National Report on HABs in China

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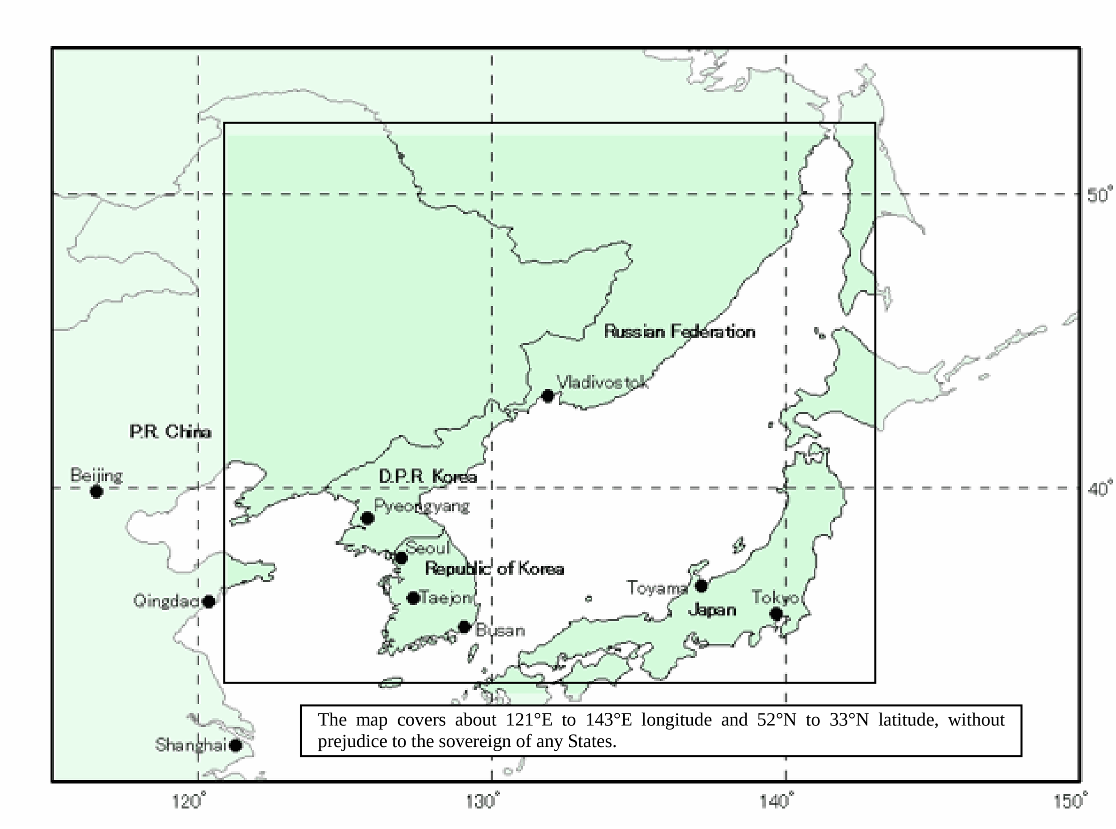
I. INTRODUCTION

The microscopic planktonic algae are the main primary producers in the marine ecosystem. They are critical food for filter feeding bivalve shellfish, such as oysters, mussels, scallops, clams, as well as the larvae of commercially important crustaceans and finfish. Microalgae play a very important role in marine food webs. In normal cases, the proliferation of planktonic algae is beneficial for aquaculture and wild fisheries operations. However, in some cases, algal blooms caused by toxic or harmful algal species can have a negative effect, causing heavy losses to aquaculture, the fisheries industry and tourism operations, and having major environmental and human health impacts. Hallegraeff (1993) noted that among the 5000 species of extant marine phytoplankton, some 300 species can at times occur in such high numbers that they obviously discolour the surface of the sea (so-called 'red tides'), while only 40 or so species have the capacity to produce potent toxins that can find their way through fish and shellfish to humans.



Geographic coverage of NOWPAP Region (adapted from Japanese National Report)

1. Definition of red tide in China

Harmful algal blooms (HABs) were called red tides in the past years because of the intense (often reddish) discolouration of the seawater by the pigments in the algae involved. However, the term red tide is too general: it includes dense accumulation of phytoplankton species which can visibly discolour 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 there are 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 always have harmful or toxic effects. These effects involve different toxins produced by the algae resulting in fish and other marine animal kills, as well as more general environmental effects.

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

2. Present situation of HABs in China

For many years, HABs have had a severe economic impact on shellfish and finfish resources, public health, and the aquatic environment throughout the coastal regions of China. It is now evident that the magnitude, frequency and geographic extent of these occurrences have increased significantly over the last several decades. This phenomenon severely affects China, since the country rely heavily on coastal fisheries and mariculture for their food supply and economics development.

Fish kills are the main economic effects caused by HABs in China. Some algal species can seriously damage fish gills, either mechanically or through production of hemolytic and hemagglutinating substances. Wild fish stocks have the ability to move away from bloom areas, whereas caged fish are absolutely exposed to such noxious algal blooms.

In recent China, a long-term bloom caused one million Chinese dollars worth of aquaculture product losses in Bohai Bay in 1989 (Qi *et al*, 1993). A massive fish kill and PSP toxicity cases were also recorded in Tolo Harbour (Lam et Yip, 1989) and various parts of Hong Kong waters (Lam *et al*, 1987). In 1998, an historical record bloom affected Hong Kong and other nearby South China waters (Lu and Hodgkiss, 1999). Almost all caged fishes were killed by the bloom, resulting in estimated direct losses of HK$315 million in Hong Kong plus over HK$20 million in nearby South China waters.

In 2003, the national sea waters witnessed altogether 119 cases of marine red tides, added up area about 14.55 thousand square kilometers. Compared to that of 2002, either events or affected areas are increased (Table Ⅰ-1).

Table I-1 Contrast of marine red tide events in Chinese coastal waters in 2002-2003 (adapted from SOA)

Sea Areas	**Number of Red Tide Events**		**Added up areas (km^2)**	
	2002	2003	2002	2003
Yellow Sea	3	5	310	410
Bohai Sea	14	12	300	460
East China Sea	51	86	9 000	12 990
South China Sea	11	16	540	690
Total	79	119	10 150	14 550

According to the monitoring data from 2000 to 2004, the higher number of HABs were recorded from Zhejiang, Fujian and Guangdong Provinces, which were located in the East and South China seas. Comparing with these three provinces, the HABs in coastal provinces along Yellow Sea and Bohai Sea were relative lower (Figure 1.1).

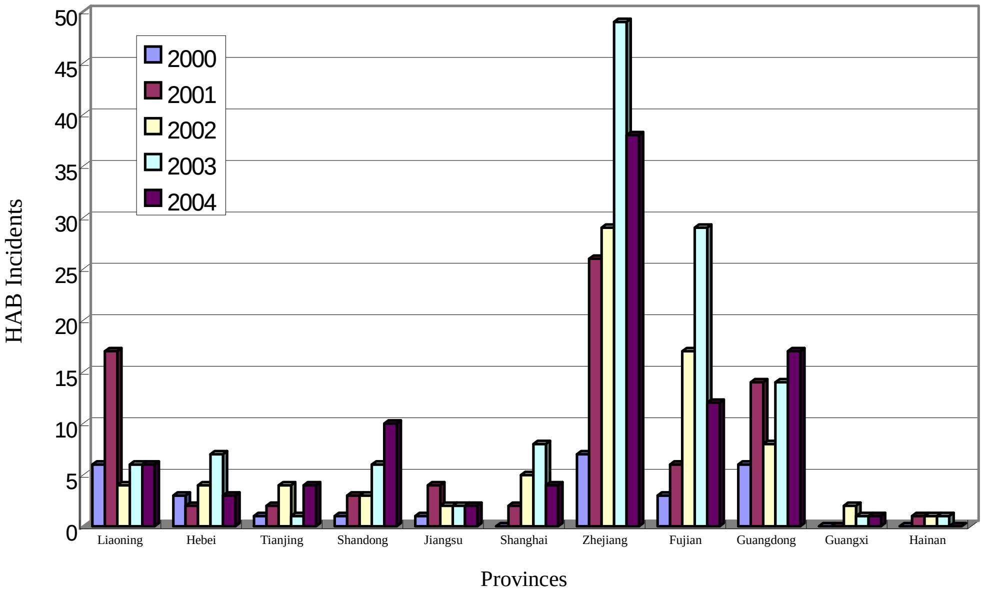


Figure 1.1 HAB incidents in coastal provinces during 2000-2004

From long term statistics point of view, the HAB occurrences in coastal China have been increased all the time, with a sharp increase after 2000 (Figure 1.2). The explanations for this increasing are: a) the HAB incidents were increased with increased marine eutrophication; and b) the national routine HAB monitoring network has been applied.

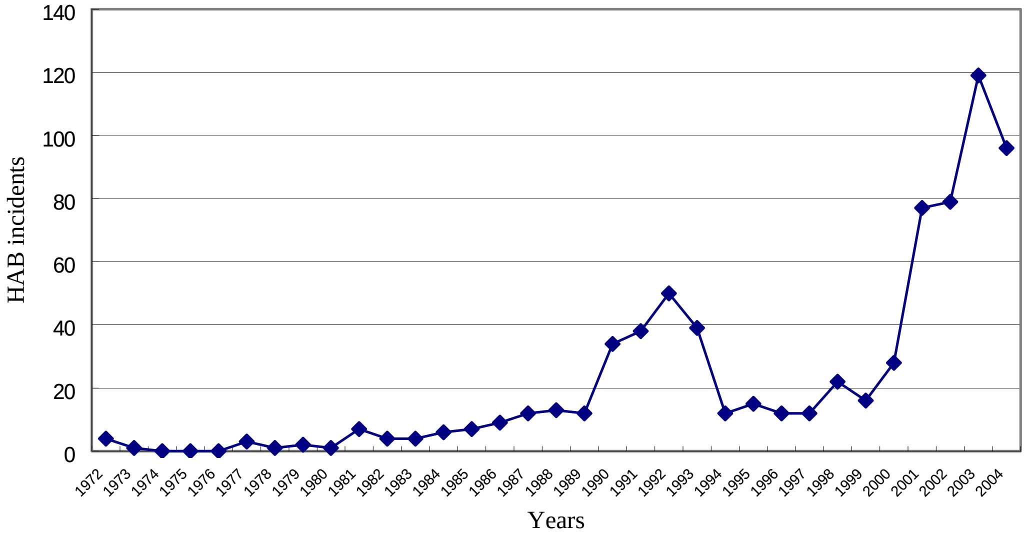


Figure 1.2 HAB incidents in coastal China from 1972 to 2004

There are several higher frequent HAB occurrence areas in coastal China (Fig. 1.3). They are: Liaodong Bay, Bohai Bay, Laizhou Bay (Bohai Sea); Jiaozhou Bay, Dalian Bay, Haizhou Bay (Yellow Sea); Changjiang Estuary, Zhoushan waters, Eastern Zhejiang and Southern Fujian waters (East China Sea); Dapeng Bay, Daya Bay, Beibu Bay, Northern Hainan waters (South China Sea).

