Reasons and Effects of Toxic Algae and Harmful Algae Blooms and Current Issues

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Abstract: Algal toxins are the toxins produced by algae living in lakes or oceans, and cause increasing poisoning cases, with acute symptoms and even some long-term effects. Diarrhetic shellfish poison (DSP), paralytic shellfish poison (PSP), neurotoxic shellfish poison (NSP), amnesic shellfish poison (ASP) and ciguatoxin are the 5 main algal toxins that may affect human. There are a series of cases which might be critical lessons, such as blue-green algae in Dane County in 2002, Harmful algal blooms (HABs) in Taihu Lake WuXi China, and massive died-off of murres Gulf of Alaska in 2015-2016. However, how algal toxins and HABs affect human and the environment have not been fully understood. Research revealed human factors such as eutrophication, international interaction, as well as natural reasons such as climate changes, migration of cephalopods carrying algal toxins, etc. Intervention including activating carbon and reversing osmosis, or application of chemical to directly react with toxins, may not be able to apply on cleaning the lake or oceans. It is also challenging to provide guidance on buying or feeding coral reef with potential risks. Future studies and measures are required to optimize the main reasons that caused algal toxin poisoning and HABs.

1. Introduction

Algal toxins, as the name suggests, are the toxins produced by algae living in lakes or oceans. Mostly, the cases of reporting poisoning by algal toxins are reported in the 20th and 21st centuries. There are more than 50000 algal toxins poisoning cases are reported every year and the frequency of reporting algal toxins poisoning has been increasing [1]. The possible acute symptoms include diarrhea, paralysis, nausea, vomiting, dizziness, and pain. Some algal toxins such as paralytic shellfish poison (PSP), neurotoxic shellfish poison (NSP) and ciguatoxin may even be fatal to human caused by paralyzing respiratory system, but death caused by NSP poisoning is rare, and ciguatoxin have many different species with different fatality [1, 6]. Most of deaths causing by algal toxins are PSP poisoning. Furthermore, although most of cases do not cause death, some toxins have long term effects like oncogenes or, memory losing, feeling confusing, and inhibiting the motility of sperms of mammals, as well as reducing fertility [7]. However, despite the widespread cases, it has been lacking specific medicines to treat most of algal toxins, while supportive care has been used as a main clinical treatment on victims such as resting, breathing support.

Harmful algal blooms (HABs) are also called “red tide” which means that harmful algae overgrowth in water. The origin of the algal toxins and harmful algae blooms is same – the algae, and the two phenomena are highly correlated [8]. For example, if some toxic algae are involved in HABs, their toxins will be more serious than single poisoning case due to larger amount of toxins and more difficult to remove them [2, 4]. Algal toxins may also affect animals., America, Japan, China, and many countries have reported the massive death of feeding animals like marine lives and live stocks caused by algal toxins or HABs [1, 3], which consequently causes the reduction of fishing and agriculture production [1, 9]. Algal toxins and HABs may impact people not only on individual health, but also health, economy, and society in many areas [8]. For example, obviously, contaminated marine lived cannot be consumed, hence fishing would be influenced. Besides, if algae contaminate the fresh water

supply for town, the normal lives of the resident would be affected. A typical case, in Wuxi, a city which is located near the Taihu Lake, the freshwater supply has been contaminated by algae, which causes disorders like snaped up bottled water and restaurants cannot operate normally [1, 2, 7, 10-12].

Increasing reports of algal toxins poisoning and harmful algae blooms are caused by serval reasons including lack of enough monitoring stations, increasing international interactions, climate change, as well as inappropriate processing wastewater discharging. International interactions may help the transferring of algae into other regions; climate change especially the global warming and El Nino would expand the area that are suitable for algae to growth; moreover, discharging of wastewater would catalyse the growth of algae. There has been research to test the amount of algal toxins in different healthy and died seabirds in Alaska, and the results showed that poisoning was not the direct reasons for the death of marine lives [3]. Physical and chemical solutions for solving algal toxins and HABs have come up. However, all those methods are not perfect and may not be able to be used to clean algae in large lakes or oceans.

This review introduces the main algal toxins and discusses the reasons causing the increasing reports of algal toxins poisoning and harmful algae blooms, as well as the possible ways to deal with algal toxins poisoning and HABs.

2. Chemical properties of algal toxins

There are 5 main algal toxins--diarrhetic shellfish poison (DSP), paralytic shellfish poison (PSP), neurotoxic shellfish poison (NSP), amnesic shellfish poison (ASP) and ciguatoxin.

