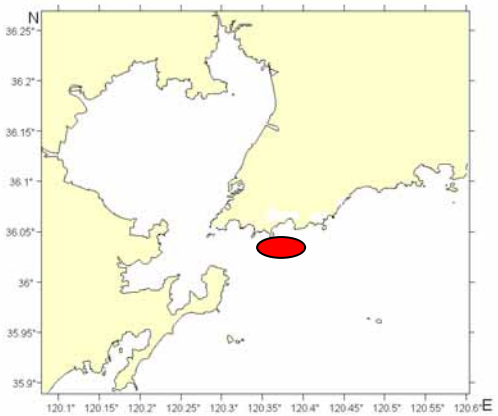
HAB event	HAB area	Causative species
12/06/2005-17/06/2005	Lingshan Bay	*Heterosigma akashiwo*
12/06/2005	Fushan Bay	*Skeletonema costatum*
05/07/2006-09/07/2006	Fushan Bay	*Mesodinium rubrum*
08/2006	Fushan Bay	*Mesodinium rubrum*
23/08/2006-24/08/2006	Fushan Bay	*Chaetoceros socialis*
07/06/2007-10/06/2007	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.*
26/08/2008	Fushan Bay	*Noctiluca scintinllan*

Table 15 Locations of HAB events recently in Dalian coastal waters

HAB event	HAB area	Causative species
06/09/2004	Jinshatan, Dalian	*Chattonella marina*
25/09/2004	Jinshatan, Dalian	*Alexandrium catenella*
25/06/05	Caotun Waters, Dalian	*Noctiluca scintinllands*
26/08/05~03/09/05	Zhuanghe Waters, Dalian	*Chaetoceros affinis*
29/08/05~02/09/05	Zhuanghe Waters, Dalian	*Chaetoceros affinis*
08/05/06	Zhuanghe Waters, Dalian	*Noctiluca scintinllands*
27/02/08	Dalian Bay, Dalian	*Thalassiosira nordenskioldi*, *Skeletonema costatum*
08/08	Xinghai Bay, Dalian	*Chattonella marina*



June, 2005



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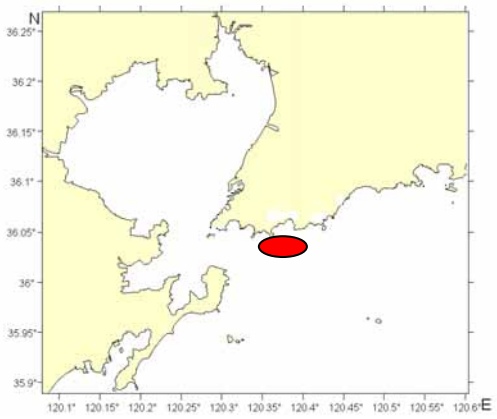

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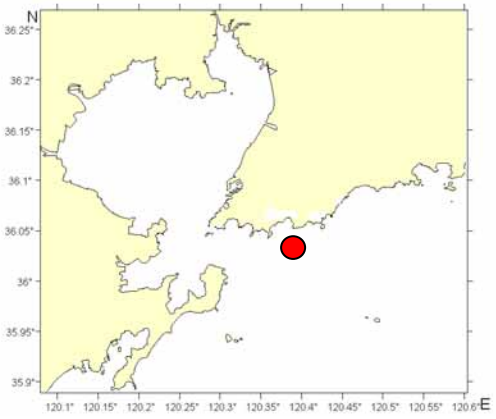

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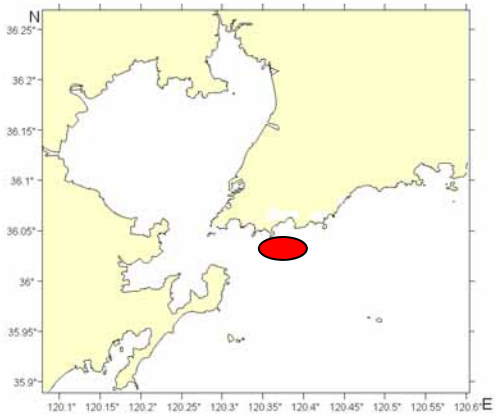

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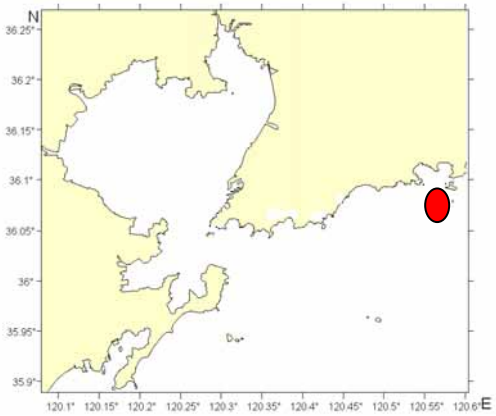

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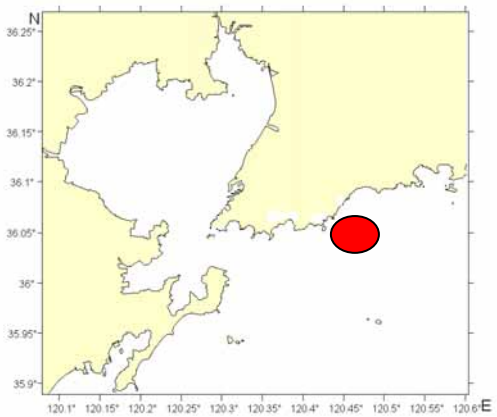

