Chapter 15
Harmful Algal Blooms in the Coastal Waters of China

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15.1 Introduction: Current Situation of HABs in the Coastal Waters of China

Harmful algal blooms are a natural ecological phenomenon caused by fast reproduction or accumulation of algae, which may have disastrous economic or ecological consequences, such as mass mortality of marine animals, seafood contamination, alteration of marine food webs, or deterioration of tourism industries. Typical HAB events include not only high-biomass blooms ("red tides" or "brown tides") formed by microalgae but also "green tides" caused by some macroalgal species [see also Chap. 16, Liu and Zhou (2018)]. In China, harmful algal blooms (HABs) are probably the most severe marine ecological problem. Under the support of Ministry of Science and Technology (MoST), National Natural Science Foundation of China (NSFC), Chinese Academy of Sciences (CAS), and State Ocean Administration (SOA), conducted under the umbrella of the Chinese Ecology and Oceanography of HABs (CEOHAB) Programme, a component of GEOHAB Asia [see also Chap. 14, Furuya et al. (2018)], many studies have been carried out to investigate the

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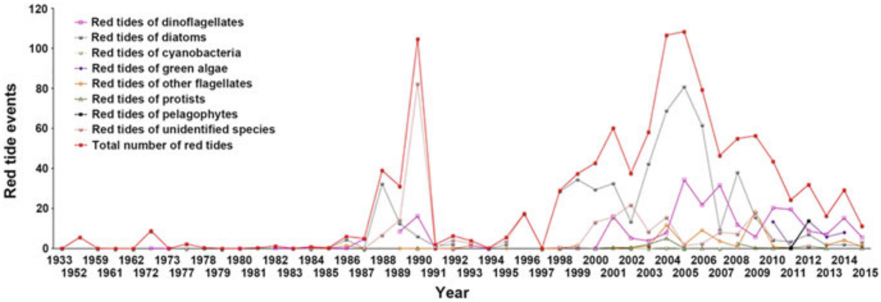

Fig. 15.1 Different red tide events recorded in the coastal waters of China (data from National Marine Environmental Monitoring Center, State Oceanic Administration)

mechanisms and impacts of HABs and to develop monitoring methods, control measures, and prevention strategies against HABs [see also Chap. 21, Yu et al. (2018)].

An increasing number of HAB events have been recorded in the coastal waters of China during the last two decades (Fig. 15.1). Before the 1990s, the recorded number of HABs (red tides with negative impacts) was quite limited. Most of the red tides were caused by nontoxic diatoms and affected a relatively small area of the Chinese marine waters. Since the year 2000, the recorded number of HAB events every year has reached 50−80. Many HABs have lasted for more than a month and have covered large areas up to thousands of square kilometres. In addition, the causative species of HABs also exhibited significant changes. The HABs are generally found in the coastal waters of the Bohai Sea, the East China Sea, and the South China Sea, and each sea area has its representative HAB problems. Green tides caused by green alga *Ulva* (*Enteromorpha*) *prolifera* have mainly taken place in the southern Yellow Sea and are described in more detail in Liu and Zhou (2018, Chap. 16).

15.1.1 Red Tides of Dinoflagellates in the East China Sea

In the East China Sea, the area adjacent to the Changjiang River estuary is the most notable region for red tide outbreaks (Zhou et al. 2001). Intensive red tides of dinoflagellates were first observed in this region at the beginning of the twenty-first century. Since then the red tides have become a recurrent phenomenon. The red tides of dinoflagellates, which can last from early May to the middle June each year, affect an area up to 10,000 km^2. The major causative species of the red tides, *Prorocentrum donghaiense* and *Karenia mikimotoi*, are harmful both to the aquaculture industry and to marine ecosystems. For instance, a red tide of *K. mikimotoi* in 2005 led to mass mortality of cultured fish in the sea area around Nanji Island, and the economic loss was estimated to be 30 million RMB (nearly US$4,500,000). In 2012, another red tide of *K. mikimotoi* destroyed the abalone aquaculture industry along the coast of Fujian Province, and the economic loss was around 2 billion RMB (nearly US$300,000,000).

