Environmental and Health Effects Associated With Harmful Algal Bloom and Marine Algal Toxins in China[1]

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The frequency and scale of Harmful Algal Bloom (HAB) and marine algal toxin incidents have been increasing and spreading in the past two decades, causing damages to the marine environment and threatening human life through contaminated seafood. To better understand the effect of HAB and marine algal toxins on marine environment and human health in China, this paper overviews HAB occurrence and marine algal toxin incidents, as well as their environmental and health effects in this country. HAB has been increasing rapidly along the Chinese coast since the 1970s, and at least 512 documented HAB events have occurred from 1952 to 2002 in the Chinese mainland. It has been found that PSP and DSP toxins are distributed widely along both the northern and southern Chinese coasts. The HAB and marine algal toxin events during the 1990s in China were summarized, showing that the HAB and algal toxins resulted in great damages to local fisheries, marine culture, quality of marine environment, and human health. Therefore, to protect the coastal environment and human health, attention to HAB and marine algal toxins is urgently needed from the environmental and epidemiological view.

Key words: HAB; Algal toxins; Environment effect; Health effect

INTRODUCTION

Harmful Algal Bloom (HAB) has been spreading and increasing along the coast over the world in the past two decade, causing damage to the marine environment and threatening human life[1]. About 60-80 harmful or toxic phytoplankton species are responsible for causing the environmental and health effect by forming HAB and producing marine algal toxins. Since marine algal toxins are responsible for more than 60 000 intoxication incidents per year, with an overall mortality rate of 1.5% on a worldwide basis, most HAB researches are concerned with the species that pose a risk to human health and other mammals. Concerning the ecology and sustaining of environment, more researches regarding HABs and their effects on aquatic organisms have been carried out recently[2]. The problem of the occurrence of HAB and toxic algal incidents has not been fully recognized in the Chinese mainland until some HAB incidents caused great loss to the fishery and marine culture in late 1970s and a shellfish toxin investigation was undertaken along the Chinese coast in 1998-1999[3,4]. To further explore the HAB formation mechanism and its harmful effect, a

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National Basic Research Priority Project (CEOHAB, Ecology and Oceanology of Harmful Algal Bloom of China) has been launched since 2001, while nearly at the same time, a national monitoring system has been set up along the Chinese coast. However, there is still an obvious gap in the epidemiological knowledge of HAB and marine algal toxins in the Chinese mainland. To better understand the effect of HAB and marine algal toxins on marine environment and human health in China, this paper gives the general information on HAB occurrence and marine algal toxin incidents, as well as their environmental and health effects.

BACKGROUND OF HAB AND MARINE ALGAL TOXINS

HAB and Red Tide

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. The phenomenon was previously called “red tide”. This natural phenomenon has been found long time before. The first red tide reported to kill fish was that described in the Old Testament of the Bible（Exodus 7:20-21）: “all the water of the river was changed into blood. The fish in the river died and the river itself became so polluted that the Egyptians could not drink the water” [1].

Presently HAB has been used to refer to the phenomenon, which focuses on the toxic or harmful event. According to CEOHAB, it is defined as: proliferation of algae in marine or brackish waters which can cause massive fish kills, contaminate seafood with toxins, and alter ecosystems in ways that humans perceive as harmful, while it also includes the event in which some species cause toxic effects even at low cell densities, and in which not all causative species are technically “algae”. A wide range of organisms are involved, including dinoflagellates, other flagellates, cyanobacteria, diatoms, and other phytoplankton.

Toxic and harmful blooms cause negative impacts and economic losses in many parts of the world. There are four categories of deleterious effects, including risks to human health, loss of natural or cultured seafood resources, impairment of tourism and recreational activities, and damages to non-commercial marine resources and wild life[5].

Marine Algal Toxins

Phytoplankton species that produce toxins are currently included in the broad term HAB. Among all the above adverse effects of HAB, “risk to human” might have been better understood since it threats human health and even life. To the current knowledge, approximately 20 species of dinoflagellates, and one diatom are known to produce toxins. Shellfish and finfish in affected waters could accumulate the toxins. When ingested by humans, the toxins could cause neurological or diarrheic symptoms. The toxins could also influence the life activity of marine organisms directly or through food chain[6]. Five major classes of shellfish poisonings have been identified by the symptoms of humans: paralytic shellfish poisoning (PSP), diarrheic shellfish poisoning (DSP), amnesic shellfish poisoning (ASP), neurotoxic shellfish poisoning (NSP); ciguaterra fish poisoning (CFP). Their basic structures are shown in Fig. 1.