Figure 1.3 High frequency areas of red tide occurrences in China coastal Waters

3．Marine and coastal environment of NOWPAP region in China

NOWPAP regions in China are Bohai Sea and Yellow Sea (Fig.1.4). The Yellow Sea is located between the China and Korea. The Yellow Sea is that semi-enclosed body of water bounded by the Chinese mainland to the west, the ROK Peninsula to the east, and a line running from the north bank of the mouth of the Yangtze River (Chang Jiang) to the south side of Cheju Island. It is connected to the East China Sea to the south. It has a maximum depth of 152 m. The length approximately 1,000 km, with the greatest width of 700 km and area of 466,200 km^2. The floor of the Yellow Sea is a geologically unique, post-glacially submerged, and shallow portion of the continental shelf. The seafloor has an average depth of 44 m, a maximum depth of about 100m, and slopes gently from the Chinese continent and more rapidly from the ROK Peninsula to a north-south trending seafloor valley with its axis close to the ROK Peninsula. This axis represents the path of the meandering Yellow River (Huang He) when it flowed across the exposed shelf during lowered sea level and emptied sediments into the Okinawa Trough. The Sea annually receives more than 1.6 billion tons of sediments, mostly from the Yellow River (Huang He) and Yangtze River, which have formed large deltas. The Yellow Sea is connected to the East China Sea in the south, forming a linked circulation system. Major rivers discharging directly into the Yellow Sea include the Han, Yangtze, Datung, Yalu, Guang, and Sheyang. The Liao He, Hai He, and Yellow River around the Bo Hai have important effects on salinity in the western Yellow Sea, whereas the Yangtze River exerts strong influence on the hydrography of the southernmost part of the Sea. Recent reductions in Yellow River flow have led to changes in hydrography and water circulation, thereby leading to ecosystem changes. All rivers have peak runoff in summer and minimum discharge in winter.

The littoral provinces are Shandong Province, Liaoning Province, and Jiangsu Province. The coastal population is 41,420,000, among which 12,940,000 to the north of Yellow Sea is 31% of total amount, and 28,650,000 to the south of Yellow Sea is 69%. The population density is 431 people/km^2.

The Bohai Sea, also known as (though redundant) Bo Hai or Bohai Gulf, is a enclosed interior sea located at 37° 07′ ~41° N and 117° 35′ ~122° 15′ , It connected with the Yellow Sea on the east via the Bohai Strait. The line linking Laotieshan of the Liaoning Peninsula and the Cape of Penglai on the north coast of the Shandong Peninsula is the boundary between the Bohai and Yellow seas. The Bohai Sea covers an area of 77284 km^2 and has a continental coastline of 2668 km long. With an average water depth of 18 m and a maximum of 85 m, it has over half of its sea area shallower than 20 m. Located in the northern temperate zone, the Bohai Sea is neither extremely hot in summer nor severely cold in winter. The multi-year mean air temperature is 10.7℃， the precipitation 500~600 mm and the seawater salinity 30ppt.

The Bohai Sea is formed by the Liaodong Peninsula to the northeast and the Shandong Peninsula to the south. Bohai Sea consists of three bays: Laizhou Bay to the south, Liaodong Bay to the north, and Bohai Bay to the west. The rivers Huang He (Yellow River), Liao He, and Hai He empty into the sea.

Bohai Sea borders Shandong province, Liaoning province, Hebei province, and Tianjin municipality. Port cities on Bo Hai coast include Dalian, Yingkou, Jinzhou, Qinhuangdao, Tanggu, Longkou and Yantai. Bohai Sea is an inland sea. Total coastal population is 46,560,000, with population of 11,270,000 along the coast of Liaodong Bay, population of 21,560,000 along the coast of Bohai Bay, and population of 13,730,000 along the coast of Laizhou Bay. The population density is 419 people/km^2.

Figure 1.4 Geographic coverage of Yellow Sea and Bohai Sea

Harmful Algal Blooms (HAB) occurring in the coastal waters off southern and eastern ROK have caused loss to the aqua-culture industry and probably large-scale mortality of natural fin- and shellfish. However, the frequency and the area of the outbreak of HABs in the coastal waters off western ROK (Yellow Sea) are lower than those off southern and eastern ROK. High turbulence intensity and turbidity caused by strong tidal current might inhibit the growth of HAB organisms. Recently, however, the frequency and the area of the HAB outbreaks have increased in the Yellow Sea coast, particularly in the area where huge artificial constructions, such as an underwater dam or dike were built. The constructions might restrict the circulation of water masses and reduce the turbulence intensity and turbidity. Under this circumstance, red tide organisms grow fast and form red tide patches. The number and frequency of the trade ships between western cities in ROK and eastern cities in PRC have continuously increased. Therefore, the transport of red tide organisms in ballast waters might be partially responsible for the increase in the frequency and the area of red tides. Huge discharge from the Changjiang River during the summer monsoon season might carry the seed organisms or somehow inoculate existing spores.

II. DATA AND INFORMATION USED

Data and information used for the report are mainly from published literatures and materials.

Red tide study and monitoring in China are relatively later compared to other coastal countries in the world. The earlier red tide data and information was from fishmen’s observation and few research projects. So the earlier data is discontinuous and not completed.

1. Situation of HAB Occurrence

Red tide monitoring program is conducted by State Oceanic Administration (SOA). The monitoring program started from late 1980, and the monitoring network is still under construction. Late on, some local government in coastal areas have their own monitoring programs focused on mariculture waters. SOA has issued “Year Report of Chinese Marine Environmental Quality” since 1990, and some coastal provincial government have also issued their local Year Report since 2001. Red tide data has also been published in these reports. The data from the “Year Report of Chinese Marine Environmental Quality” and local government Year Report has been used by this report.

There are also many scientific projects on red tides working on different coastal areas. These projects focused on red tide occurrences, mechanisms, species diversity, toxicity, and mitigation. The published literatures are one of the main data and information resources of this reports.

1.1 Red tide

The chapter introduces situation on red tides in Chinese waters based on monitoring data summarized in table III.1 recommended by guideline. The data on Situation of Red tide is originated from “Year Report of Chinese Marine Environmental Quality” issued by SOA, Regional Year Report of seawater environmental quality issued by local governments, as well as some scientific publications.

1.2 Toxin-producing Plankton

This chapter introduces situation on toxic and potentially toxic species, which observed in Chinese waters. The presented data on toxic events and toxic species, which observed in Chinese waters and known to be toxic in other NOWPAP countries, has been summariaed in the chapter. The data used in this chapter is originated mainly from scientific publications. Some othea data is from year reports of both SOA and local governments.

2. Monitoring

This chapter describes the situation with monitoring of HAB in China. The routine and trace monitoring programs are introduced in the chapter.

3. Progress of Researches and Studies to Cope with HABs

Present research and studies about HAB in Chinese waters are introduced in this chapter. Publications on the current progress of HAB studies from different institutions and scientists were collected for recognizing the directions of researches and studies of HAB in Chinese marine waters in the future.

4. Literature Including Newly Obtained Information

Information of literatures about HAB was obtained by using HAB Reference Database which has been constructed by CEARAC/WG3. Section indexes conform to the categories in HAB Reference Database. Literatures including newly obtained information are presented.

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5. Training Activities to Cope with HABs

This section describes the international training courses attended by Chinese scientists in 1995-2003.

6. National Priority to Cope with HABs

Interviews with Chinese researchers and scientists of the relevant field were conducted to collect their ideas on necessary efforts to cope with HABs.

7. Suggested Activity for the NOWPAP Region

Interviews with Chinese researchers and scientists of the relevant field were conducted to collect their ideas on necessary efforts to promote the solution of HAB problems.

In summary, the data and information used in this report are:

- Year Report of China Marine Environment (1990-2003) (State Oceanic Administration of China)
- Year Report of Marine Environment of Shandong Province, Hebei Province, Liaoning Province and Tianjing municipality (2001-2003)
- Published references and data
- Results from related research projects
- Personal communication

III. RESULTS

1. Situation of HAB Occurrence

This chapter introduces situation of HAB in China, focusing on Yellow Sea and Bohai Sea waters. Most of HABs are recognized by red tide monitoring. Because a large percentage of HABs are not caused by toxin-producing plankton, and fish-kills rather than shell-fish poisonings are more common in the area. Therefore, Red Tides discussed in this section mainly include non-toxic and fish-kill events, but some toxin-producing plankton are also discussed. Situation of Red tide occurrences in Yellow Sea and Bohai Sea in China is summarized in Table Ⅲ-1.

1.1 Red Tide

1.1.1 Type of HAB

In history point of view, red tide is a common name widely used by public and scientific communities in China. Recently red tide refers only to phenomena in which the density of plankton increases to concentration which coloring seawater. Water discoloration is observed due to the plankton cell increase, and mass mortality of fish and shellfish is occasionally happened.

A total of 6 red tide events out of 112 cases caused mass mortality of fish and shellfish during 1998–2004 in Chinese waters of the Yellow Sea and Bohai Sea. Other 106 cases were harmless, even though there are some harmful species such as *Alexandrium catenella, Chattonella antiqua, Chattonella marina , Kerania mikimotoi, Phaeocystis* sp., and *Heterosigma akashiwo* involved in the causative species.

Compared to the East China Sea and the South China Sea, The red tide in Yellow Sea and Bohai Sea has characteristics of larger affected areas and long lasting time (Table Ⅲ-2).

Table III-1 Situation of Red Tide Occurrence in Yellow Sea and Bohai Sea, China

Event No.	Location (name of the sea area) *1	Approximate Area suffered (km2)	Type of HAB Red tide or Toxic	Duration dd/mm/yy -dd/mm/yy	Causative species	Max. cell density cells/L	Mitigation Activity and effectiveness	Damage	
								Fishery resources*2	Human health*3
1	Huanghua, Hebei	1300	HAB	1989	*Gymnodinium* sp	No data	No data	38 million dollar	No data
2	Laizhou Bay	1/3 Bay area	Red tide	18/6/1990	No data	No data	No data	No data	No data
3	Jiaozhou Bay	80 000	Red tide	26/6/1990	No data	No data	No data	No data	No data
4	Baidaihe, Hebei	110	No data	28/6/1990-4/7/1990	No data	No data	No data	No data	No data
5	Laizhou Bay	No data	Red tide	June, 1990	*Noctiluca scintillans*	No data	No data	No data	No data
6	Laizhou Bay	10	Red tide	19-20/8/1990	No data	No data	No data	No data	No data
7	Laizhou Bay	1200	Red tide	26/8/1990	No data	No data	No data	No data	No data
8	LaizhouBay	1000	Red tide	30/8/1990	No data	No data	No data	No data	No data
9	North LaizhouBay	No data	Red tide	1/9/1990	No data	No data	No data	No data	No data