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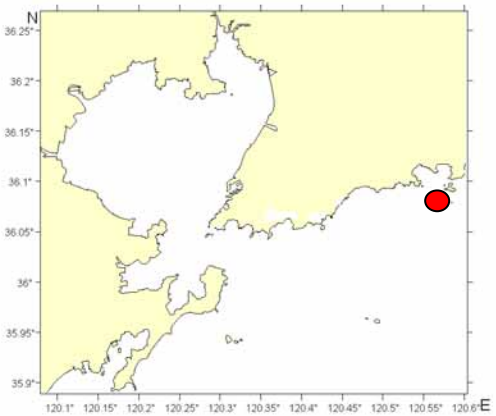
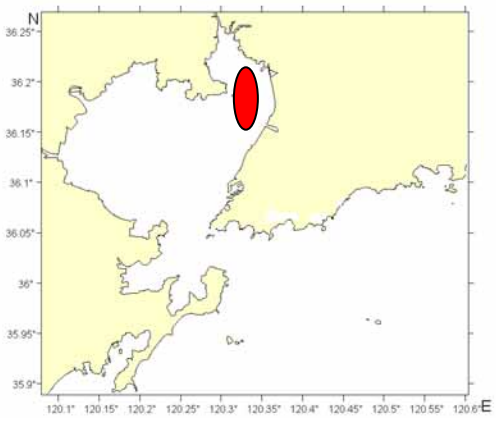
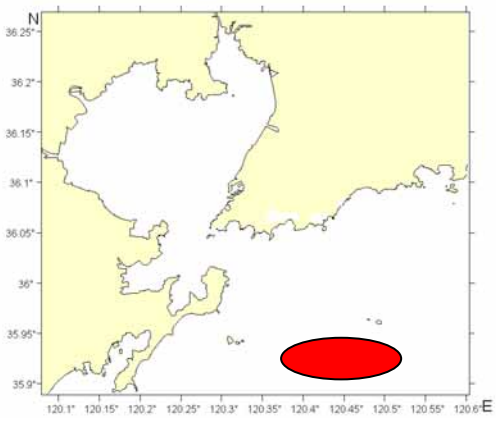


September, 2007



June, 2008



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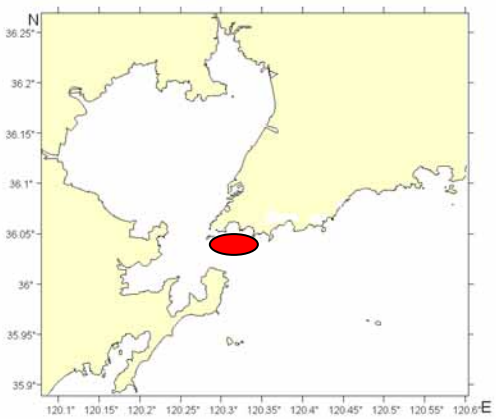

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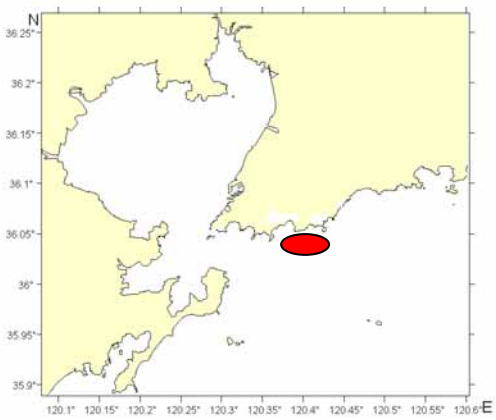

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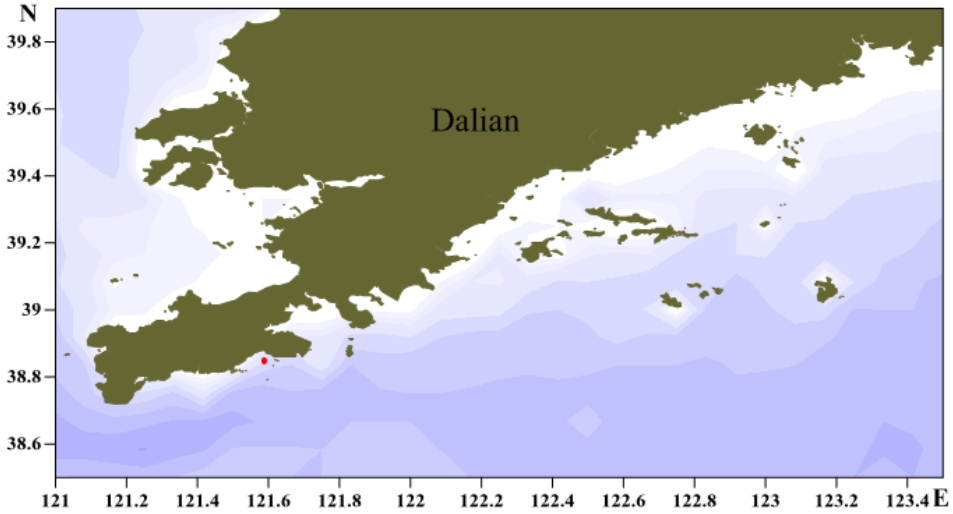
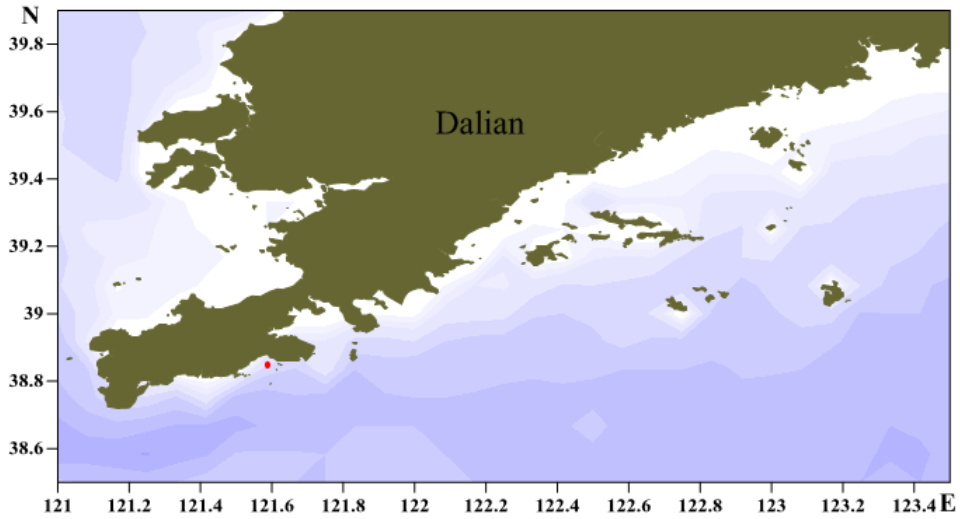