PSP

There are over 20 water-soluble compounds of STX congeners responsible for PSP produced by *Alexandrium*, *Gymnodinium*, and *Pyrodinium* species. The early PSP record was

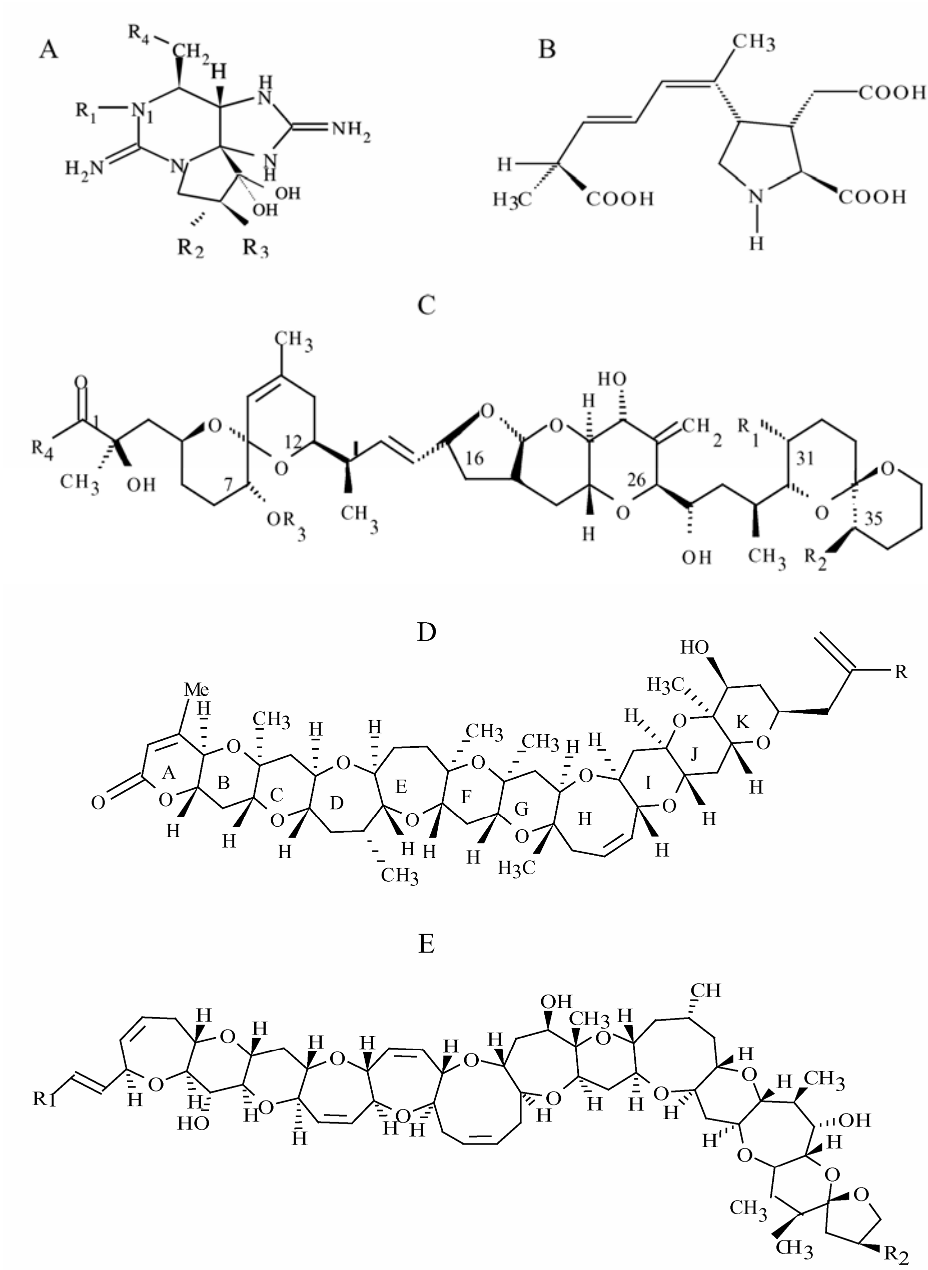

FIG. 1. Basic structure of marine algal toxins (A) Saxitoxin, (B) Dpmoic acid, (C) Okadaic acid, (D) Brevetoxin, (E) Ciguatoxin.