10	Changhai county, Liaoning	No data	HAB	1990	No data	No data	No data	2.5 million dollar due to death scallops	No data
11	Shrimp pond, Dalian	No data	Red tide	May to July, 1991	*Exuviaella cordata*	7.5×10^{7}	No data	Loss of shrimp	No data
12	Liaodong Bay	100	Red tide	4/7/1991-12/7/1991	*Noctiluca scintillans*	4.9×10^{7}	No data	No data	No data
13	Jiaozhou Bay	No data	Red tide	April, 1992	No data	No data	No data	No data	No data
14	East Qingdao	1200	Red tide	12/5/1992	No data	No data	No data	No data	No data
15	Jiaozhou Bay	1000	Red tide	August, 1992	No data	No data	No data	No data	No data
16	Dalian Bay	40	Red tide	11/8/1993	No data	No data	No data	No data	No data
17	Laizhou Bay	90	Red tide	6/6/1995	*Noctiluca scintillans*	2.16×10^{7}	No data	No data	No data
18	Liaodong Bay	100	Red tide	20/8/1995	No data	No data	No data	No data	No data
19	Penglai, Laizhou Bay	1	Red tide	13-14/4/1997	No data	No data	No data	No data	No data
20	Bohai Bay	3	Red tide	28/6/1997	No data	No data	No data	No data	No data
21	Jiaozhou Bay	10	Red tide	3-8/7/1998	*Skeletonema costatum*	4.5×10^{6}	No data	No data	No data
22	Yantai, Laizhou Bay	100	HAB	August, 1998	No data	No data	No data	4 million dollar Fishery losses	
23	Bohai Sea	5000	toxic	16/8/1998-19/9/1998	*Ceratium furca*, *Dinophysis ovata*	1.25×10^{6}	No data	15 million dollar Fishery losses	DSP detected
24	Yantai, Bohai	170	HAB	15/8/1998-10/9/1998	*Gymnodinium sanguineum*	No data	No data	Shellfish death	No data
25	Laizhou Bay	No data	Red tide	2/9/1998	No data	No data	No data	No data	No data
26	Liaodong Bay	No data	Red tide	18/9/1998	*Ceratium furca*	No data	No data	No data	No data

27	Liaodong Bay	No data	Red tide	29/9/1998	*Ceratium furca*	No data	No data	No data	No data
28	Bohai Bay	No data	Red tide	1/10/1998	No data	No data	No data	No data	No data
29	Bohai Bay	800	Red tide	3/10/1998	*Gonyaulax spinifera.*, *Ceratium furca*	No data	No data	No data	No data
30	Bohai Bay	No data	Red tide	9/10/1998	No data	No data	No data	No data	No data
31	Jiaozhou Bay	No Data	Red tide	8-15/6/1999	*Eucampia zoodiacus*	2.3×10^6	No data	No data	No data
32	Bohai Bay	1500	Red tide	2-4/7/1999	No data	No data	No data	No data	No data
33	Dalian Bay	No data	HAB	July, 1999	*Exuviaella marina*	8.1×10^6	No data	No data	DSP detected
34	Bohai Sea	6300	Red tide	13-21/7/1999	*Noctiluca scintillans*	No data	No data	No data	No data
35	Dalian Bay	100	Red tide	17-21/7/1999	*Noctiluca scintillans*	No data	No data	No data	No data
36	Penglai, Shandong	680	Red tide	17/7/1999	*Noctiluca scintillans*	No data	No data	No data	No data
37	South Dalian	30	Red tide	18/7/1999	No data	No data	No data	No data	No data
38	Jiaozhou Bay	26	Red tide	23/7/1999	*Skeletonema costatum*		No data	No data	No data
39	Xiaomai Island, Qingdao	60	Red tide	26/7/1999	No data	No data	No data	No data	No data
40	Shidao, Shangdong	160	Red tide	6/8/1999	No data	No data	No data	No data	No data
41	Central Bohai Sea	30	Red tide	25/9/1999	No data	No data	No data	No data	No data
42	Liaodong Bay, Bohai	350	Red tide	9-15/7/2000	*Noctiluca scintillans*	No data	No data	No data	No data

43	Liaodong Bay	No data	HAB	July 2000	*Prorocentrum* sp.	No data	No data	Death of jellyfish	No data
44	Bohai Bay	1040	Red tide	23/7/2000	No data	No data	No data	No data	No data
45	North Wentuozhi Island, Bohai	217	Red tide	13/8/2000	No data	No data	No data	No data	No data
46	Changxin Island, Bohai Sea	44	Red tide	13/8/1/2000	No data	No data	No data	No data	No data
47	Zhuanghe, Yellow Sea	827	HAB	2/8/2000	No data	No data	No data	15 million dollar	No data
48	Southeast Qikou	180	Red tide	20-21/7/2000	No data	No data	No data	No data	No data
49	Beidaihe, Tianjing	3	Red tide	23/7/2000	No data	No data	No data	No data	No data
50	Tanggu, Tianjing	134	Red tide	25/7/2000	No data	No data	No data	No data	No data
51	Jiaozhou Bay	2	Red tide	20-23/7/2000	*Noctiluca scintillans*	No data	No data	No data	No data
52	Dandong, North Yellow Sea	No data	Red tide	24/5/2001	No data	No data	No data	No data	No data
53	Bohai Bay	No data	Red tide	26/5/2001	No data	No data	No data	No data	No data
54	Bohai Bay	No data	Red tide	19/6/2001	No data	No data	No data	No data	No data
55	Jiaozhou Bay	5	Red tide	11-12/6/2001	*Noctiluca scintillans*	No data	No data	No data	No data
56	The Coast of Jiangsu	1000	Red tide	20/6/2001	*Skeletonema costatum*	No data	No data	No data	No data
57	Jiaozhou Bay	20	Red tide	7-12/7/2001	*Mesodinium rubrum*	No data	No data	No data	No data

58	Yingkou, Liaodong Bay	360	Red tide	15-16/7/2001	*Noctiluca scintillans*	No data	No data	No data	No data
59	Bayuquan, Liaodong Bay	770	Red tide	12-23/8/2001	*Leptocylindrus danicus*	No data	No data	No data	No data
60	Yalujiang Estuary, North Yellow Sea	1100	Red tide	24/8/2001-14/9/2001	*Eucampia zoodiacus*, *Chaetocerus socialis*	No data	No data	No data	No data
61	Liao River Estuary	130	Red tide	25-26/8/2001	*Navicula* sp.	No data	No data	No data	No data
62	Bayuquan, Liaodong Bay	100	Red tide	27-30/8/2001	*Mesodinium rubrum*, *Eucampia zoodiacus*	No data	No data	No data	No data
63	Qinghuangdao Bay, Bohai Sea	0.5	Red tide	3-4/6/2002	*Noctiluca scintillans*	No data	No data	No data	No data
64	Jingtang Habour, Bohai Bay	15	Red tide	16-17/6/2002	*Noctiluca scintillans*	No data	No data	No data	No data
65	Jingtang Habour, Bohai Bay	0.5	Red tide	27/6/2002	*Gymnodinium* sp., *Noctiluca scintillans*,	No data	No data	No data	No data
66	Qinghuangdao Bay, Bohai Sea	8	HAB	25/7/2002	*Chattonella marina*	No data	No data	No data	No data
67	Laizhou Bay	20	HAB	10/8/2002	*Noctiluca scintillans*	No data	No data	0.6 million dollar	No data
68	Laizhou Bay	30	HAB	15/8/2002	*Skeletonema costatum*	No data	No data	1 million dollar	No data

69	East Liaodong Bay	10	Red tide	28/5/2003	*Noctiluca scintillans*	No data	No data	No data	No data
70	Dandong waters, Yellow Sea	30	Red tide	June 2003	No data	No data	No data	No data	No data
71	Dalian Bay	15	HAB	July 2003	*Heterosigma akashiwo*	No data	No data	No data	No data
72	Jiaozhou Bay	200	Red tide	July 2003	*Coscinodiscus asteromphalus*	No data	No data	No data	No data
73	Qinghuangdao, East Bohai Sea	70	Red tide	25-26/4/2003 -	*Noctiluca scintillans*	No data	No data	No data	No data
74	Liaodong Bay	10	Red tide	28/5/2003	*Noctiluca scintillans*	No data	No data	No data	No data
75	Qinghuangdao, East Bohai Sea	8	Red tide	28/5/2003-4/6/2003	*Noctiluca scintillans*	No data	No data	No data	No data
76	Liaodong Bay	140	HAB	28/5/2003	*Noctiluca scintillans*	No data	No data	Fish kills	No data
77	Qinghuangdao, East Bohai Sea	0.2	Red tide	12/6/2003	*Noctiluca scintillans*	No data	No data	No data	No data
78	Luanhe, Qinghuangdao, East Bohai Sea	12	Red tide	21/6/2003	*Noctiluca scintillans*	No data	No data	No data	No data
79	Qinghuangdao, East Bohai Sea	1	Red tide	25-27/6/2003	*Noctiluca scintillans*	No data	No data	No data	No data

80	Dagu Harbour, Tianjing	100	Red tide	1-8/7/2003	*Noctiluca scintillans*	No data	No data	No data	No data
81	Bohai Bay	2	Red tide	12-13/8/2003	*Noctiluca scintillans*	No data	No data	No data	No data
82	Laizhou Bay	No data	Red tide	2003	*Gonyaulax spinifera*	No data	No data	No data	No data
83	Jiaozhou Bay	No data	Red tide	9-28/2/2004	*Rhizosolenia* sp.	No data	No data	No data	No data
84	Yellow River Estuary	1850	HAB	11-18/6/2004	*Phaeocystis* sp.	No data	No data	No data	No data
85	Central Bohai Bay	3200	HAB	12-18/6/2004	*Kerania mikimotoi*	No data	No data	No data	No data
86	Jingshitan ， Dalian ， Yellow Sea	No data	HAB	6/9/2004	*Chattonella antiqua*	No data	No data	No data	No data
87	Jingshitan ， Dalian ， Yellow Sea	No data	HAB	25/9/2004	*Alexandrium catenella*	No data	No data	No data	No data

Table III-2 The characteristics of red tide occurrences in different seas of China

Seas	Higher red tide occurrences area	Characteristics	Frequent occurrence time
Bohai Sea and Yellow Sea	Liaodong Bay, Bohai Bay, Laizhou Bay, Dalian Bay, Jiaozhou Bay	Large scale and long lasting time	July to September
East China Sea	Changjiang Estuary, Zhoushan waters, Xiangshan Bay	Large area	June to August
South China Sea	Dapeng Bay, Daya Bay, Tolo Harbour, Zhelin Bay,	More causative species, smaller area	March to May

1.1.2 Causative Species

So far a total of 23 species caused red tides in Chinese waters of Yellow Sea and Bohai Sea (Table Ⅲ-3). They are belong to 4 taxonomic group of phytoplankton and one group of zooplankton: dinoflagellates, diatoms, raphidophytes, haptophytes, and ciliates.