The red tides of dinoflagellates in the East China Sea have been intensively studied during the last 15 years. The distribution pattern and dynamics of *P. donghaiense* red tides have been described, and the over-enrichment of nitrate from the Changjiang River has been shown to be a major reason for these dinoflagellate red tides (Zhou and Zhu 2005; Zhou et al. 2008). The ability of *P. donghaiense* to use organic forms of phosphorus (P) has been found to be an important adaptive strategy, allowing it to compete with rapid-growing diatoms under P-limiting conditions (Ou et al. 2008). Based on the role of nutrients in the formation of dinoflagellate red tides, nitrogen (N) reduction has been suggested as an important strategy to control the blooms in the long term (Zhou et al. 2008). Some questions, however, remain and will need further study in the future.

Although dinoflagellate red tides are generally dominated by *P. donghaiense*, in some years, the dominant species changes into fish-killing *K. mikimotoi*. The mechanism for this change in dominant species is still poorly understood. Furthermore, while the dinoflagellate red tides in the East China Sea are affected by nitrate transported from the Changjiang River, they are also affected by phosphate from the Taiwan warm current through upwelling [see also Chap. 12, Glibert et al. (2018a)]. The role of the Taiwan warm current and its variability in the formation of large-scale dinoflagellate blooms still need to be further examined to have a better understanding on the mechanisms causing dinoflagellate red tides.

15.1.2 Red Tides of **Phaeocystis globosa** *in the South China Sea*

The coastal waters along the South China Sea are also a notable region for red tides in China. Before the late 1990s, most of the red tides recorded in the South China Sea were confined in a relatively small region in bays such as Dapeng Bay, Daya Bay, and Shenzhen Bay. Large-scale red tides were seldom reported until the late 1990s, when an extensive red tide occurred in Zhelin Bay, Quangdong Province (Chen et al. 1999). This red tide caused mass mortality of cultured fish, and the economic loss was estimated to be 70 million RMB (about $10,000,000). This species can form giant gelatinous colonies in the coastal waters of China. The size of the colonies, with hundreds of cells embedded in a polysaccharide matrix (mucus), varies from several millimetres to over 2–3 cm (Shen et al. 2000). Since then, red tides of *P. globosa* have become a recurrent phenomenon, with significant interannual variation in scale and intensity. From the year 2010, intensive red tides of *P. globosa* started to appear in Beibu Gulf, an isolated area in the northwestern part of the South China Sea previously considered free of HABs. Red tides of *P. globosa* occurred in northern Beibu Gulf in 2014 and 2015 and posed potential threats to the operation of cooling systems of a nuclear power plant. Up to now, research on red tides of *Phaeocystis* sp. has been generally limited to specific biological studies, and knowledge on the ecology and oceanography of *P. globosa* in this region is still quite limited.

15.1.3 Brown Tides in the Bohai Sea and Yellow Sea

The Bohai Sea, a semi-enclosed inland sea, is another notable region for red tides in China. In the 1980s and 1990s, intensive red tides of dinoflagellates *Noctiluca scintillans*, *Prorocentrum* spp. and *Ceratium furca* were reported (Song et al. 2016). In 2009, a unique HAB started to appear in the coastal waters of Qinhuangdao, with significant negative impacts on the aquaculture industry of scallops, *Argopecten irradians*. Based on the pigment composition of phytoplankton samples collected during the bloom and the results of molecular clone library analysis, the major bloom-forming species was determined to be the pelagophyte, *Aureococcus anophagefferens* (Kong et al. 2012a; Zhang et al. 2012), the causative species of brown tides along the east coast of the USA. Henceforth, blooms of this species have become a recurrent phenomenon in this region. In 2010, the bloom affected an area over 3000 km^2 and led to economic loss of 200 million RMB (about US $30,000,000). This was the first brown tide event recorded in the coastal waters of the Pacific Ocean. The presence of *A. anophagefferens* has since been documented in other studies (Zhen et al. 2016; Xu et al. 2017). Besides the coastal waters of Qinhuangdao, a similar "brown tide" event was recorded in the Sanggou Bay of the northern Yellow Sea in 2011 (Kong et al. 2012b).

Brown tides have been considered to be ecosystem disruptive algal blooms (EDABs, e.g., Sunda et al. 2006). The emergence of brown tides in the east coast of the US led to reduction in shellfish resources and degeneration of seagrass beds. The Bohai Sea and the Yellow Sea are important spawning and nursing grounds and host many shellfish aquaculture areas. The consequences of the brown tides in the Bohai Sea and Yellow Sea attracted much attention. However, the reason why brown tides suddenly appeared in the Bohai Sea is still not known.