September, 2004



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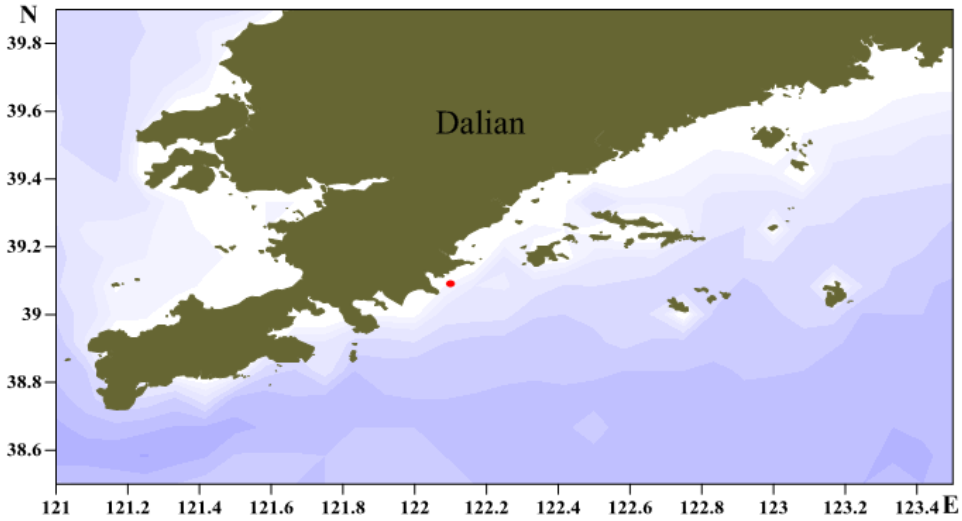
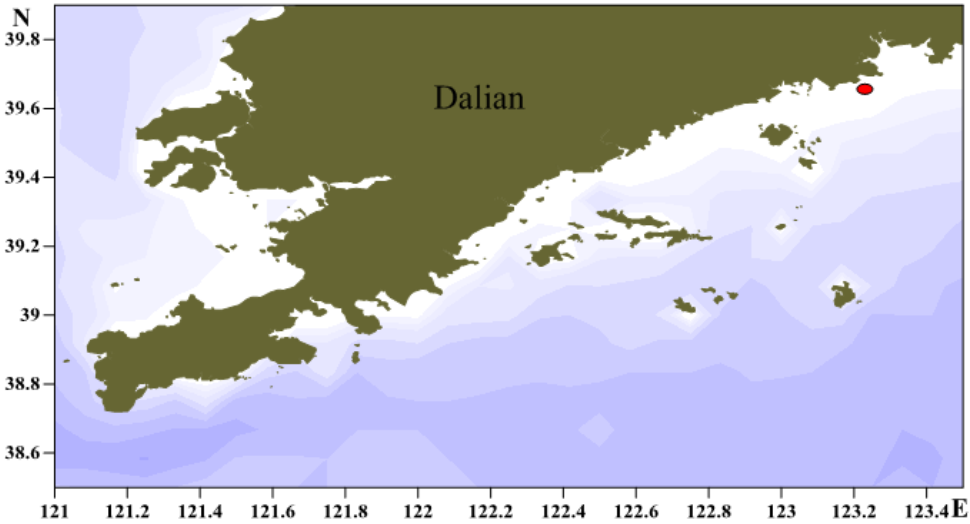


June, 2005



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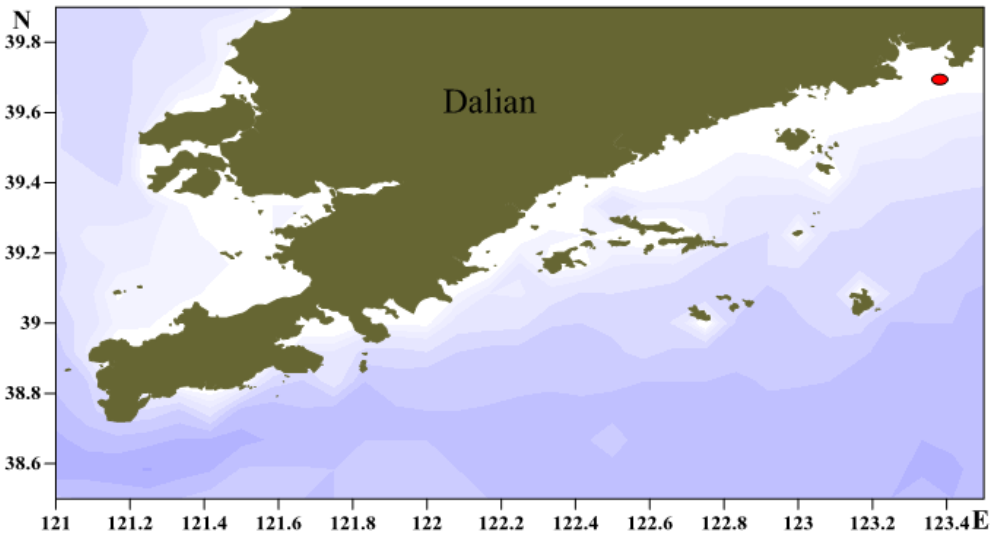