British Columbia in the west coast of Canada, with the death of a member of Capt. George Vancouver's crew from eating mussels in 1793[7]. PSP can be fatal to humans due to respiratory failure when ingested in a small dose. Symptoms are neurological numbness, tingling and burning of the lips and skin, giddiness, ataxia and fever. Severe poisoning may lead to general muscular incoordination, and respiratory distress[8]. STX could bind with high affinity to site 1 on the voltage-dependent sodium channel, inhibiting channel conductance and thereby causing blockade of neuronal activity.

DSP

DSP is generally resulted from okadaic acid and analogues, including the dinophysis toxins DTX-1, 2, and 3. These lipid soluble toxins are found to be produced by *Dinophysis* sp and *Prorocentrum lima*. Okadaic acid and DTX-toxins have been shown to cause injury to the intestinal mucosa, and are implicated in tumor promotion[9]. The first incidence of human shellfish-related illness occurred in Japan in the late 1970s. The major symptom was diarrhea, which is often mistaken as bacterial diarrhea.

ASP

ASP is caused by domoic acid produced by the diatom *Pseudo-nitzschia multiseries* (*Nitzschia pungens f. multiseries*). The first recorded occurrence of ASP was in Prince Edward Island, Canada in 1987 when about 100 persons became ill and several died after eating shellfish. Symptoms included loss of balance, nausea, headache, disorientation, and vomiting. The condition resulted in the permanent loss of short-term memory. These water-soluble toxins have also been recently shown to cause deaths in Californian sealions[10]. Domoic acid is a tricarboxylic amino acid that acts as an analog of the neurotransmitter glutamate and is a potent glutamate receptor agonist.

NSP

NSP is due to 10 currently identified lipid soluble brevetoxins, which are produced by the dinofalgellate *Karenia breve* (=*Gymnodinium breve*)[11]. Brevetoxins bind with high affinity to site 5 on the voltage-dependent sodium channel, resulting in persistent activation or prolonged channel opening. It was first documented in Florida in the 1950s. *G. breve* blooms occur almost annually in the Gulf of Florida, where they kill fish, and manatees[12]. No human deaths have been recorded due to NSP. However, symptoms of NSP include nausea, tingling and numbness of the perioral area, loss of motor control, and severe muscular ache. Inhalation of the organism aerosols irritate the eyes and nasal passages, leading to coughing and asthma-like symptoms[13].

CFP

CFP is resulted from lipophilic ciguatoxins (CTX) produced by the benthic alga *Gambierdiscus toxicus*. Herbivorous fin-fish subtropical and tropical, clams and marine snails may also accumulate the toxin. CTX intoxication can be fatal, producing symptoms similar to NSP toxins, although CFP cases are typically more severe and include vomiting and diarrhea. The Ciguatoxins are structurally related to the brevetoxin for binding to site 5 on the voltage-dependent sodium channel[14].

The LD_{50} of the above toxins and their regulations restricting for sale or harvest of shellfish in many countries including China are shown in Table 1. More recently, other algal toxins, including azaspiracid, the “fast acting toxins” (gymnodimine, the spirolides, and pinnatoxins), and *Pfiesteria* and estuary-associated syndrome have been reported and under investigation[15-18].

HAB AND MARINE ALGAL TOXINS IN CHINA

HAB Occurrence in China

The first documented HAB event in the Chinese mainland caused by *Noctiluca scintillans* and *Skeletonema costatum* along the Zhejiang coast in 1933 was recorded by H. Fei, which killed marine organisms such as razor clam and other shellfish species[19]. The Chinese government and scientists concerned started to pay greater attention to HAB after the extremely devastating *Prorocentrum minimum* bloom in the Bohai Sea in August 1977. This HAB event covered an area of 560 km^2 and lasted for 20 days, causing mass fish mortality and resulting in great losses to the local fishery[20]. With increased awareness and economic development along the coast of the Chinese mainland, the occurrence of HAB has increased dramatically each year. In each of three successive years from 1998, heavy HAB, a scale of several thousand square kilometers, occurred in the Bohai Sea, East China Sea or South China Sea. HAB has been increasing rapidly along the Chinese coast since the 1970s, and they occurred more frequently along the south coast than along the north coast. Thus, at least 512 documented HAB events have occurred from 1952 to 2002 in the Chinese mainland, although some of the events were defined as “red tide” referring to a water discolouration event. An average loss of more than RMB 10 million yuan (1.2 million US$) are related to HAB occurred each year. The main areas of HAB occurrence are the Bohai Sea, Changjiang Estuary and the South China Sea. The peak HAB seasons are likely delayed from the south to the north coast, which is March-May in the South China Sea, June-August in the East China Sea, and July-September in the Bohai Sea and the Yellow Sea[21].