15.1.4 Toxic Algal Blooms in the Coastal Waters of China

Toxic algal blooms, as well as their associated seafood contamination issues, are another big concern in China. Blooms of toxic dinoflagellate, *Alexandrium* spp. associated with paralytic shellfish poisoning (PSP) have been reported in the northern Yellow Sea, the Changjiang River estuary and its adjacent waters, and some bays in the South China Sea (Gao et al. 2015). Blooms of toxic dinoflagellate, *Dinophysis* spp. have been reported in the Bohai Sea, the East China Sea, and the South China Sea. Recently, many toxic dinoflagellate species were identified, such as *Alexandrium fundyense*, *A. pacificum*, *Gymnodinium catenatum*, *Dinophysis* *acuminata*, *and D. fortii*, and toxin production characteristics have been studied, based on cyst germination experiment or single-cell analysis (Gu et al. 2013a, b; Li et al. 2015).

Many phycotoxins, including saxitoxin (STX) and its analogues, okadaic acid (OA), dinophysis toxins (DTXs), pectenotoxins (PTXs), yessotoxins (YTXs), azaspiracids (AZA), gymnodimines (GYM), and spirolides (SPX), have been detected in shellfish samples collected along the coast of China (Li et al. 2017; Liu et al. 2017). Some poisoning events have also been reported. In 2008, seven people were poisoned and one died in Jiangsu Province, due to the consumption of contaminated clams by paralytic shellfish toxins (PST). In May 2011, more than 200 people were poisoned in Zhejiang Province and Fujian Province by eating mussels with high levels of OA and DTXs (Li et al. 2012). In April 2016, another poisoning incident in Qinhuangdao was reported, due to the consumption of PST-contaminated mussels.

15.2 Evolution of HABs in the Coastal Waters of China

From the 1970s to now, HABs in China have undergone significant changes. First, the recorded bloom-forming species have been becoming more and more diversified. There have been blooms of diatoms, dinoflagellates, haptophytes, cyanobacteria, cryptophytes, raphidophytes, and pelagophytes (Fig. 15.1). Some bloom-forming species, such as *A. anophagefferens*, were never reported before recent years. Second, the emerging blooms have shifted from diatoms to flagellates that tend to be “harmful”. Toxic or harmful algae have occupied an increasing proportion in the bloom-forming species over the last decade (Fig. 15.2). The dinoflagellate red tides in the East China Sea, brown tides in the Bohai Sea, and *Phaeocystis* red tides in the South China Sea all have had major impacts on the aquaculture industry and on the health of natural ecosystems. *Prorocentrum donghaiense*, although nontoxic, has been shown to exhibit strong inhibitory effects on reproduction of the keystone zooplankton species, *Calanus sinicus* in the East China Sea (Lin et al. 2014). Third, the cell size of bloom-forming species on average exhibits a trend of getting smaller. Cell size of some bloom-forming species, such as *Phaeocystis* spp. and *A. anophagefferens*, is only 2–8 μm. This makes it difficult to carry out routine monitoring and identification of harmful algal blooms based on traditional microscopic approaches.

HAB development in China is driven largely by land-based pollution and climate change. Many studies have suggested that the occurrence of HABs is closely related with coastal eutrophication caused by nutrient pollution (Zhou et al. 2008; Li et al. 2014). With rapid urbanization of coastal zones and increasing fertilizer use in large river basins, huge amounts of N and P are discharged into the sea in different forms, aggravating the coastal eutrophication problem [see also Chaps. 4, 12, Glibert et al. (2018a, b)]. For example, the Changjiang River estuary and its adjacent waters are characterized by high concentration of NO_3- and high N/P and N/Si ratios. In the coastal waters of Bohai Sea, however, the organic forms