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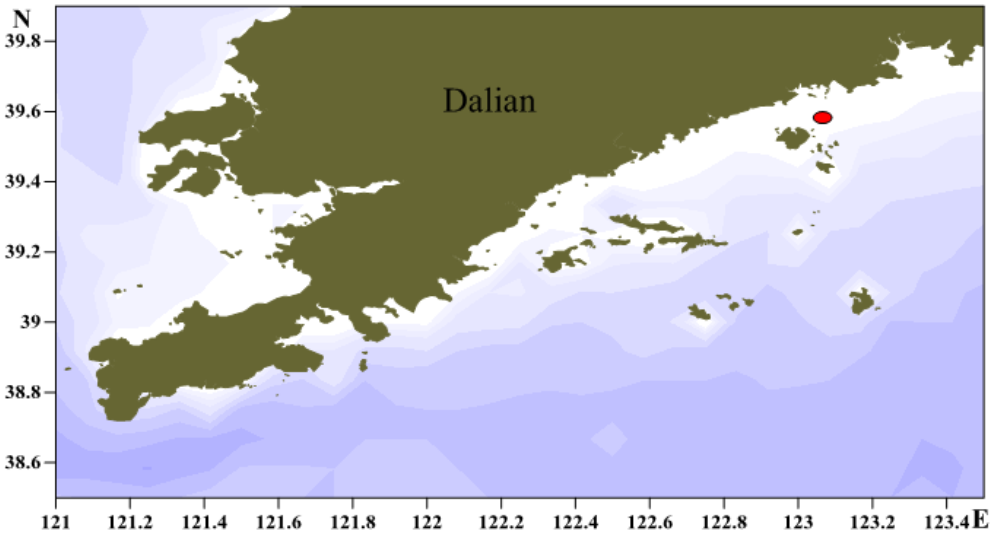
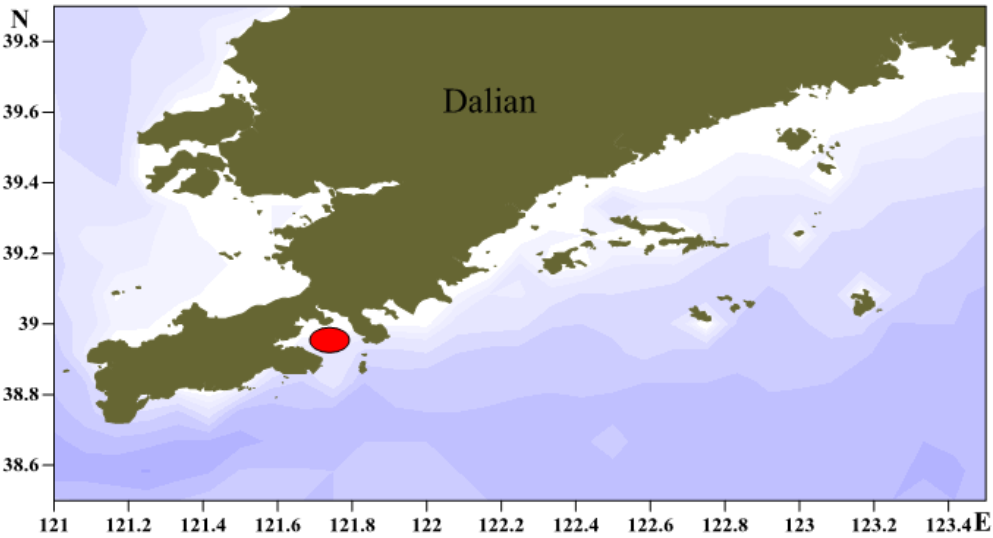
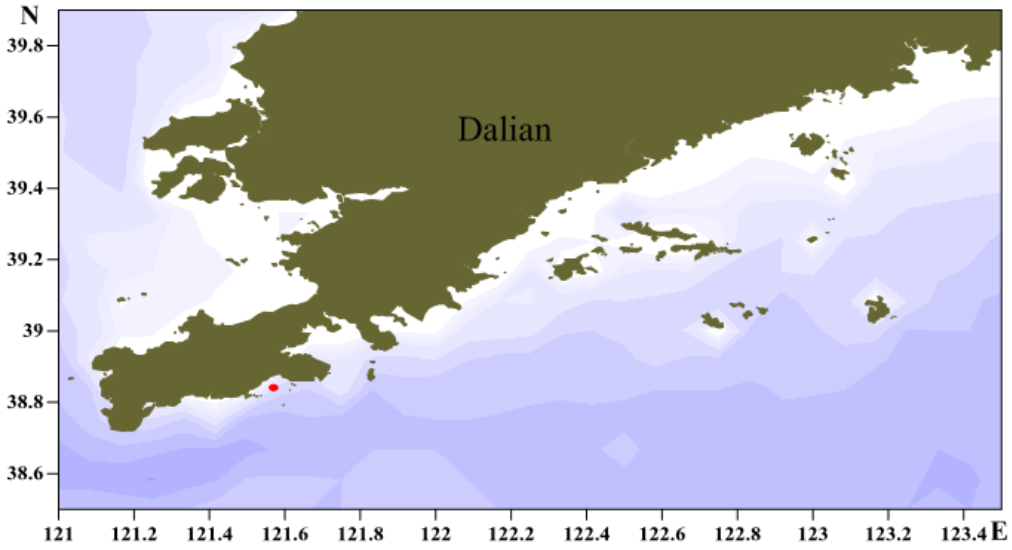


May, 2006



Feb, 2008



August, 2008

Figure 9 Locations of HAB events in recent years

Moreover, comparing with historical records, Jiaozhou Bay is believed to be another source of HAB events in Qingdao, 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 are 2008 Olympic sailing competition waters. Therefore, more data on HAB from 2005 to 2008 in east coastal waters of Qingdao were available than related information on other areas. As a result, this chapter will discuss status of recent HAB events and results of environmental monitoring mostly based on data in east coastal waters of Qingdao.

5.5. Causative species

In case of Qingdao coastal waters, as shown in the table 16, there were 9 causative species of HAB events and most frequent species were *Heterosigma akashiwo*、*Mesodinium rubrum* and *Skeletonema costatum*, 2 times respectively.

Table 16 Causative species of HAB events recently in Qingdao coastal waters

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
08/2006	*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
08/2008	*Noctiluca scintinllan*	Dinoflagellate

According to monitoring results during 2004~2006 conducted by NCSEMC, diatoms are dominant species of communities in Qingdao target waters. 86 species of diatoms were tested out of 108 species in total, and the percentage was 79.63%. *Skeletonema costatum* was the most common species of diatoms. Besides *Skeletonema costatum*, *Mesodinium rubrum* and *Heterosigma akashiwo* are the other 2 important species that occurred during these years.

In case of Dalian coastal waters, as shown in table 17, there were 6 causative species of HAB events and most frequent species were *Noctiluca scintinllands, Chattonella marina* and *Chaetoceros affinis,* 2 times respectively.

Table 17 Causative species of HAB events recently in Dalian coastal waters

HAB event	Causative species	Causative genus
06/09/2004	*Chattonella marina*	Raphidophyceae
25/09/2004	*Alexandrium catenella*	Dinoflagellate
25/06/05	*Noctiluca scintinllands*	Dinoflagellate
26/08/05~03/09/05	*Chaetoceros affinis*	Diatom
29/08/05~02/09/05	*Chaetoceros affinis*	Diatom
08/05/06	*Noctiluca scintinllands*	Dinoflagellate
27/02/08	*Thalassiosira nordenskioldi, Skeletonema costatum*	Diatom
08/08	*Chattonella marina*	Raphidophyceae

5.6. Maximum density of each HAB event

Table 18 shows the maximum density of each HAB event that occurred in Qingdao target waters during 2005-2008. Within these HAB events, the maximum density was recorded in June 2005 at Lingshan Bay, reaching 9.54×10^7 cells/L.