As one of the most frequent HAB occurrence areas, Hong Kong first began its reporting of HAB events in the early 1970s. In 1983, Lam and Ho[22] pointed out that the increasing HAB and related fish-killing events in Hong Kong were correlated with increased urbanization of that region. From 1980 to 1997, 496 HAB events were recorded in Hong Kong waters[23]. As recorded, the most frequent HAB occurrence area in Hong Kong was at Tolo Harbour (involving more than 70% of the total HAB events), Mirs Bay and Port Shelter (all located at the north east of Hong Kong). In Hong Kong, 70% of the HAB occurred during the period from December to May.

In Taiwan, China, *Alexandrium minutum* has been a main causative HAB species. Blooms of this species were first recorded in a crab culture pond in Pintoung County in November 1986. Since the late 1980s, blooms of this species have caused mass mortality of cultured fish and grass prawn and PSP contamination of shellfish, as well as frequent intoxication of humans in Taiwan[4,24]. The species was classified as *Gonyaulax tamarensis*, or *A. tamarense* in the early literature[25].

Marine Algal Toxin in Coast China

Several studies on PSP toxin in shellfish and its causative organisms have been focused on Guangdong, Hong Kong and Taiwan[4,26-28]. In Hong Kong, PSP was first detected in shellfish samples in Tolo Harbor in 1985[29]. PSP in seafood from Hong Kong showed two peaks with the main peak occurring in spring and the other in autumn[30]. However, not until a recent investigation of PSP and DSP toxins along the Chinese coast, was it found that the two toxins were distributed widely along both the north and south coasts of the Chinese mainland[4]. This investigation also indicated that DSP was more frequently detectable than PSP along the Chinese coast. The frequency of occurrence and toxin levels of PSP in the southern coast areas were higher than those in the northern coast. Extremely high PSP toxicity (>20 000 MU/kg) was detected in shellfish samples collected in Tai Tam Bay, southeast of Hong Kong in March 1990 due to a bloom of *A. catenella* [31]. The highest level of DSP in the Chinese mainland, 10 micro g/g was found in blue mussel collected on Oct. 2, 1998 at Jvhua Island, in Liaodong Bay during a bloom of *Ceratium furca* and *Dinophysis fortii* [32].

TABLE 1

LD_{50} and MPL of Marine Algal Toxins

Toxin	LD_{50} (*i.p.*Mouse μg/kg)	MPL (μg/100 g Flesh)	MPL (Mouse Unit)
PSP	10	80	400
DSP	200	16 or 20	5
ASP	120	2000	Sensitivity Very Low
NSP	200	80	20
CTX	0.25-0.9	3.5	Sensitivity Too Low

Health and Environmental Effect of HAB and Algal Toxins

The HAB and algal toxins have resulted in great damages to local fisheries, mariculture, marine environment, and human health in China. Table 2 summarizes the HAB and marine algal toxin events during the 1990s in the Chinese mainland, Hong Kong and Taiwan. The records of shellfish poisoning events in the Chinese mainland showed that more than 1 800 people were affected and 31 people died[4,25]. Several illnesses were suspected to be caused by the consumption of DSP contaminated marine products in 1995[33]. CFP is also a frequent algal toxin problem in the Hong Kong area. More than 200 documented CFP poisoning events have occurred in Hong Kong since 1989, resulting in intoxication of more than 1 000 people. Although most of these CFP incidents were due to the consumption of imported coral reef fish, the causative HAB species *Gambierdiscus toxicus*, has also been found recently in local waters[34]. Similar to Hong Kong, PSP and CFP are two of the most frequent algal toxins in Taiwan[25]. Since less awareness of marine algal toxins in the public health system in the Chinese mainland, the statistical data might be much less than the real situation.