The most common causative species are diatoms and dinoflagelltes. *Noctiluca scintillans*, *Skeletonema costatum,and Mesodinium rubrum* are the principal causative species in the region. *Noctiluca scintillans, Skeletonema costatum, Gymnodinium* sp.*, Gymnodinium sanguineum* , *Ceratium furca*， *Prorocentrum* sp., caused mass mortality of fishery resources. DSP were detected after a Dinophysis ovata bloom in Bohai Sea in August 1998, and a *Exuviaella marina* (*Prorocentrum lima*) bloom in Dalian Bay in July 1999 (Zhou *et al*. 2001)

Table III-3 Red Tide Causative Species in Yellow Sea and Bohai Waters

Species
Dinoflagellates:
Alexandrium catenella
Ceratium furca
Dinophysis ovata
Gonyaulax spinifera
Gymnodinium sanguineum
Gymnodinium sp.
Exuviaella marina
Exuviaella cordata
Kerania mikimotoi
Noctiluca scintillans
Prorocentrum micans
Prorocentrum minimum
Raphidophytes:
Chattonella antiqua
Chattonella marina
Heterosigma akashiwo
Haptophytes:
Phaeocystis sp.
Diatoms:
Chaetocerus socialis
Coscinodiscus asteromphalus
Eucampia zoodiacus
Leptocylindrus danicus
Navicula sp.
Rhizosolenia sp.
Skeletonema costatum
Ciliates:
Mesodinium rubrum

1.1.3 Cell Density

The cell density of red tide are varied depending on different causative species (i.e. cell size). The usual number of maximum cell density in the red tide events in this area remains at the level of several thousands cells/ml.

Noctiluca scintillans: the maximum density recorded was 4.9×10^7 cells/L in July 1991 in Liaodong Bay. Normally cell density of a *Noctiluca scintillans* bloom is 1.5×10^6 cells/L in Bohai and 3.0×10^6 cells/L in Dalian Bay, compared to that of 8-58 $\times 10^7$ cells/L in Changjiang Estuary and 2.4×10^9 cells/L in Shenzhen Bay (Zhao & Cheng, 2000).

Skeletonema costatum: the maximum cell density of *Skeletonema costatum* in Dalian Bay was 7.2×10^7 cells/L. *Skeletonema costatum* is on of the most common causative species in Chinese coastal waters. In Jiaozhou Bay, the bloom density was 4.5×10^6 cells/L(Huo *et al.* 2001). In Changjiang Estuary, the cell density can reach 10^7 cells/L. 10^7 cells/L.

Ceratium furca: a bloom of *Ceratium furca* in Bohai covered 5000 km^2 and lasted about two months in August 1998. The maximum cell density was 1.25×10^6 cells/L.

Heterosigma akashiwo: a common causative species in Dalian Bay. The maximum density for this species is 5×10^8 cells/L.

Gymnodinium sp.: the maximum density for the blooms of this species was 3×10^8 cells/L.

Exuviaella cordata: only one case of bloom induced by this species was recorded in shrimp pond of Dalian. The maximum cell density was 7.5×10^7 cells/L. (Zhou et al. 2001).

Exuviaella marina (*Prorocentrum lima*): was also only record in Dalian Bay. The maximum cell density was 8.1×10^6 cells/L (Zhou *et al*. 2001). DSP was detected.

Eucampia zoodiacus: another common causative species of diatom in the area. The maximum cell density was 2.3×10^6 cells/L.

1.1.4 Location

In China, as described earlier, the locations of the most frequent red tide occurrence in Yellow Sea and Bohai Sea are Dalian Bay, Liaodong Bay, Bohai Bay, Laizhou Bay, Jiaozhou Bay, and Donggang waters (Fig. 3.1). Liaodong Bay and Bohai Bay are locations where red tides occurred most often.

Figure 3.1 The hot spots of red tide occurrences in Chinese waters of Yellow Sea and Bohai Sea

Monitoring on red tide occurrence in China has mainly been in charged by State Oceanic Administration (SOA). Red tide occurrence in Yellow Sea and Bohai Sea has been mainly conducted by the North Sea Environmental Monitoring Center of SOA (in Qingdao), and the National Marine Environmental Monitoring Center of SOA (in Dalian). Environmental

Protection Agency and Department of Agriculture also have their local laboratories for monitoring red tide in coastal waters and fishing area, respectively. Besides, the 5 local coastal government along Yellow Sea and Bohai Sea, Liaonin, Hebei, Tianjing, Shandong, and Jiangsu, have their marine environmental and fishery laboratories to carry out the regular monitoring, but monitoring area of each laboratory is small and limited to enclosed bays and fish farms. Frequency of the monitoring differs from laboratories. Data reported from individual laboratories of prefecture governments based on different monitoring schemes from each other.

The occurrence of red tide in Chinese waters of Yellow Sea and Bohai Sea was summarized as in Table 4. The data summarized in the table is mainly from annual Year Report of China Marine Environment (from 1990 to 2003) issued by State Oceanic Administration of China. Other data resources used in the table are from publications and Year Reports from local coastal provinces.

1.1.5 Approximate suffered area

Compared to that of the South China Sea, the areas that affected by red tides are relative large in Bohai Sea and Yellow Sea. The oceanographic, meteorological, and biological conditions may the major factors to decide this pattern of bloom distribution.

One of the characteristics of red tide occurrences in Bohai Sea and Yellow Sea is that of large areas. From recorded data of 1990-2004, the percentage of approximate suffered areas are: 100-1000km^2 (30.3%), 10-100km^2 (28.8), more than 1000 km^2 (22.8), less than 10 km^2 (18.1%). It means that in Bohai Sea and Yellow Sea, about 50% of red tide affected areas were larger than 100 km^2 (Fig. 3.2).

From 1998 to 2004, the yearly average areas of red tide in Bohai Sea and Yellow Sea is 4300 km^2. Except those of in 2002 and 2003, red tide areas in the other years are more than 2000 km^2, with the maximum of 9300 km^2 in 1999 (Fig. 3.3).

Compared to the Bohai Sea, red tide areas in Yellow Sea are much smaller. Generally, the yearly red tide area in Yellow Sea is less than 1000 km^2, with an average area of 560 km^2. Whereras in Bohai Sea, the yearly red tide area is more than 2000 km^2 in most years, with an average area of 3800 km^2 (Fig. 3.4).

Normally, compared to other seas in China, red tide suffered areas in the Bohai Sea and Yellow Sea are larger than that of the South China Sea, and less than that of the East China Sea(Fig.). In recent years, there were big red tides of *Prorocentrum donghaiense* (i.e. *Prorocentrum dentatum*) every year. The largest red tide suffered areas in the East China Sea were caused by this species. But in the Bohai Sea and Yellow Sea, the larger red tide suffered areas were caused by different causative species. They are: *Noctiluca scintillans, Skeletonema costatum, Ceratium furca, Gymnodinium* sp., *and Karenia mikimotoi*, ect.

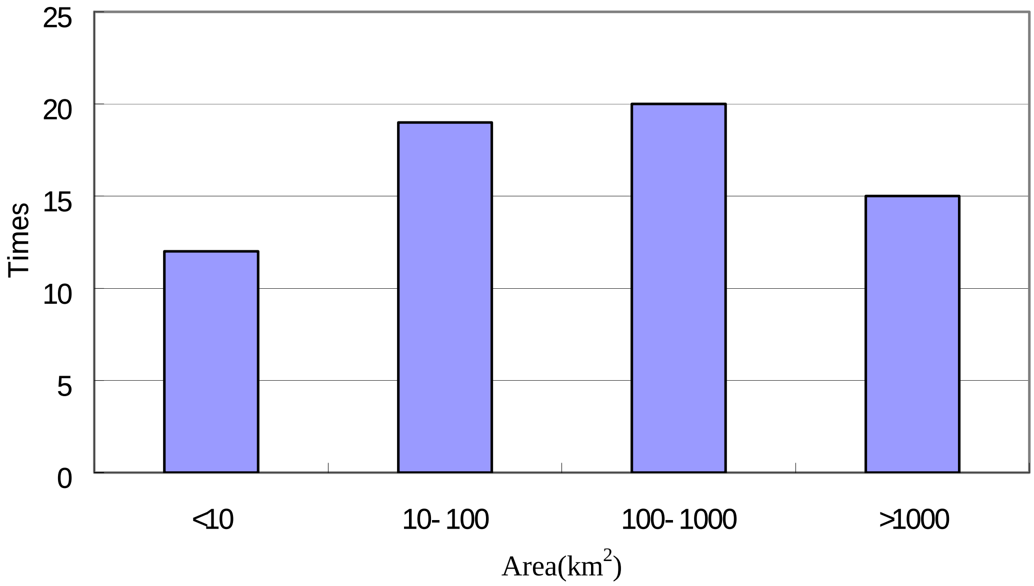

Figure 3.2 Histogram of red tide area in Bohai Sea and Yellow Sea(1990-2004)

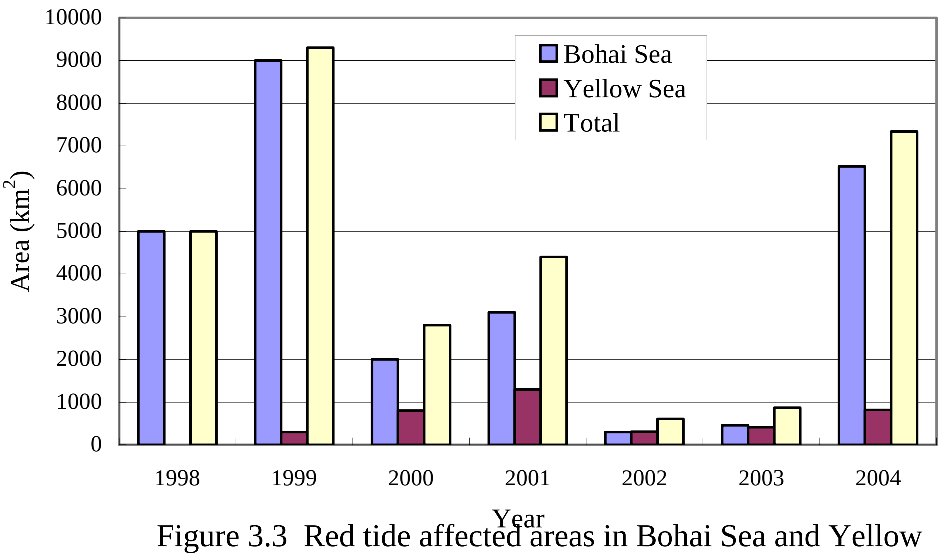

Figure 3.3 Red tide affected areas in Bohai Sea and Yellow Sea (1998-2004)

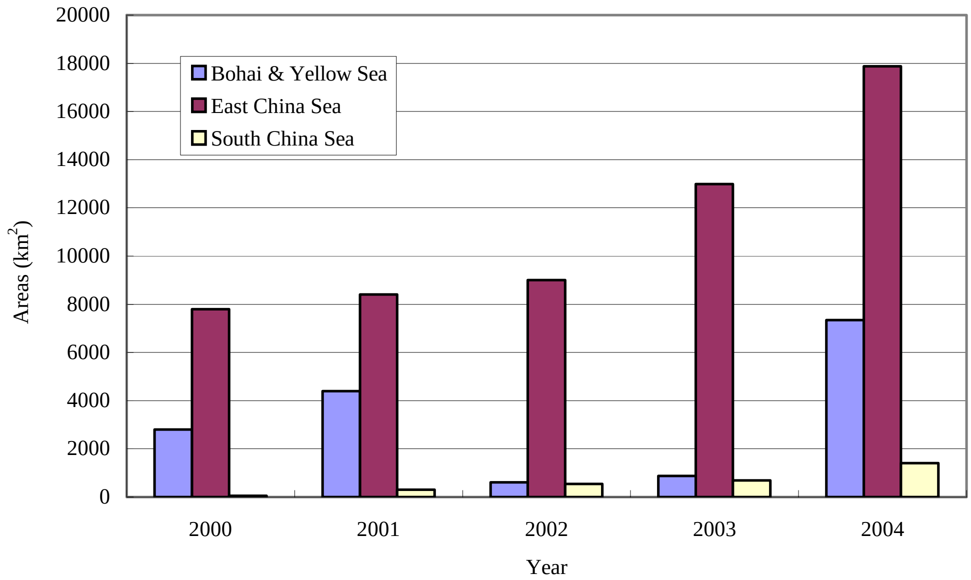

Figure 3.4 Comparison of red tide affected areas among the North China Sea (Bohai Sea and Yellow Sea), East China Sea, and SOuth China Sea

1.1.6 Duration

(1)Continuous days of red tide event

Because most of the red tide events were only recorded by the starting date without finish date, Yearly average of continuous days of red tide event is not easy calculated.