Table18 Maximum density of each HAB event recently in Qingdao coastal waters

HAB event	Causative species	Maximum density(cells/L)
12/06/2005-17/06/2005	*Heterosigma akashiwo*	$9.54x10^7$
08/2006	*Mesodinium rubrum*	/
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*	$5.2x10^5$
26/08/2006	*Noctiluca scintinllan*	$3.2\ x10^5$

There were no recent records on maximum density of HAB events in Dalian coastal waters.

5.7. Status of HAB induced fishery damage

There were not official statistic data on fishery damage caused by HAB events in Qingdao target waters. According to estimations from 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.

Meanwhile, fishery damage would be more intensive in Dalian coastal waters than in Qingdao. It was recorded that a HAB event occurred in Changhai waters on 1990 caused great death of cultural scallops, as a result, economic loss was over 20 million Chinese Yuan. Moreover, a 827 km^2 HAB event occurred in Zhuanghe waters, 2000 also resulted serious fishery damage at an amount of 120 million Chinese Yuan. Provided by such intensive fishery damages in Dalian waters, NMEMC executed HAB monitoring framework since 2003 in Zhangzi Island coastal waters to protect cultural fishery in such area.

5.8. Status of target species

According to recent 12-year records of Qingdao HAB events in table 5, major causative species are *Heterosigma akashiwo*, *Mesodinium rubrum* and *Skeletonema costatum*, with diatoms and zooplankton especially playing significant roles. In some cases, although maximum density did not reach HAB occurrence level, biomass of *Mesodinium rubrum* and *Skeletonema costatum* were also as high as close to warning standards. Therefore, target species in Qingdao coastal waters should be micro-phytoplankton, *Skeletonema costatum, Heterosigma akashiwo* and micro-zooplankton, especially *Mesodinium rubrum* (Table 19). A decreasing trend of causative species' size is also present, and as such reason, some small micro-diatoms and micro-zooplankton are taking place of macro-planktons such as *Noctiluca scintinllans*.

Table 19 Target species of HAB and high biomass events recently in Qingdao coastal waters

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

Based on data of Dalian HAB events since 1990 in table 6, major causative species are *Noctiluca scintinllands, Chattonella marina* and *Chaetoceros affinis.*Differing with Qingdao,HAB events, in Dalian coastal waters, dinoflagellate species are most dominant, followed by diatoms. For events occurred in these years, *Chattonella marina*, representing for raphidophyceae, took similarly significant role with dinoflagellate and diatom (Table 20). Therefore, target species in Dalian waters are supposed to be macro-dinoflagellate, *Noctiluca scintinllands*, followed by macro- raphidophyceae, *Chattonella marina* and diatom, *Chaetoceros affinis*. As a result, miniaturization is not a remarkable trend for causative species in Dalian coastal waters. Macro-phytoplanktons, like *Noctiluca scintinllands* are still common dominant species currently, accomplished by appearance of some micro-diatoms, especially *Chaetoceros affinis.*

Table 20 Target species of HAB events recently in Dalian coastal waters

Specie name	2004	2005	2006	2008	total
Diatom		2		2	4
Skeletonema costatum				1	1
Chaetoceros affinis		2			2
Thalassiosira nordenskÖldii				1	1
Dinoflagellate	1	1	1		4
Noctiluca scintinllans		1	1		2
Exuviaella marina					1
Alexandrium catenella	1				1
Raphidophyceae	1			1	2
Chattonella marina	1			1	2

5.9. Environmental monitoring results during HAB events in Qindao, august of 2007

In August of 2007, there was a HAB event occurred in Qingdao target waters 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 21. 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, changes of environmental factors in station 20 during the event on 20-23 of August in 2007 are showed in Table 22.