In a recent investigation of CEOHAB, it was found that toxic *Alexandrium* sp. reached to the density of 10^5 cells/L, together with *Prorocentrum donghaiense* 10^7 cells/L in a massive bloom covering 1000 km^2 in May 2002 in the vicinity sea area of Zhoushan Islands in East China Sea[35]. PSP-like poisoning event by eating marine snail *Nussarius succinstus* occurred in Zhejiang, Fujian, Guangdong provinces in recent years. More than fifty people were poisoned, and three were killed in May 2002 and the species has been banned for sale during that period[36]. The cause is still under investigation. Therefore, to protect the environment and human health, great attention should be paid to HAB and marine algal toxins from the environmental and epidemiological view.

TABLE 2

HAB and Marine Algal Toxin Events During the 1990s in China

Type	Location Name	Latitude	Longitude	Level	Impact	Organism	Time
PSP	Yantai	121°10'	37°30'	133		Scallop *Chlamys farreri*	1997.9.22
PSP*	Zhejiang				Five People Poisoned and One Died	*Nussarius succinstus*	1994
PSP							
	TaiTam Bay, HK	114°20'	22°10'	max>400 000		Shellfish	1990.3
	Mirs Bay, HK	114°10'	22°40'	80 000		Shellfish	1990.4
	Dapeng Bay	114°10'	22°40'	300		Scallop	1990, Spring
	Dapeng Bay	114°10'	22°40'	120		Scallop	1990, Autumn
	Dapeng Bay	114°10'	22°40'	120	Four People Poisoned and Two Were Killed on March 28	Scallop, Mussel	1991, Spring
	Dapeng Bay	114°10'	22°40'	100		Scallop	1991, Autumn
	Daya Bay	114°10'	22°30'	514		Scallop, Mussel	1991, Spring
	Hong Kong	114°10'	22°20'	320		Scallop, *Chlamys nobilis*	1996.9.17
	Daya Bay	114°10'	22°30'	2340		Scallop visceral *Chlamys nobilis*, *Perna viridis*	1999.1
	Dapeng Bay	114°10'	22°40'	174		Scallop Visceral *Chlamys nobilis*	1999.1
	Taiwan	120°20'	22°30'	9800/visceral, 600/other tissue	Eight People Were Poisoned	*A.minutum, Hiatula* sp.	1991.2
DSP	East Coast of Liaodong Bay	120°40'-121°50'	40°-41°	max 1000		Bivalves	1998.9.29-10.2
	Tianjin	117°30'	39°	30.43		Scallop *Chlamys fareri*	1996.9.5

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Type	Location Name	Latitude	Longitude	Level	Impact	Organism	Time
	Qingdao	120°20'	36°	54.29		*Venerupis philippinarum*	1997.3.25
	Zhoushan	122°	30°	29.71		Scallop	1996.8.5
						Chlamys farreri, *Mytilus edulis*	
	Shenzhen	114°	22°40'	22.14		*Mytilus edulis*	1997.7.3
		114°	22°40'	84.57		*Mytilus edulis*	1997.8.3
	Hong Kong	114°	22°10'		Several People Illness From Eating Shellfish From Mirs Bay		1992
		114°	22°10'		Several Illness From Marine Products Resulted 1 000 People		1995
CFP	Hong Kong	114°	22°10'		Poisoned. Mostly Caused by Imported Fish. Maricultured		
Animal/Plant Mortalities	Liaodong Bay, Bohai Bay and Laizhou Bay	118-121°	37°30'-40°30'		Shrimp, Shellfish Affected	*Ceratium furca*	1998.9.16-10.19
	Tianjin and Huanghua	118°10'	38°21'		100 Million Jellyfish Were Killed		2000/07/20-21
	Yantai	121°30'-122°	37°30'-40°30'		Scallop, Seacucumber, Abalone and Benthic Fish Killed	*Gymnodinium sanguineum*	1998.08
	East coast of Zhejiang	122°	28°25'		Fish, Shellfish Killed		1990.5
	Xiamen	118°08'	24°30'		Fish Killed	*Chaetoceros* sp.	1997
	Weitou Bay to Quanzhou Bay	24°3-25°10	118°30-118°50		Fish, Clam Died	*Cochlodinium* sp.	1990 mid June
	Xiamen	118°08'	24°30'		Shrimp Killed	*Alexandrium tamarense*	1994
	Quanzhou to Shanwei	22°50'-25°10'	115°20'-118°50'		Fish Killed	*Phaeocystis pouchetii*	1997
	Raoping	117°10'	23°40'		Fish Killed	*Phaeocystis pouchetii*	1999
	Dapeng Bay	114°10'	22°40'		Fish Killed	*Chattonella marina*	1991.3.2