Most red tides occurred in Bohai Sea and Yellow Sea were less than a week, some of them only lasted one day or couple of days. But some red tide events lasted longer times. A red tide of *Ceratium furca* occurred in Bohai Sea in 1998 has lasted 40 days. Another red tide of *Eucampia zoodiacus* and *Chaetocerus socialis* occurred in the north Yellow Sea has lasted 20 days.

(2)Seasonal characteristics of red tide occurrence

Monthly change of red tide occurrence in Bohai Sea and Yellow Sea was revealed in Figure 3.5 . Red tides occur normally from February to October with high frequency from May to September. June, July and August is the most frequent season of the red tide occurrence.

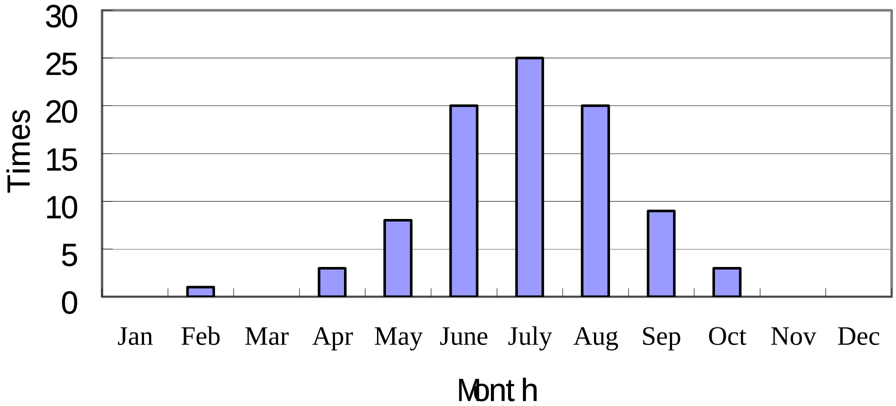

Figure 3.5 Monthly frequency of red tide occurrences in Bohai Sea and Yellow Sea （1990-2004）

1.1.7 Mitigation activity and effectiveness

(1)Preventive measures

Chinese central government and coastal local governments have made great efforts to control effluent of organic matters and nutrients from land for reducing eutrophication and red tide occurrences since 1980’s. They have implemented effluent control, public education, and improvement of sewage system. These were effective preventive measures from red tides.

The policy of wastewater control has enforced effluent standards such as COD, nitrogen, and phosphorous on facilities specified by central or local governments in order to meet water quality standards of bay areas.

In order to reduce nutrient effluent from domestics, governments have promoted public education to enhance public awareness of environmental protection. The policy of public education has also contributed reduction of organic matters and nutrients from public sector.

China is a developing country. Although governments have made great efforts to control environment quality, the water quality have not well controlled yet with high growth rate of economy. Compared to the Yellow Sea, water pollution in Bohai Sea was still considerate (Figure 3.6-3.7).

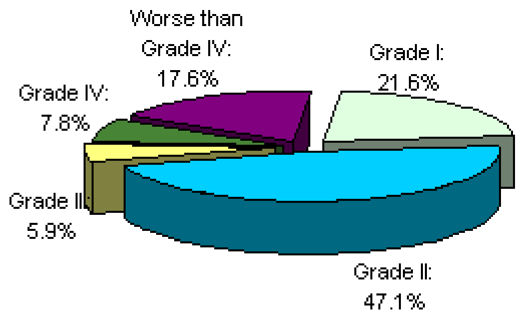

Figure 3.6　Water Quality of Bohai Sea in 2003

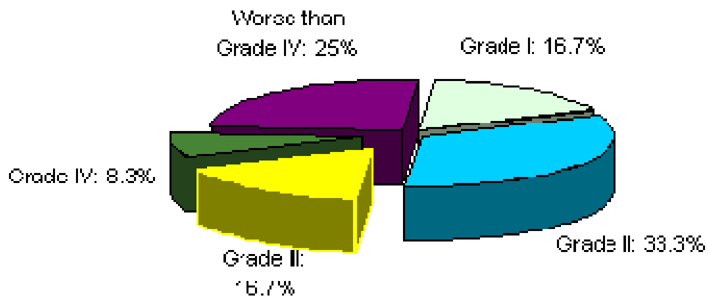

Figure 3.7　Water Quality of the Yellow Sea in 2003

Bohai sea is one of the country's most populous and developed areas. Fishery, salt production, transportation and oil and gas development have long been pillars of local economy in those areas.　In recent years, governments of Liaoning, Hebei and Shandong provinces and Tianjin Municipality around the rim have set ambitious goals on the development of the ocean-based economy. However, economic growth has also produced side effects -- pollution of seawater became more and more serious. So far Bohai Sea has been the second worst polluted waters (after the East China Sea) in China. The shape of the Bohai gulf limits the inflow and outflow of waters, which means the sea's self-clean ability is poor, and excessive discharge of pollutants makes the situation worse. As a result, the frequency and area of red tide are high in the region.

By the end of 2001, China government has launched "Blue Sea Action Program" in the Bohai rim area with the aim to halt discharge of industrial wastes, to monitor environmental pollution and to restore the damaged ecological system in the sea. At least 55.5 billion yuan (US$6.7 billion) in total investment will make the 15-year program the biggest ever effort of China to improve ocean environment. By the year of 2005, enterprises along the Liaohe, Haihe and Yellow rivers, which all end up running into the Bohai gulf, will have to meet the state standards of waste discharge, and a number of waste water disposal centers will be established in cities concerned. Discharges of major pollutants, such as nitrogen, phosphor, heavy metals and crude oil, will be cut by 10 to 20 percent by the same time.

Implementation of the plans for the periods of 2006-2010 and 2011-2015 is expected to further bring about decrease in pollutant discharges, establishment of sustainable ecological system, and eventual improvement of the ocean environment of Bohai

So far, four provinces off the Bohai Sea have banned phosphorus in all the offshore areas. The phosphorus content in municipal wastewater has been dramatically reduced. Nutrient effluent reduction is an essential component for mitigation measure against red tides.

(2)Reactive measures

So far there have not been any cost-effective measures against red tide in China. Direct measures against red tide are very limited applied. So far physical measures, such as aeration of seawater by pumping and fish-pen sinking, have sometimes been used by some fishmen in fish farm areas.

Clay–spraying is a practical and reactive measure against red tides. This measures has been studied in China since 1990’s. Laboratory studies have demonstrated that clay is one of the effective agents to eliminate many kinds of red tide cells. In China, clay–spraying has not yet been applied in large-scale open waters. But this measures has been successfully applied in some small-area shrimp ponds to eliminate red tides.

Several algaecide chemicals and natural products are testing for effective against red tides in China. The principal for those chemical algaecides are environmental friendly, cost-effective and high efficiency.

1.1.8 Damage

In the Bohai Sea and Yellow Sea area, seven (7) species brought about mass mortality of fish, shrimp, jellyfish and shellfish resulting in economic loss of fishery industry (Table Ⅲ-4). The causative species are: *Ceratium furca* , *Exuviaella cordata*, *Gymnodinium* sp., *Gymnodinium sanguineum*, *Noctiluca scintillans*. *Prorocentrum* sp., and *Noctiluca scintillans*. The most serious damage was caused by *Gymnodinium* sp. in Bohai Bay in 1989.

Table III-4 Fishery damage due to red tide in the Bohai Sea and Yellow Sea

Location	Month/year	Causative species	Fishery damage	
			Fish /shellfish species	Economic loss (million US$)
Huanghua, Hebei, Bohai Bay	Aug to Oct, 1989	*Gymnodinium* sp.	Fishes, shellfish and shrimp	38
Changhai county, Liaoning	1990	No data	scallops	2.5
Dalian	May to July, 1991	*Exuviaella cordata*	shrimp	No data
Yantai, Laizhou Bay	August, 1998	No data	No data	4.0
Bohai Sea	8-9/1998	*Ceratium furca*		15
Yantai, Bohai	Aug to Sep, 1998	*Gymnodinium sanguineum*	shellfish	No data
Liaodong Bay	July 2000	*Prorocentrum* sp.	jellyfish	No data
Zhuanghe, north Yellow Sea	August, 2000	No data	No data	15
Laizhou Bay	August, 2002	*Noctiluca scintillans*	fish	0.6
Laizhou Bay	August, 2002	*Skeletonema costatum*	fish	1.0
Liaodong Bay	May,2003	*Noctiluca scintillans*	fish	No data

1.2 Toxin-producing Plankton

1.2.1 Type of HAB

Most common shellfish poisonings in China are Paralytic Shellfish Poisoning (PSP) and Diarrhetic Shellfish Poisoning (DSP). They are caused by bivalves consuming specific toxin-producing planktons, and symptoms of intoxication would appear when these bivalves are consumed by humans. Species known to cause shellfish poisoning include *Alexandrium tamarense, A. catenella* and *Gymnodinium catenatum* for PSP, and several species from genus *Dinophysis* for DSP. So far PSP and DSP have been observed in China.

1.2.2 Causative Species

Most of the toxin monitoring and studies have been focused on shellfish species. In laboratory study, 4 species of *Alexandrium tamarense*, *A. minutum*, *A.catenella*, and *Gymnodinium catenatum* have been proved to be responsible for PSP. Several species of *Dinophysis fortii*, *D. ovata*, *D. acuminata and Exuviaella marina* were probably responsible for DSP in China.

1.2.3 Cell Density

Cell density of toxic plankton is not being monitored, while the toxicity of shellfish has been recorded. Though cell density is not propotional to the toxicity, the toxicity of shellfish seems to be an indicator of the cell density.

1.2.4 Location

The network of the toxicity monitoring of aquatic shellfish is under construction in China. So we lack of routine toxicity monitoring data. So far the toxicity monitoring have been conducted when there was a toxic bloom. For exporting seafood, shellfish toxicity is detected by National Administration for Quality Supervision, Inspection and Quarantine. Most data of shellfish toxicity is from individual researches.

The occurrence of toxin-producing plankton can be detected through the red tide monitoring stations. Because the production area of poisoned shellfish does not always coincide exactly with the blooming area of toxin-producing plankton, but shows their approximate distribution area.