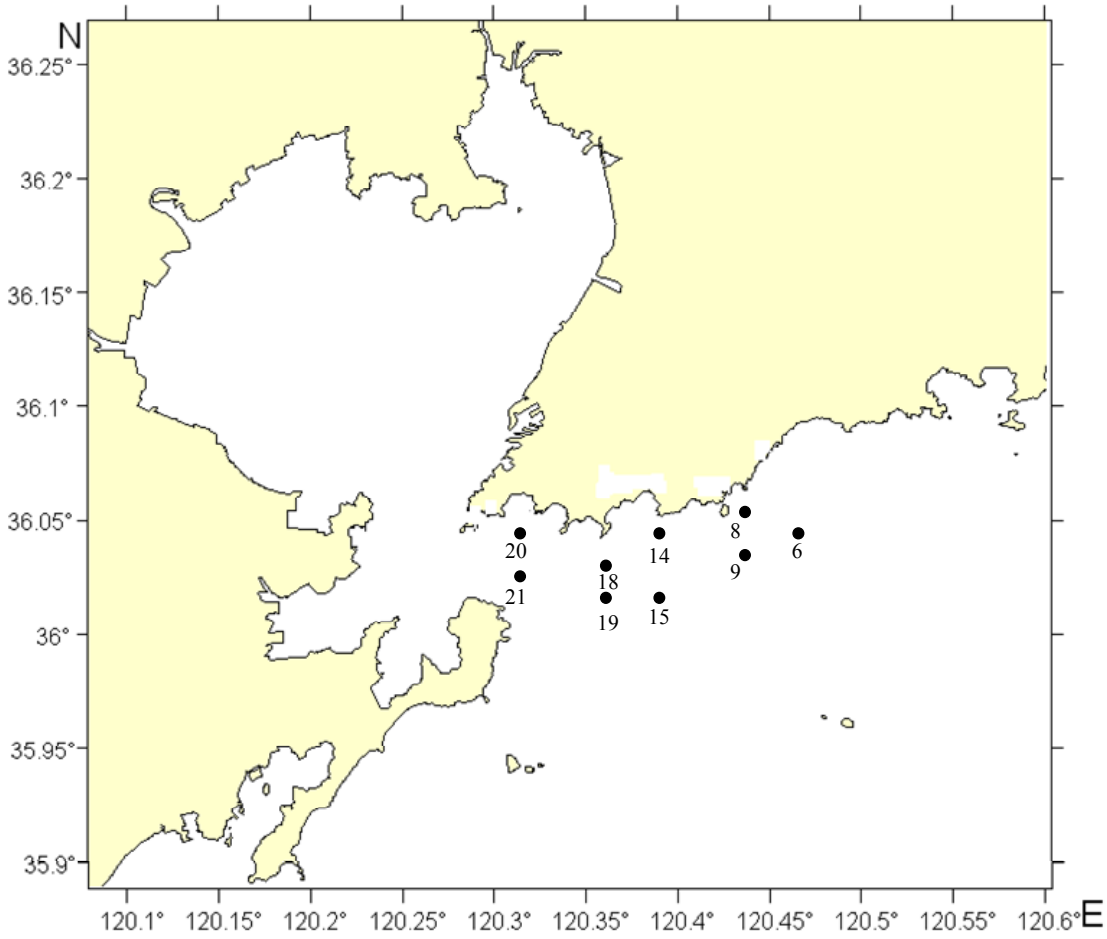


Figure 10 The location of monitoring stations during the HAB event in August of 2007

Table 21 Environmental monitoring results during HAB event in August of 2007

Station	Temperature(℃)	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 22 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 normal level and water temperature was also lower than multi-year mean level. *Skeletonema costatum* is a species that can grow in a wide range of salinity. As a result, it became the dominant species during this HAB event.

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

Table 23 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 24

Table 23 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 24 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

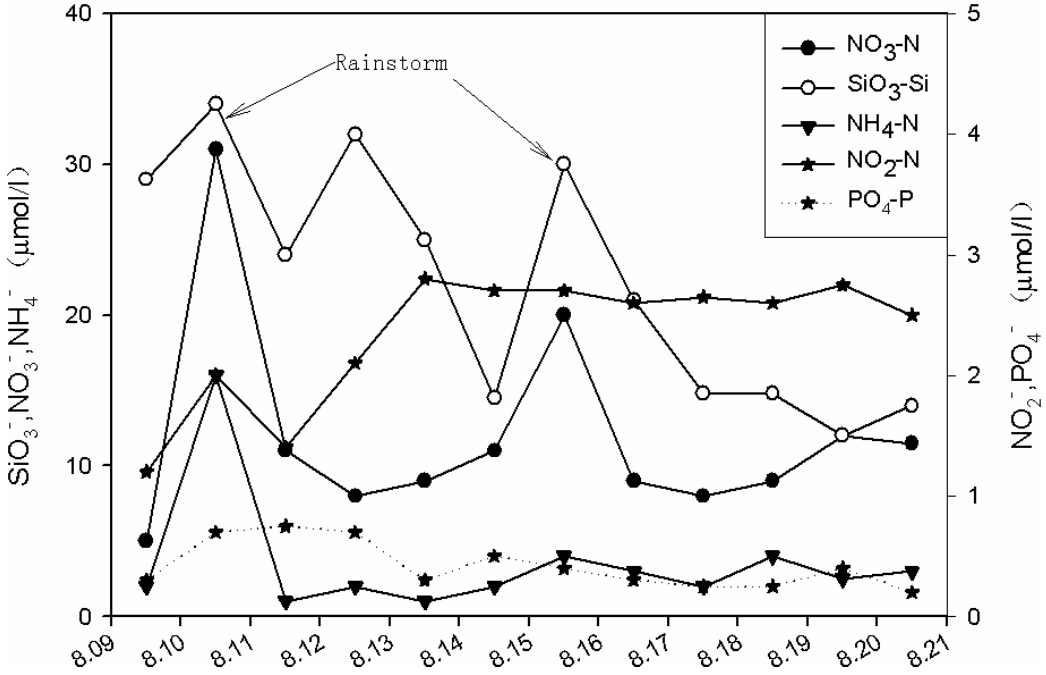


Figure 11 Nutrient changes in August of 2007

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. Such great rainfall input extra terrestrial nutrients into the target area. As a result, concentration of silicate increased over 10 times, along with significant improvements in concentrations of other nutrients. As shown in figure 11, concentrations of both silicate、nitrate and ammonium were over 30μmol/L, and concentration of phosphate was over 0.6μmol/L. Therefore, sufficient nutrients and suitable environmental conditions resulted in this HAB event lasting 4 days.

5.11. Meteorological observation parameters

Meteorological data were recorded in table 25, 26 during the *Skeletonema costatum* HAB event in 2007. Major parameters included temperature、air pressure、wind speed、wind direction and so on.

Table 25 Meteorological observation parameters during the 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 26 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, 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 was also favorable for phytoplankton growth, without being disturbed by strong waves. In summary, the meteorological condition was also fit for *skeletonema costatum* blooming.

5.12. Environmental assessment criterion of Zhangzi Island coastal waters

Differing with Qingdao coastal waters, there were not direct environmental parameters of Dalian coastal waters recorded in this report. Instead, environmental condition in such target area would be described by some indices. As illustrated before, there were several recorded fishery damage caused by HAB events in Dalian coastal waters, thus NMEMC executes routine monitoring framework in Zhangzi island coastal waters since 2003, aiming to protect such area out of risk of HAB events. For this target, after field monitoring, pH index (D_{pH}), DO index (D_{DO}), nutrient quality index (D_U), HAB risk index (D_R), desease incidence index (D_D) are suggested separately according to analyses of varied parameters, afterwards, an environmental comprehensive risk index (I_E) would be issued by grading summation of all previous indicies together. Finally, fishery suitability in target area would be classified and announced due to issued I_E grade.

Illustration and classification criterion of each index are introduced in detail as followed:

pH index（D_{pH}）: Generally speaking, pH value of sea water ranges from 7.5 to 8.5 in balance of different acid and alkali sources and being controld by CO_2-HCO_3^- -CO_3^{2-} system essentially. Changes of this system would break balance of acid and alkali inevitably, representing pH value changes directly, implying influence on lives in waters indirectly. Therefore, D_{pH} is issued to assess acidity and alkalinity in coastal waters, classifying pH value as 3 grades in form of index value 1, 3 and 5, ranging from 7.5 to more than 9.5, and higher pH value it is, higher grade it will be.