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Type	Location Name	Latitude	Longitude	Level	Impact	Organism	Time
	Pearl River Estuary, HK	112°-114°20'	21°30'-22°20'		Fish Killed	*Karenia mikimotoi*	1998.3-4
	Daya Bay	114°40'	22°30'		Fish Killed	*Chaetoceros spp.*	
		114°40'	22°30'		Fish Killed	*G. mikimotoi*	1998.5
	Shenzhen Bay	114°	22°40'		Fish Killed	*G. intriatum and Phaeopolykrikos harmanii*	
	Shengzhen-Huiyang	114°40'-115°	22°20'		Fish Killed	*Srippsiella trochoidea*	2000.8.17-20
	Daya Bay	114°40'	22°30'		Fish Killed	*Srippsiella trochoidea, Peridinium quinquecorne*	2000.9.3-6
	Pingdong, Taiwan	120°20'	22°30'		Cultured-fish Killed	*Alexandrium minutum*	1992/06
					Cultured-fish Killed	*A. minutum*	1992/12
					Cultured-fish Killed	*A. minutum*	1993/03
					Cultured-fish Killed	*A. minutum*	1995/03
					Cultured *Hiatula* sp. Contain Toxins		1996/06
					Cultured-fish Killed	*A. minutum*	1997/01
					Cultured-fish Killed	*A. minutum*	1997/03
					Cultured-fish Killed	*A. minutum*	1997/04
					Cultured-fish Killed	*A. minutum*	1997/02
	Kaohsung, Taiwan	120°10'	22°30'		Cultured-fish Killed	*A. minutum*	1997/05
					Cultured-fish Killed	*A. minutum*	1997/04
					Cultured-fish Killed	*A. minutum*	1997/05
					Cultured-fish Killed	*A. minutum*	1997/12
					Cultured-fish Killed	*A. minutum*	1998/01

Note. PSP unit: micro g STX equiv./100 g wt; DSP unit: micro g /100 g wt. *The toxin has not been confirmed but caused PSP like symptom.

DISSCUSSION

Since poisoning can be resulted from the ingestion of seafood contaminated with marine algal toxins, it is important for clinicians and other units in the public health department in China to establish an adequate surveillance system so that poisoned persons could be identified for further diagnostic investigation. Large-scale epidemiological studies are also needed to find its effect on human health.

The term of red tide is still widely used in the Chinese mainland, and the indication of red tide by water discoloration is adopted mostly in the routine marine environment monitoring. Since it is most important to protect the environment and human health, the priority should be given to the harmful and toxic event during the monitoring, and it is important to prevent intoxication by monitoring shellfish for the presence of these toxins.

The seas around China cover a large area of about 3 000 000 km^2. At present, however, The Chinese mainland, Hong Kong and Taiwan each utilizes different systems to monitor HAB. Therefore, for the greater China region, there might also be differences in monitoring methods and monitoring frequency as well as in defining HAB events. It is crucial for all areas to coordinate in reporting their various regional HAB and marine algal toxin poisoning events, in order to further develop and set up common and efficient HAB alarm systems. China also shares common sea areas with Korea, Japan, Vietnam, the Philippines, etc. Therefore, as suggested by Asia Pacific Economic Cooperation (APEC), IOC Sub-commission for Western Pacific (WESTPAC) and North Pacific Marine Science Organization (PICES), regional and international coordination should be strengthened for better exchanging information on harmful, especially toxic algal bloom events.

HAB and marine algal toxins have become a potential influential factor on the marine environment and marine culture industry in China, and it is clear that in some case human activities may directly contribute to their occurrence. Therefore, we also recommend that focus be placed on the research which explores the relationship between human activity and HAB occurrence in key coastal areas, in order to better foster and maintain a sustainable development of both marine culture and healthy marine ecosystems along the Chinese coast.

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