Figure 3.8 shows Distribution of shellfish toxin in coastal China. The PSP and DSP are widely distributed in whole coasts of China. The toxin occurrence, frequency and shellfish toxin levels in southern parts of Chinese coast are greater than those in northern areas (Zhou *et al*. 1999).

Figure 3.8 Distribution of shellfish toxin in coastal China (Zhou et al. 1999)

There were two toxic blooms recorded in the Bohai Sea area. One was a bloom of *Ceratium furca* and *Dinophysis ovata* which covered 5000 km^2 in Bohai Sea area in 1998. DSP toxin was detected in the shellfish after the bloom ar the region. Another bloom was caused by *Exuviaella marina* in the shrimp pond in Dalian in 1999. DSP have also been detected in the shellfish collected from the same pond.

1.2.5 Approximate suffered area

Since the monitoring is being conducted not on the plankton density, but on the meat of the shellfish at the production site. Even though that DSP was detected after a 5000 km^2 bloom of *Ceratium furca* and *Dinophysis ovata*, the planktonic bloom area was not the exactly same as the toxin distribution. So extensiveness of the toxin suffered area is still unknown.

1.2.6 Duration

(1)Continuous days of toxin-producing plankton blooms

The toxicity of shellfish does not directly correspond to the cell density of toxin-producing plankton in the ambient water. Because there was no routine monitoring program on toxin, the relationship between toxin-producing plankton bloom and shellfish toxicity is unknown.

(2)Seasonal characteristics of toxin-producing plankton blooms

Only three toxin-producing plankton blooms have been recorded in the Bohai Sea and Yellow Sea. The causative species were *Dinophysis ovata, Exuviaella marina,* and *Alexandrium catenella*. The three blooms occurred in July, August and September respectively. This blooming pattern coincided exactly with the seasonality of bloom in the region. So that toxin-producing plankton blooms seems to be abundant from summer to autumn.

1.2.7 Mitigation activity and effectiveness

So far monitoring of the toxicity of shellfish has been an only substantial mitigation measures applied to the shellfish production area. Since monitoring of toxins contained in shellfish is mandatory only when there is a toxin-producing plankton bloom, or to those mollusk for exporting to other countries. If the monitoring results are higher than the quarantine limit, marketing of harvested shellfish from that area should be banned.

1.2.8 Damage

Shellfish intoxication has been wide spread in China, especially in southern China, since late 1960's. Common symptoms for PSP are numbness around lips and tongues after 30 minutes of consumption, and in severe conditions difficulties in moving bodies. In worst cases, it leads to death due to suffocation within 12 hours. The most death cases were because of PSP intoxication.

Table III-5 Shellfish Poisoning Events in China (Zhou et al, 1989)

Time	**Province**	**Toxin**	**Poison**	**Died**	**Shellfish**	**Algal species**
1967-1979	Zhejiang	PSP	423	23	*Nussarius succinstus*	ND*
1986	Taiwan	PSP	30	2	*Soletellina diphos*	*Protogonyaulax tamarense*
1986.11	Fujian	(PSP？)	136	1	*Ruditapes phillipenensis*	*Gymnodinium* sp. (?)
1989.2	Guangdong	PSP	5	-	*Pinna pectinata*	ND
1989.11	Fujian	(PSP？)	4	1	*Nussarius succinstus*	ND
1991.2	Taiwan	PSP	8	-	*Soletellina diphos*	*Alexandrium tamarense*
1991.3	Guangdong	(PSP？)	4	2	*Perna viridis*	ND
1994.6	Zhejiang	(PSP？)	5	1	*N. succinstus*	ND

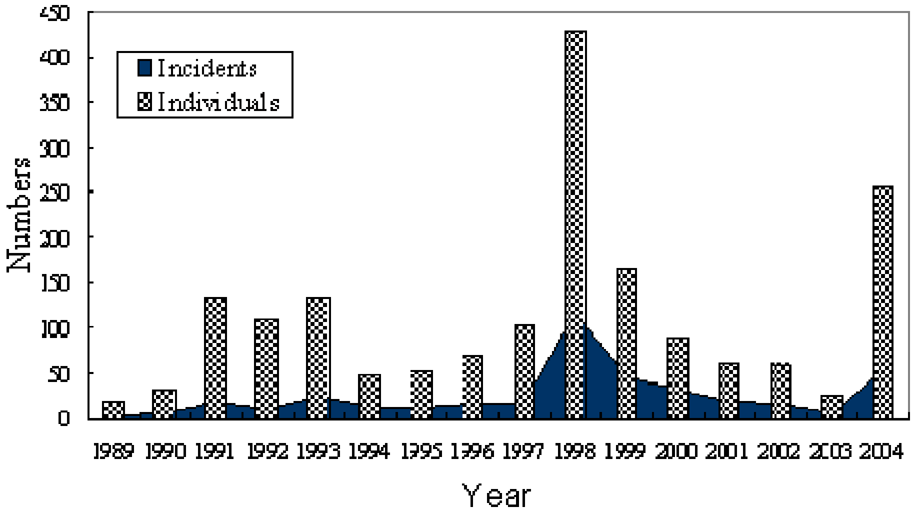

Fig. 3.9 Toxic events of ciguatera fish poisoning in Hong Kong
(Data from DH, Hong Kong)

More than 600 persons have suffered from shellfish intoxication since 1967 when the first patient was reported (Table III-5). 30 people died because of the PSP. Almost all intoxication cases were from southern China.

Ciguatera caused human intoxication in southern China (Fig. 3.9)

2. Monitoring

2.1 Red Tide

In China, State Oceanic Administration (SOA), State Environmental Protection Agency (SEPA), Department of Agriculture are in charge of red tide monitoring. SOA conduct routing monitoring along whole coasts of China. Department of Agriculture focuses coastal sea areas with fishery/aquaculture activities, while SEPA mainly monitoring estuary area receiving inflow of large rivers. Some coastal governments have their own fishery environmental laboratories to conduct red tide monitoring in native waters. Among these agencies, SOA is the most responsible for red tide monitoring in China.

2.1.1 Regular Monitoring on HAB

In China, monitoring on red tide occurrence has mainly been conducted by brunches of SOA in different seas. The North Sea Brunch in Qingdao, and Marine Environmental Monitoring Center in Dalian of SOA are carrying out the regular monitoring in the Yellow Sea and Bohai Sea.

The monitoring is conducted by ship cruising, as well as satellite remote sensing and aerial monitoring survey using an aircraft.

Based on dynamics of red tide occurrences, so far SOA have set up 33 key red tide monitoring sites where red tide frequently occurred. Figure 3.10 shows some of these key monitoring sites, with 4 in the Yellow Sea and Bohai Sea.

Figure 3.10　The Key Red Tide Monitoring Zone in Coastal China

2.1.2 HAB Trace Monitoring

Red tide is usually observed by water discoloration. Local people, usually fishermen, notify a nearby fishery environmental laboratory of local government of a red tide occurrence, researchers of the laboratory begin the observation and research on the red tide event. The researchers complete plankton sampling usually in several hours after the notification. And when the situation requires the continuous observation of the red tide event, the fishery laboratory conducts trace monitoring. If the red tide is a large-scale one, or if the causative species is potentially harmful, a brunch of SOA is informed to conduct further trace monitoring.

2.2 Toxin-producing Plankton

As mentioned earlier, the network for regular monitoring of toxic plankton and shellfish toxin is under construction. In recent couple of years, several laboratories of SOA, as well as some local fishery environmental laboratories have started monitoring shellfish toxins and toxin-producing plankton.

In addition to the monitoring by these laboratories, the guidelines of the Department of Agriculture issued a criteria for shellfish toxins (Table Ⅲ-6). Shellfish seldom sampled from culturing areas and seafood markets for poisoning monitoring in order to prevent shellfish poisoning and sustain safe supply of major shellfish products. Frequency of mentoring depends on dynamic of toxic plankton and shellfish harvest season in different seas.

Table III-6 Criteria set up by the guidelines for shellfish poisoning

	PSP	DSP
Stop of harvesting , shipping and marketing	-above 80 μg/kg of whole meat	Non-detectable

3. Progress of Researches and Studies to Cope with HAB

As red tides have been one of the major marine ecological disasters in China, Chinese central and local government have pay much attention to the problem. State Oceanic Administration, State Environment Protection Agency, Department of Agriculture, as well as Department of Science and Technology of China have suggested and issued some topics, as cited below, to be studied in future.

3.1 Prevention, Mitigation and Control of HABs

The goal of HAB researches and studies is to protect marine ecosystem, public health and natural resources. Therefore, studies of prevention, mitigation and control of HABs are priority in China.

Yu *et al.*(1995) studied the effects of different kinds and concentrations of clays, of the second component PACS（polyhydroxy aluminum chloride），and of pH on the coagulation rate of different HAB causative species. The results showed that the coagulation rate was more rapid in the system of kaolin than in that of montmorillonite, and that the kinetics equation for these systems described biomolecular reaction，in which the rate constant was varied in the process of coagulation．The potential energy and radius of interaction between clay particles and organism cells were the major factors controlling the coagulation rate. The increase of clay concentration could accelerate coagulation，but was not the most effective way．Adding PACS in clays appeared to be the most effective way of increasing the coagulation rate.

Pan *et al.* (2000) introduced ocean color remote sensing application system which has been developed by the Second Institute of Oceanography, SOA, located at hangzhou，China in 1997．The system includes the data receiving processing, distribution, calibration/validation and application．The ocean color remote sensing data have been applied in monitoring coastal water color environment，such as the spatial distribution of chlorophyll, suspended material concentration，red tide detection and coastal current study. The technique of monitoring and forecasting of HAB, especially large-scaled HAB, by satellite remote sensing are developing in China.

Sun et al. 2004) studied the inhibition effect of sophorolipid and removal efficiency of loess on *Cochlodinium polykrikoides* and *Alexandrium tamarense*. Algal sedimentation tests in the laboratory and in the field revealed that the combination of sophorolipid and loess showed synergistic effects both on the removal efficiencies and on the mitigation cost. The concentration of 1g/l loess and 5mg/l sophorolipid was determined as the optimum ratio for *C. polykrikoides* mitigation. In the field test, the effective concentration of loess and sophorolipid in the combination group was reduced to 10% and 25%, respectively, compared to the non-combination group, and the cost decreased more than 60%. The combination of loess and sophorolipid was considered as a promising novel method in harmful algal bloom mitigation.

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- Sun Xiaoxia, Young-Ju Lee and Joong-Ki Choi (2004). Synergistic effect of sophorolipid and loess combination in harmful algal blooms mitigation. *Marine Pollution Bulletin*, No.48: 863–872.

3.2 Mechanism of Large-scale and Harmful Blooms

The scale of HAB in China has been larger and larger. There are thousands of km^2 red tides in the East China Sea every year. Large-scaled blooms has also been frequently recorded in the Yellow Sea and Bohai Sea.

Red tides have long been considered to be linked with marine eutrophication. Zou and Dong (1983) first reported relationship of red tide occurrences with eutrophication in Bohai Bay. Xu et al (2004) studied the influence of nutrients input on the red tide occurrence.