DO index (D_{DO}): Dissoved oxygen (DO) is a significant parameter for water quality provided that its value varied sensitively with organisms and reducing substances raising, hence DO saturation is also issued as an index (D_{DO}). As a classification, DO satuation, ranging from less than 105% to over 110% is classified as 3 grades in form of index value 1, 3 and 5, and higher DO saturation it is, higher grade it will be.

Nutrient quality index (D_U): Nutrient quality reflects trophic condition of target waters being

suit for cultural fishery or not. Provided by this target, Nutrient quality index (D_U) is issued by getting dissoved inorganic nitrogen (DIN), dissoved inorganic phosphorus and COD concentration into calculation together and finally drawing an eutrophication value (E), ranging from less than 0.7 to over 1.5. By classifying E into 3 grades in form of index value 1, 3 and 5, D_U is determined, and higher E it is, higher grade it will be.

HAB risk index (D_R): As a risk of cultural fishery, HAB events are also brought into consideration, by issuing HAB risk index (D_R). This index is judged by 2 major aspects, Chla concentration and biomass of dominant species. Further illustrating, dominant species are classified into 5 types by its length. For each type, there is a classification according to biomass, representing by index value. Classified grades and index value of different dominant species types are same. Meanwhile, Chla is classified into coincident grades as biomass. Finally, D_R is drawn by putting Chla and biomass of dominant species together and classified according to grades of them. In practically using, D_R is classified into 3 grades initially, representing index value 1, 2-20 and 25, meaning low HAB risk, potential HAB risk and HAB occurrence respectively. Consequently, grade 2 is sub-divided into 8 sub-grades further, representing by value index ranging from 2 to 20. Being similar with other indices, higher index value it is, higher risk of HAB it will be.

Desease incidence index (D_D): Disease incidence index (D_D) is introduced as an assessment result of cultural disease risk by considering biomass of 2 bacteria types, fecal coliform and vibrio. According to biomass of each bacteria, D_D is classified into 3 grades initially in practical application, representing index value 1, 3 and 4-25, meaning no disease, light disease risk and heavy disease risk, higher biomass it is, higher index value it will be. Moreover, grade 3 is sub-divided into several sub-grades by criterion of 2 bacteria biomass and pH value in target waters. Higher biomass as well as lower pH value it is, higher disease risk it will be.

Environmental comprehensive risk index (I_E): After assessments by separate indices, environmental comprehensive risk index (I_E) is finally issued by summation of each index value. The formular is:

$$I_E = D_{pH}+D_{DO}+D_U+D_R+D_D$$

After estimated, index value of I_E estimated is classified into 4 grades, reflecting suitability for cultivation in target waters. Classification criterion of I_E is described particularly in table 27 as followed.

Table 27. I_E classification criterion

I_E ranges	<13	14-18	19-28	>28
Environmental quality	Fine	Comparatively fine	ordinary	Comparatively poor
Cultural suitability	Suit for cultivation	Comparatively suit for cultivation		Not suit for cultivation

5.13. Environmental assessment results of Zhangzi Island coastal waters

From 2003 to 2008, NMEMC held 49 monitoring frameworks in Zhangzi Island cultural waters. Based on monitoring parameters, D_{pH}, D_{DO}, D_U, D_R, D_D and I_E were indicated, and cultural suitability of each case was resulted (Table 28).

Table 28. Cultural suitability of Zhangzi Island coastal waters

Date	D_{pH}	D_{DO}	D_U	D_R	D_D	I_E	Cultural suitability
05/06/03	1	1	5	3	No data	10	Suit for cultivation
18/06/03	1	1	5	1	1	9	Suit for cultivation
15/07/03	1	1	5	7	1	15	Comparatively suit for cultivation
30/07/03	1	1	5	1	1	9	Suit for cultivation
15/08/03	1	1	5	4	1	12	Suit for cultivation
01/09/03	1	1	5	4	1	12	Suit for cultivation
16/09/03	1	1	5	1	1	9	Suit for cultivation
29/09/03	1	1	5	1	1	9	Suit for cultivation
15/05/04	1	1	1	10	1	14	Comparatively suit for cultivation
31/05/04	1	1	1	1	1	5	Suit for cultivation
15/06/04	1	1	5	1	1	9	Suit for cultivation
30/06/04	1	1	1	5	1	9	Suit for cultivation
15/07/04	1	1	1	1	1	5	Suit for cultivation
31/07/04	1	1	1	1	1	5	Suit for cultivation
15/08/04	1	1	1	1	1	5	Suit for cultivation
31/08/04	1	1	1	4	1	8	Suit for cultivation
15/09/04	1	1	1	1	1	5	Suit for cultivation
30/09/04	1	1	1	1	1	5	Suit for cultivation
16/06/05	1	1	1	1	1	5	Suit for cultivation
01/07/05	1	1	1	1	1	5	Suit for cultivation
16/07/05	1	1	1	1	1	5	Suit for cultivation
01/08/05	1	1	1	1	1	5	Suit for cultivation
16/08/05	1	1	1	1	1	5	Suit for cultivation
01/09/05	1	1	1	1	1	5	Suit for cultivation
16/09/05	1	1	1	6	1	10	Suit for cultivation
30/09/05	1	1	1	1	1	5	Suit for cultivation
16/05/06	1	1	1	1	1	5	Suit for cultivation
01/06/06	1	1	1	1	1	5	Suit for cultivation
16/06/06	1	1	1	1	1	5	Suit for cultivation
01/07/06	1	1	1	1	1	5	Suit for cultivation
16/07/06	1	1	1	1	1	5	Suit for cultivation
01/08/06	1	1	1	2	1	6	Suit for cultivation
16/08/06	1	1	1	1	1	5	Suit for cultivation
01/09/06	1	1	1	1	1	5	Suit for cultivation

15/09/06	1	1	1	1	1	5	Suit for cultivation
01/10/06	1	1	1	1	1	5	Suit for cultivation
16/10/06	1	1	1	1	1	5	Suit for cultivation
01/11/06	1	1	1	1	1	5	Suit for cultivation
17/05/07	1	1	1	1	1	5	Suit for cultivation
01/06/07	1	1	1	1	1	5	Suit for cultivation
18/06/07	1	1	1	1	1	5	Suit for cultivation
02/07/07	1	1	1	7	1	11	Suit for cultivation
17/07/07	1	1	1	1	1	5	Suit for cultivation
01/08/07	1	1	1	1	1	5	Suit for cultivation
16/08/07	1	1	1	1	1	5	Suit for cultivation
01/09/07	1	1	1	9	1	13	Comparatively suit for cultivation
16/09/07	1	1	1	1	1	5	Suit for cultivation
16/10/07	1	1	1	1	1	5	Suit for cultivation
01/11/07	1	1	1	1	1	5	Suit for cultivation

From table 28 above, it could be concluded that environmental quality of Zhangzi Island cultural waters was fine by and large.