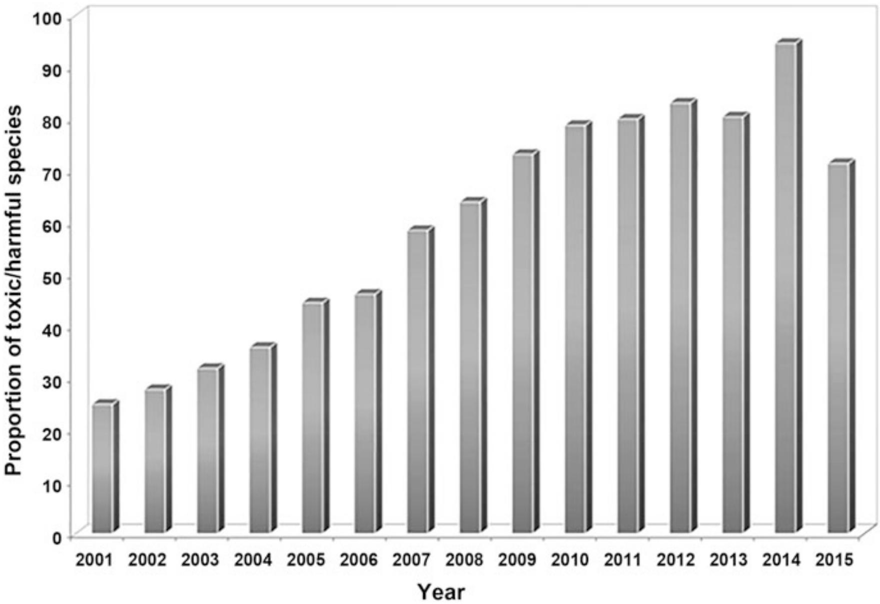

Fig. 15.2 Proportion of toxic/harmful species in recorded bloom-forming microalgal species in the coastal waters of China

of N are more prominent. This will lead to the proliferation of different groups of microalgae with distinct adaptive strategies. Climate change is another important factor likely affecting HABs. The rise in temperatures in the coastal waters of China is significant. Strong regional climate events, such as El Niño and La Niña, may alter oceanic currents and precipitation on land, affecting the occurrence of HABs [see also Chap. 5, Wells and Karlson (2018)]. Unfortunately, knowledge of this aspect is still very limited.

15.3 Strategies to Prevent HABs in the Coastal Waters of China

To support sound measures for managing HABs and to develop effective prevention strategies against HABs, there is an increasing need to carry out fundamental studies on the underlying mechanisms of HAB events, including the diversity of bloom-forming microalgal species, the adaptive features and competitive strategies of bloom-forming species, the major factors driving the evolution of HABs, and the relationship between HABs and the health of marine ecosystems. Furthermore, continued research on the economic and ecological consequences of HABs is urgent.

In addition, techniques for observing and predicting HABs should be emphasized. The diversification of bloom-forming species makes it a considerable challenge to detect bloom formers at the early stages. Therefore, it is necessary to develop sensitive and specific in situ monitoring facilities based on molecular biology, microscopic examination, and analytical chemistry. The development of numerical models for specific HABs will also increase the ability of early warning and prediction.

Finally, there is an urgent need for effective control technologies and prevention strategies for HABs. At present, modified clay has been successfully applied to control some HAB events in China [see Chap. 21, Yu et al. (2018)]. However, considering the intensive scale of most HABs occurred in China, measures to control land-based pollution and coastal eutrophication are more important to prevent HABs in the long run.

References

Chen JF, Xu N, Jiang TJ et al (1999) A report of *Phaeocystis globosa* bloom in coastal water of southeast China. J Jinan Univ 20(3):124–129 (in Chinese, with English abstract)

Furuya K, Iwataki M, Lim PT et al (2018) Overview of harmful algal blooms in Asia. In: Glibert PM, Berdalet E, Burford M et al (eds) Global ecology and oceanography of harmful algal blooms. Springer, Cham, pp 289–308

Gao Y, Yu RC, Zhang QC et al (2015) Distribution of *Alexandrium fundyense* and *A. pacificum* (Dinophyceae) in the Yellow Sea and Bohai Sea. Mar Pollut Bull 96:210–219

Glibert PM, Al-Azri A, Allen JI et al (2018a) Key questions and recent research advances on harmful algal blooms in relation to nutrients and eutrophication. In: Glibert PM, Berdalet E, Burford M et al (eds) Global ecology and oceanography of harmful algal blooms. Springer, Cham, pp 229–259

Glibert PM, Beusen AHW, Harrison JA et al (2018b) Changing land, sea- and airscapes: sources of nutrient pollution affecting habitat suitability for harmful algae. In: Glibert PM, Berdalet E, Burford M et al (eds) Global ecology and oceanography of harmful algal blooms. Springer, Cham, pp 53–76

Gu HF, Liu TT, Vale P et al (2013a) Morphology, phylogeny and toxin profiles of *Gymnodinium inusitatum* sp. nov., *Gymnodinium catenatum* and *Gymnodinium microreticulatum* (Dinophyceae) from the Yellow Sea, China. Harmful Algae 28:97–107

Gu HF, Zeng N, Liu TT et al (2013b) Morphology, toxicity, and phylogeny of *Alexandrium* (Dinophyceae) species along the coast of China. Harmful Algae 27:68–81