Zooplankton community structure in the blooming area (Xu, 2004), and Distribution and germination of dinoflagellate cysts (Gu *et al*., 2004) were also closed related with red tide occurrences.

- Reference List -

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- Gu Haifeng, Lan Dongzhao, Fang Qi and Wang Zonglin (2003). Distribution and germination of A*lexandrium sp.* cysts in coastal areas of Southeast China Sea. *Chinese Journal of Applied Ecology*, 14(7): 1147-1150.

3.3 Taxonomy of HAB Causative Species

New taxonomic measures has been introduced and applied in rapid and accurate identification of HAB causative species.

Leo *et al*. (2004) have studied new technique for identification of dinoflagellates by using two dimension proteome reference maps.

Chen et al. (1999) have studied molecular identification of 7 strains of *Alexandrium* from the South China Sea. The result showed that rDNA ITS region could serve as criteria for the species identification.

- Reference List -

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- Chen Yueqin, Qu Lianghu, Zeng Longmei, Qi Yuzao and Zeng Lei, 1999. Molecular identification of red tide toxic Alexandrium tamarense-A. catenella from the South China Sea. Acta Oceanologica Sinica, 21(3): 106-112.

4. Literature Including Newly Obtained Information

Following sections show summaries of major papers published after 2000, which are stored in HAB Reference Database.（All papers that are published after 2000 are listed in appendices）. Section indexes conform to the categories in HAB Reference Database.

4.1 Occurrence and Monitoring

Qi Yuzao *et al* (2003) reports on the history of red tide occurrences and harmful algae blooms in China. The number of cases, ecology of some higher frequent red tide occurrence areas, damage to fishery, economic loses, and monitoring of plankton and toxins have been studied and reviewed.. Zhou Mingjiang *et al* (2001) have also summarized red tide occurrences and monitoring in China.

Wang *et al* (2004) reported the distribution of *Alexandrium* spp. and *Gymnodinium catenatum* cysts in surface sediments along the Chinese coasts from 2000 to 2001. Results showed that both cysts distributed widely in the China Seas, and were detected almost in all stations. *G. catenatum* occurred commonly but in Less concentrations than that of *Alexandrium*. Gu *et al* (2004) have also studied cyst formation，development of *Alexandrium tamarense* from Yangtse River Estuary and its relation to bloom dynamics.

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4.2 Mechanism and Environment

Zhou *et al* (2003) analyzed the main environmental characteristics such as currents and water body, diluted water and its turning direction, upwelling, front, nutrients and its sources, and plankton community in the Changjiang River estuary and its adjacent sea areas which could affect the growth, migration, assembling, resting and competition of harmful algae to form red tides. Analyses were also conducted to reveal features of the red tides events recorded in this area in terms of time, location and causative species.

Wang *et al* (2004) studied dynamics of macronutrients in East China Sea area and the role of these nutrients in red tide outbreaks.

Zheng *et al* (2002) have studied relationship between three isolated strains of bacteria and the alga *Alexandrium*. The results revealed that two of the isolated strains of bacteria could inhibit *Alexandrium* growth at a higher concentration, and promote *Alexandrium* growth at a lower concentration. The third bacteria strain didn’t show any effect on growth of *Alexandrium.*

Xu *et al* (2002) studied the physical oceanographic factors in the dynamic mechanism of the occurrence and spread of HAB by using numerical simulation.

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4.3 Physiology

When to search the key factors in causing big red tide in the East China Sea, Li *et al* (2003) demonstrated that under mesocosm condition, *Skeletonema costatum* grew better than *Prorocentrum dentatum* under high nutrients conditions, but *Prorocentrum dentatum* could survival better than *Skeletonema costatum* under nutrients limited conditions.

Shen et al (2000) studied characteristics and life cycle of *Phaeocystis globosa*, the species made serious problems in the South China Sea and now start to bloom in Bohai Sea.

Huang et al (2000) have studied effects of Fe and Mn on growth and cell size of *Alexandrium tamarense* under different culture conditions. Dong *et al* (2003) have also studied effect of Fe on physiological and biochemical features of *Heterosigma akashiwo*

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4.4 Taxonomy

The taxonomy of causative species of *Prorocentrum* in the East China Sea has drawn much attention by scientist. By comparison with original species description, Lu Douding *et al* (2003) suggested that the present one should be renamed. By detailed SEM study, Lu Songhui (2003) the species from the East China Sea was the same as those so-called *P. dentatum* in other waters.

New technologies have been employed in the identification of HAB species. Chen *et al* (2002) identified Phaeocystis species by using molecular identification and origin analysis. By means of clone and sequence analysis of 5.8S rDNA, Zhang *et al* (2004) distinguished two species of *Prorocentrum*.

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4.5 Mitigation and Management

Based on managerial experiences and data obtained by the functional department of the government in marine environmental protection, Yi (2003) expounds on the efforts in red tide management and disaster reduction from many angles including the monitoring systems and means as well as red-tide scientific research. She concluded that red tide management is an important task facing marine managerial workers in a longer time to come to further strengthen prediction, disaster prevention and mitigation of red tide in developing and using the ocean, and protecting the marine eco-environment.

Song *et al* (2003) described an effective clay-complex system for removal of different red tide causative organisms.

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4.6 Others

Zhou et al (2004) studied the effects of a PSP producing dinoflagellate *A lexandrium tamarense* on marine bivalves at their several important life stages: egg , S2shape larva, eyespot larva, juvenile and adult. The results showed that the hatching, survival, activity, filtration and growth were adversely affected by the alga, and the impact was significant with the increased algal density. The inhibitory effect on egg hatching was most significant, which the hatching rate was only 30% of the control when exposed to the alga at 100 cells/ cm^3 after 36 h. Further experiment showed that the algal culture, cells and cell fragments have the inhibitory effect, but no effect from the cell free medium, cell contents and standard STX. The results indicated that the alga can produce unknown toxins, rather than PSP, associated with the cell surface. Li *et al* (2002) studied effect of toxic dinoflagellate *Alexandrium tamarense* on growth and energy budget of two marine bivalves.

Yan *et al* (2001) studied a toxicity bioassay by using bloom seawater during a bloom in Jiaozhou Bay in July 2000. The results showed that both the bloom seawater collected *in situ* and the algae cultured in f/ 2 medium in laboratory had acute toxic effects on *Artemia salina*. At 24h , the survival rates of *A. salina* were 83 and 73 % , respectively. The toxicity to mouse were in a range of equivalent to STX 0. 87～1. 8μg/L. While *Neomysis awatschensis* was not apparently affected. Suggestion to apply these bioassay methods in the toxicity assessment of HAB events and report any of the results to relative authorities as indiscerptible part of an HAB report were suggested.

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5. Training Activity to Cope with HAB

The following section describes the training activities conducted nationally and internationally.

5.1 Training Activity on National Basis

The red tide related training courses have been organized by departments of Chinese government. These government departments include State Oceanic Administration (SOA), State Environmental Protection Agency (SEPA), Department of Agriculture. The objectives of courses depended on different organizations. Examples of courses are given in Table Ⅲ-7.

Table III-7　Training courses held in China

Course number	Date and Venue	Objectives	Trainee	Traner	Period	Content
1	2002, National Marine Environment Monitoring Centre, SOA, Dalian	• monitoring marine environments related to red tide; • identification of red tide causative species; • toxin analyse	Personnel from marine environment monitoring centres in different brunches of SOA in charge of red tide / shellfish poisoning problems	Scientists and experienced researchers from Centres and Institutes of SOA	7 days	• monitoring marine environments related to red tide; • toxin analyse
2	September 2001, Institute of Oceanography, Chinese Academy of Science, Qingdao	Improvement of HAB toxin detection techniques	Personnel from universities and institutes in charge of red tide / shellfish poisoning problems or interest in red tide study.	Scientists from China and Germany	10 days	HPLC techniques for detection of PSP and DSP
3	10-21/9/2002, Institute of Oceanography, Chinese Academy of Science, Qingdao	Improvement of the participant skills in disease control in shrimp and mollusk	Personnel from universities and institutes interested in fisheries study.	Scientist from institutions in fisheries	11 days	Lecture and round table discussion on healthy aquaculture and disease control in shrimp and mollusk.
3	July 2004, Zhoushan Marine Environment Monitoring Centre, Zhoushan, Zhejiang	Improvement of red tide related marine environments monitoring.	Personnel from environment monitoring center of environmental authorities in coastal Provinces.	Experienced experts from SEPA	7 days	• red tide related marine environments monitoring; • identification of harmful common species; • toxin detection

5.2 Training Activity on International Basis

Chinese scientists have participated in the international programs for technical training relating to HAB. So far Chinese scientists and students have participated 11 training courses organized by IOC, IOC/APEC, IOC/WESTPAC, IOC/DANIDA. These courses focused on biology, taxonomy, ecology, toxicology, monitoring of harmful algal blooms. The courses that Chinese scientists participated are listed in Table Ⅲ-8.

Table III-8 International Training Courses Attended by Chinese Scientists in 1995-2004

No	Date and Venue	Course Name	Objectives	Content	Organization/sponsor	Trainees
1	17-21/7/1995, School of Fisheries Science, Kitasato University, Iwate, Japan	IOC/WESTPAC Training Workshop on Monitoring of PSP Plankton and Shellfish Toxicity	Training participant skills on taxonomy of HAB causative species and toxicity test, improvement in designing and implementing a monitoring programme	Lectures, field sampling, Lab practical, round table discussion. Lectures were focus on taxonomy of harmful microalgae, toxin chemistry.	IOC/UNESCO; Asian Natural Environmental Science Centre (ANESC) of the University of Tokyo; School of Fisheries Science, Kitasato University; Faculty of Agriculture, Tohoku University	Lu Songhui Institute of Hydrobiology, Jinan University
2	28/2/1997-8/3/1997, Asian Natural Environmental Science Centre (ANESC) of the University of Tokyo, Japan	IOC/WESPAC Training Course on Species Identification of Harmful Microalgae	Training participant skills on taxonomy of HAB causative species in order to monitor HABs; developing capability in WESTPAC countries for management of HAB events	Lectures, lab practical, round table discussion on monitoring technology and species identification of marine microalgae.	IOC/WESTPAC, Asian Natural Environmental Science Centre (ANESC) of the University of Tokyo, JAPAN.	Huang Changjiang Institute of Hydrobiology, Jinan University
3	23/7/1997-6/8/1997, IOC Science and Communication Centre on Harmful Algae, Botanical Institute, University of Copenhagen, Denmark.	IOC/DANIDA Training Course on the Taxonomy and Biology of Harmful Marine Micralgae.	Training participant skills on taxonomy of HAB causative species.	The training course included lectures, practical, discussions. Lectures were focus on taxonomy, ecology, toxin chemistry and monitoring of HAB.	IOC/DANIDA, IOC Science and Communication Centre on Harmful Algae, Botanical Institute, University of Copenhagen, Denmark.Botanical Institute, University of Copenhagen, Denmark.	Li Ruixiang The First Institute of Oceanography, State Oceanic Administration
4	12-18/10/1997, IOC Science and Communication Centre on Harmful Algae, Botanical Institute, University of Copenhagen, Denmark.	IOC/APEC Training Course on Harmful Marine Micralgae.	Training participant skills on taxonomy of HAB causative species.	The training course included lectures, practical, discussions. Lectures were focus on taxonomy, ecology, toxin chemistry and monitoring of HAB.	IOC/APEC IOC Science and Communication Centre on Harmful Algae, Botanical Institute, University of Copenhagen, Denmark.Botanical Institute, University of Copenhagen, Denmark.	Lu Songhui Institute of Hydrobiology, Jinan University