In most cases, it's suit for cultivation. Considering each index, D_{pH}, D_{DO} and D_D indices kept consistently low in all cases, indicating suitable pH condition, DO saturation and low desease risk in target waters all through these years.

However, there was a change of D_U value during these years in target area. As shown in figure 12, its value kept equivalently high in 2003, indicating quitely eutrophic in target waters, however, in most cases, its value dropped down to 1 since 2004, indicating feasibly trophic condition in target waters.

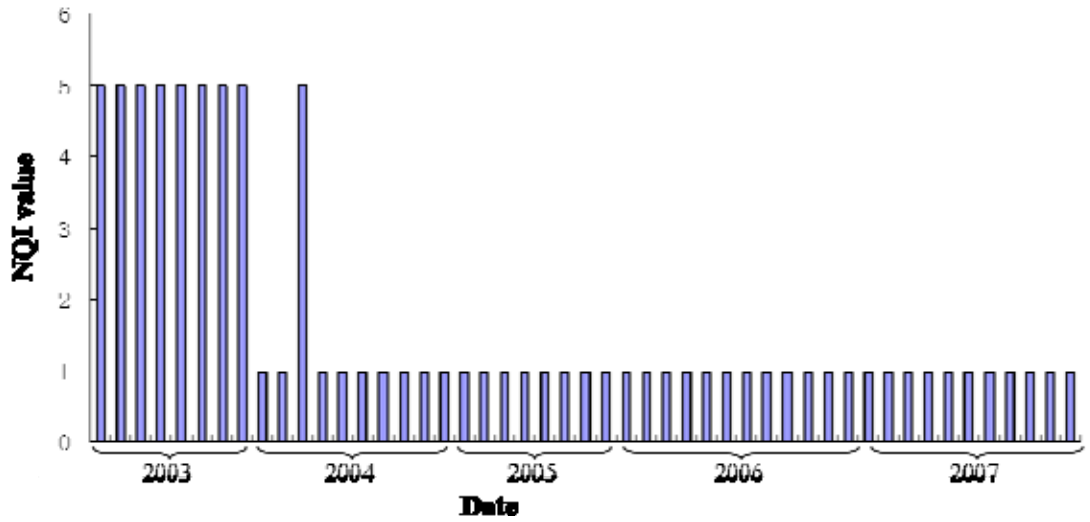


Fig 12. D_U in Zhangzi Island cultural waters

Meanwhile, D_R value fluctuated all through these years in target waters. As shown in figure 13, although most value remains as low as 1, there're still some value relatively high, the highest value could reach 10. Provided by D_R classification criterion, in some cases, Chla concentration or biomass were beyond normal level, representing potential HAB risk in target waters. Nevertheless, frequency of HAB risk is decreasing and no HAB events occurred in target waters since 2003.

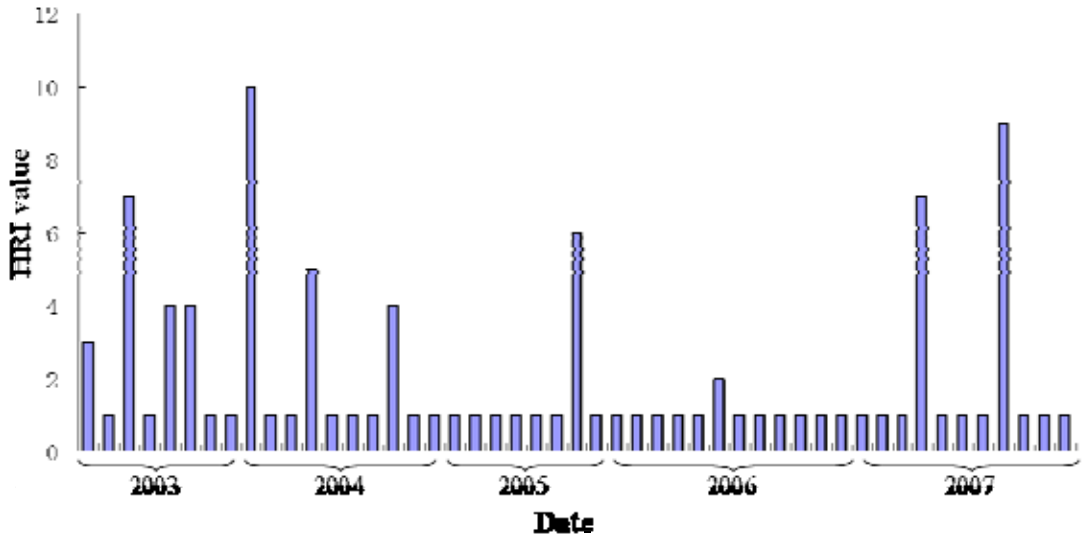


Fig 18. D_R in Zhangzi Island cultural waters

6. Conclusion

Qingdao target waters in this report, Jiaozhou Bay and east coastal waters, are some of 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 zooplanktons, mostly *Mesodinium rubrum* and also *Heterosigma akashiwo* in recent years. During HAB events, the maximum density of HAB organisms reached $9.34x10^7$cells/L. Eutrophication is one of important reasons of HAB events in target 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 HAB events occuring during this period.

Dalian target waters in this report, including Dalian bay as well as its surrounding and Zhuanghe waters, are some of HAB occurrence areas in North Yellow Sea, either. The scale of HAB events is limited in most cases, however, in a few events, the scale would be as large as hundreds of kilometers. The major causative species include dinoflagellates, mostly *Noctiluca scintinllands* as well as diatoms, mostly *Chaetoceros affinis* and also *Chattonella marina* in recent years. It was recorded that HAB events in target waters caused several fishery damage, valuing millions of Chinese yuan each time. As a result, related monitoring framework was contributed, aiming for protecting cultural fishery.

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