Kong FZ, Yu RC, Zhang QC et al (2012a) Pigment characterization for the 2011 bloom in Qinhuangdao implicated “brown tide” events in China. Chin J Limnol Oceanogr 30(3):361–370

Kong FZ, Yu RC, Zhang QC et al (2012b) Primary analyses on the causative species of a bloom in the Sanggou Bay. Mar Environ Sci 31(6):824–829 (in Chinese, with English abstract)

Li AF, Ma JJ, Cao JJ et al (2012) Toxins in mussels (*Mytilus galloprovincialis*) associated with diarrhetic shellfish poisoning episodes in China. Toxicon 60:420–425

Li AF, Sun G, Qiu JB et al (2015) Lipophilic shellfish toxins in *Dinophysis caudata* picked cells and in shellfish from the East China Sea. Environ Sci Pollut Res 22:3116–3126

Li HM, Tang HJ, Shi XY et al (2014) Increased nutrient loads from the Changjiang (Yangtze) River have led to increased harmful algal blooms. Harmful Algae 39:92–101

Li MH, Sun G, Qiu JB et al (2017) Occurrence and variation of lipophilic shellfish toxins in phytoplankton, shellfish and seawater samples from the aquaculture zone in the Yellow Sea, China. Toxicon 127:1–10

Lin JN, Yan T, Zhang QC et al (2014) *In situ* detrimental impacts of *Prorocentrum donghaiense* blooms on zooplankton in the East China Sea. Mar Pollut Bull 88:302–310

Liu D, Zhou M (2018) Green tides of the Yellow Sea: massive free-floating blooms of *Ulva prolifera*. In: Glibert PM, Berdalet E, Burford M et al (eds) Global ecology and oceanography of harmful algal blooms. Springer, Cham, pp 317–326

Liu Y, Yu RC, Kong FZ et al (2017) Lipophilic marine toxins discovered in the Bohai Sea using high performance liquid chromatography coupled with tandem mass spectrometry. Chemosphere 183:380–388

Ou LJ, Wang D, Huang BQ et al (2008) Comparative study of phosphorus strategies of three typical harmful algae in Chinese coastal waters. J Plankton Res 30(9):1007–1017 (in Chinese, with English abstract)

Shen PP, Wang Y, Qi YZ et al (2000) Growth characteristics and life cycle of *Phaeocystis globosa* Scherffel. Acta Hydrobiol Sin 24(6):635–643 (in Chinese, with English abstract)

Song NQ, Wang N, Lu Y et al (2016) Temporal and spatial characteristics of harmful algal blooms in the Bohai Sea during 1952–2014. Cont Shelf Res 122(1):77–84

Sunda WG, Graneli E, Gobler CJ (2006) Positive feedback and the development and persistence of ecosystem disruptive algal blooms. J Phycol 42(5):963–974

Wells ML, Karlson B (2018) Harmful algal blooms in a changing ocean. In: Glibert PM, Berdalet E, Burford M et al (eds) Global ecology and oceanography of harmful algal blooms. Springer, Cham, pp 77–90

Xu X, Yu ZM, Cheng FJ et al (2017) Molecular diversity and ecological characteristics of the eukaryotic phytoplankton community in the coastal waters of the Bohai Sea, China. Harmful Algae 61:13–22

Yu Z, Song X, Cao X, Liu Y (2018) Mitigation and control of harmful algal blooms. In: Glibert PM, Berdalet E, Burford M et al (eds) Global ecology and oceanography of harmful algal blooms. Springer, Cham, pp 403–423

Zhang QC, Qiu LM, Yu RC et al (2012) Emergence of brown tides caused by *Aureococcus anophagefferens* Hargraves et Sieburth in China. Harmful Algae 19:117–124

Zhen Y, Qiao L, Gu B et al (2016) Characteristics of eukaryotic microalgal community and its abiotic influencing factors during brown tide blooms near Qinhuangdao, China. Harmful Algae 57:1–12

Zhou MJ, Shen ZL, Yu RC (2008) Responses of a coastal phytoplankton community to increased nutrient input from the Changjiang (Yangtze) River. Cont Shelf Res 28:1483–1489

Zhou MJ, Zhu MY (2005) Progress of the project “Ecology and oceanography of harmful algal blooms in China”. Adv Earth Sci 21(7):673–679 (in Chinese, with English abstract)

Zhou MJ, Zhu MY, Zhang J (2001) Status of harmful algal blooms and related research activities in China. Chin Bull Life Sci 13(2):54–59 (in Chinese, with English abstract)