5	10-30/5/1998, Marine Botany Laboratory of the Stazione Zoologica 'Anton Dohrn', Naples, Italy	Advanced Phytoplankton Course: Taxonomy and Systemtics	Advanced training on taxonomy of marine phytoplankton	Instructions and microscopic examination of phytoplankton, special techniques for using LM and SEM, techniques for establishing and maintaining clonal culture.	Stazione Zoologica 'Anton Dohrn'/IOC, Marine Botany Laboratory of the Stazione Zoologica 'Anton Dohrn', Naples, Italy	Lu Songhui Institute of Hydrobiology, Jinan University
6	24-30/8/1998, School of Fisheries Science, Kitasato University, Iwate, Japan	Training Course on PSP Toxin Monitoring	Improvement of skills in designing and implementation of PSP monitoring programme	Lectures, practical, round table discussion on PSP monitoring and toxin chemistry	IOC/WESTPAC School of Fisheries Science, Kitasato University, Iwate, Japan	Jiang Tianjiu Institute of Hydrobiology, Jinan University
7	14-27/8/2000, IOC Science and Communication Centre on Harmful Algae, Botanical Institute, University of Copenhagen, Denmark.	IOC-DANIDA Training Course on the Taxonomy and Biology of Harmful Marine Microalgae	Training participant skills on taxonomy of HAB causative species.	The training course included lectures, practical, discussions. Lectures were focus on taxonomy, ecology, toxin chemistry and monitoring of HAB.	IOC/DANIDA, IOC Science and Communication Centre on Harmful Algae, Botanical Institute, University of Copenhagen, Denmark.Botanical Institute, University of Copenhagen, Denmark.	Lu Douding The First Institute of Oceanography, State Oceanic Administration, and Ironside H. Y. Lam, The Department of Ecology, The University of Hong Kong.
8	19-24/3/2001, Chulalongkorn University and Burapha University, Bankok, Thailand.	The 5th IOC/ WESTPAC Training Course on Ecology and Physiology of Harmful Algae	Improvement of research capability on ecology and physiology of harmful algae.	Lectures, practical and round table discussion on ecology and physiology of harmful algae. Development of monitoring skills on detecting PSP causative dinoflagellates and PSP toxins in shellfish.	IOC/WESTPAC, Chulalongkorn University and Burapha University, Bankok, Thailand.	Wang Yan and Xu Ning, Institute of Hydrobiology, Jinan University
9	6-17/8/2001, IOC Science and Communication Centre on Harmful Algae, Botanical Institute, University of Copenhagen, Denmark.	IOC-DANIDA Advanced Training Workshop on the Taxonomy of Harmful Marine Microalgae	Advanced workshop focusing on toxic species identification, species intercalibration, fixation and sectioning for TEM, cell counting techniques, data interpretation.	Further improvement of participants in identification of important toxic species focusing on *Alexandrium* and *Pseudo-nitzschia*, and skills in using TEM.	IOC/DANIDA, IOC Science and Communication Centre on Harmful Algae, Botanical Institute, University of Copenhagen, Denmark.Botanical Institute, University of Copenhagen, Denmark.	Lu Songhui Institute of Hydrobiology, Jinan University

10	13-18/5/2002, Marine Science Institute, University of the Philippines, Malina, Philippines	The 6th IOC/ WESTPAC HAB Training Course on Advanced Techniques on Characterization of Harmful Algae Species – Chemistry and Biology	Improvement of research capability on ecology and physiology of harmful algae.	Lectures and practical on taxonomy and chemistry of harmful marine microalgae. Technique session included plankton identification by LM, cyst processing and observation	IOC/WESTPAC	Jiang Tianjiu and Chen Jufang, Institute of Hydrobiology, Jinan University.
	1/2004, Vienam	The Advanced Training Course on Biology and Taxonomy of Hamful Microalgae.	Improvement of skills on taxonomy and ecology of harmful algae.	The training course included lectures, practical, discussions. Lectures were focus on taxonomy, ecology, toxin chemistry and monitoring of HAB.	IOC/WESTPAC	Jiang Tianjiu Institute of Hydrobiology, Jinan University, and Zhao Di South China Sea Institute of Oceanography, The Chinese Academy of Science.
11	21-27/8/2004, Nagasaki University, Japan	IOC/WESTPAC Technical Standardization Meeting (Lecture Courses) for TTR Project "Dinoflagellate Cyst Mapping" of Harmful Algal Bloom (HAB) Programme	1. Building up a standard method for sampling, identification and counting of cysts; 2. improvement of international exchange and collaboration of HAB study	Lecture; filed sampling; sample treatment, identification and data processing; research exchange and collaboration.	IOC/WESTPAC	Gu Haifeng The second Institute of Oceanography, State Oceanic Administration ; and Wang Zhaohui Institute of Hydrobiology, Jinan University

6. National Priority to Cope with HAB

HAB problem has been one of the marine ecological disasters in the coastal China. Ecological deterioration, fishery losses and toxic events have made 100 million(Chinese RMB) economic losses every year. This chapter introduces the activities of the Chinese Government to cope with HAB. Management, mitigation and control for HAB are priorities to Chinese Government. But these priorities are based further scientific studies.

6.1 Management of Eutrophication

Although there are no direct evidence that red tides are induced by eutrophication. It is clear that frequency of red tides are closely related with eutrophication. Examples are widely distributed in coastal China. The high frequency area of red tide occurrences such as Tolo harbour and Pearl River Estuary in the South China Sea, the Changjiang River Estuary in the East China Sea, Bohai Bay and Liaodong Bay. in Bohai Sea, are all highly eutrophicated.

The most of exterior rivers of China are flowing into ocean. The total drainage area reaches to 4.33 million km^2. The annual water amount entering sea was $17243x10^8$ m^3---about 64% of total annual runoff of China. The high level nutrients are inputted by big rivers such as Yellow River, Liao He River, Hai He River, Changjiang River and Pearl River. Besides, with the higher rate of economic development, industrial effluence and sewage discharge in coastal provinces make the situation worse.

State Environment Protection Agency, State Oceanic Administration of Chinese Government, and local governments around Bohai Sea now realize that control of eutrophication will be the first step to cope with HAB. The “Blue Sea Action Plan” program has been jointly mapped out to gradually mend the Bohai Sea's ecological system that has been deteriorating due to pollution and irrational exploitation of ocean resources. Same action plans have also been implemented in other seas against eutrophication.

6.2 Promotion and Improvement of Monitoring Network

Monitoring network for red tides has been proved very useful in red tide detection and early warning. The construction of nation-wide red tide monitoring network in China started at the end of 1990’s. Although 33 monitoring zones has been set up in different areas in Chinese coasts, the consistent monitoring of target harmful algal species and shellfish toxins are not enough. So improvement of the monitoring network is another priority to cope with HAB in China.

6.3 Early-warning and Mitigation System

The widespread expansion of HABs throughout Chinese coastal waters has led to increasing stress on government agencies responsible for protecting marine resources, aquaculture, public health and providing timely, accurate information to citizens, policymakers and businesses dependent on the health of these waters. local agencies that did not need to monitor have been forced to expand monitoring efforts with significantly raised costs. The inability to accurately predict the onset of blooms before they occur can be detrimental to businesses in these regions, among them commercial harvesters, aquaculturists, recreational fishermen, seafood handlers and those in the tourism industry. Clearly, there is a strong need for a monitoring, detection and mitigation system that will enable local and state agencies to work together in developing early warning systems on bloom occurrence, development, transport and providing accurate mitigation measures – such capabilities will make it possible to develop realistic mitigation strategies that minimize the risks to human health and reduce the economic impacts.

6.4 Toxin Monitoring and Detection

Although PSP and DSP have been detected in whole coasts of China, and ciguatera in southern China, toxin monitoring system in China is incomplete. The lack of sensitive assays and specific toxin standards were the major impediment to effective management of harmful algal blooms in China. Modern instrument methods offer new potential in the detection and identification of trace amounts of individual toxins. However, routing monitoring of HAB related toxins, as well as accurate information on the full spectrum of effects, and the amount of toxin leading to these effects is generally unavailable for many toxins. These problems have been priorities to be investigated.

7. Suggested Activity for the NOWPAP Region

HABs are common marine ecological disasters to all NOWPAP countries. The problem causes not only the adverse effect on fisheries and aquacultures, but also affect human health in the region. Blooms of *Cochlodinium* are good example. Same existent species in the region, such as *Karenia mikimotoi, Heterosigma akashiwo, Chattonella* are well-known HAB causative species in the region. For fighting common problems, some activities are suggested for the NOWPAP region.

7.1 Promotion of Data and Information Network

NOWPAP waters are shared by four countries. A common data and information network of HAB monitoring is very useful and necessary to all countries in the region. Much of the detailed information on environmental variability in coastal regions of NOWPAP countries is included in the network. Data includes species composition of phytoplankton, measurements of chemical and physical properties of the water from discrete samples or vertical profiles, as well as remote sensing data. The network can help data analysis in a systematic way. The monitoring data represent an extremely important resource for characterizing the temporal and spatial variability of HABs, particularly in the context of anthropogenic influences versus climate change in NOWPAP region.

7.2 International Cooperation

For better understanding and management of HABs, international cooperation is very important between countries in the NOWPAP region and with relevant international organizations. Information exchange, data sharing and cooperative studies are necessary for achieving the cooperation.

NOWPAP region comprised of four countries: Korea, Japan, Russia and China. Cooperation for research, monitoring, mitigation and management of HABs is very important further understanding and control of HAB problems. The Special Monitoring and Coastal Environmental Assessment Regional Activity Centre (CEARAC) of NOWPAP has provided such a platform for starting cooperation on HABs. Following this start point, more activities need to be done.

Except that of NOWPAP/CEARAC, there are other international organizations in the region, such as IOC/WESTPAC(Intergovernmental Oceanographic Commission /Western Pacific Committee), PICES(North Pacific Marine Science Organization) and GOOS(Global Ocean Observing System), to promote HAB monitoring and study in the region. Cooperation with these organizations are also important in the region.

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Appendices

i Abbreviation

- HAB: Harmful algae blooms
- NOWPAP: North-west Pacific Action Plan
- CEARAC: Coastal Environmental Assessment Regional Activity Centre
- SOA: State Oceanographic Administration of China
- SEPA: State Environmental Protection Agency of China
- PSP: Paralytic Shellfish Poisoning
- DSP: Diarrheic Shellfish Poisoning
- IOC: Intergovernmental Oceanographic Commission
- WESTPAC: Western Pacific
- UNEP: United Nations Environment Programme
- GOOS: Global Ocean Observing System
- PICES: North Pacific Marine Science Organization

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