2.1 Diarrhetic shellfish poison

DSP can be produced by dinoflagellates dinophytes like dinophyta obovate, dinophyton acuminata, D. acuta, and benthic dinoflagellate, *Prorocentrum lima*, *Prorocentrum concavum*, *Partulina redfieldi*. DSP is fat soluble and water insoluble. DSP poisoning may cause symptoms including vomiting and diarrhea as well as other gastrointestinal symptoms, are not serious normally and is not fatal for human in short term. However, Okadaic acid (Figure 1), the main component of DSP has been proved to cause tumour and abnormalities. DSP poisoning was firstly reported by Japan in 1976.

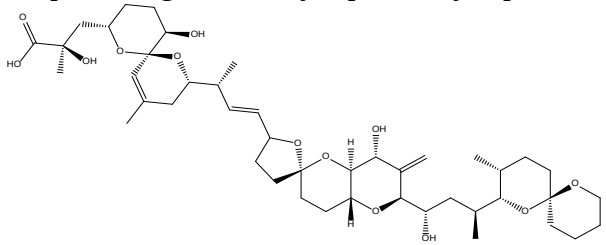

Figure 1. Structure of Okadaic acid

2.2 Paralytic shellfish poison

Paralytic shellfish poison (PSP) is one of the neurotoxins, which is main produced by *Alexandrium*, *Gymnodinium*, and *Pyrodinium* [1]. PSP is water insoluble and has thermal stability. The related PSP poisoning symptoms include paresthesia, numbness, tingling, dizziness, headache nausea and vomiting (Initial symptoms), muscle paralysis (mid-term symptoms) and difficulty breathing (serious symptoms), even death. The lethal dose for human is about 1-4 mg and the mortality rate is about 15% [1].

2.3 Neurotoxic shellfish poison

Neurotoxic shellfish poison (NSP) is produced by *Gymnodinium breve*. There have not been death cases reported so far. Human consuming shellfishes which are contaminated by *Gymnodinium breve* may cause abdominal pain, nausea, diarrhea, and vomiting, neurological palsy, body temperature deficit, myalgia, dizziness, ataxia, trembling, weakness. Similar to other algal toxins, NSP also has

thermal stability and do not sensitive to acid. Henc, it would stay in shellfish for more than 1 mouth even a year [9].

2.4 Amnesic shellfish poison

Amnesic shellfish poisoning (ASP) is the only shellfish intoxication caused by a diatom [1]. The main component of ASP is domoic acid (Figure 2). The first ASP poisoning was reported in Prince Edward Island, Canada in 1987. There were about 100 human poisoned and some people died. Symptoms including vomiting, nausea, diarrhea, abdominal cramps, haemorrhagic gastritis, dizziness, visual disturbance, memory loss, coma. There is a case that 12 people lose their memory for 18 months after ASP poisoned.

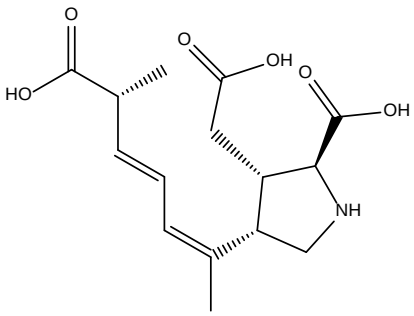

Figure 2. Structure of domoic acid

2.5 Ciguatoxin

Ciguatoxin could be isolated from more than 400 species fish, but it is produced by *Gambierdiscus toxicus*, Prorocentrum *lima* and *Pyrocystis*. It is fat soluble, water insoluble while not sensitive to heating and acid [1]. Ciguatoxin is one of the most toxic toxins known to mammals [11], and the average number of ciguatoxin poisonings worldwide has reached more than 50,000 people each year. Symptoms includes vomiting, diarrhea, numbness of extremities, mouth and lips, reversal of hot and cold sensation, muscle, and joint aches. The LD_{50} of ciguatoxin is 0.25 μg/kg [12].

Table 1. Basic characters of algal toxins

Algal toxins	Symptoms	Fatal or not	Algae
DSP	Vomiting and diarrhea	Not	Dinoflagellates
PSP	Numbness, dizziness, difficulty breathing	Yes	Dinoflagellates
NSP	Abdominal pain,nausea, weakness	Not	Dinoflagellates
ASP	Vomiting, nausea, haemorrhagic gastritis, memory loss, coma	Yes	Diatom
Ciguatoxins	Diarrhea, vomiting, dizziness, and weakness	Rare	Dinoflagellates

3. Influence of algal toxin on human society and health

Although algal toxins have become a serious health and social problem, only 2% of algal is harmful or toxic. It was found that only dinoflagellates and diatoms may produce toxins that impact human directly [1]. Human usually do not consume toxic algae directly, but other marine lives like fish, shellfish, plankton, and cephalopods may eat toxic algae and then the algal toxins would be transfer to human by food chain. Apart from consuming contaminated marine lives as food, some algal toxins may also be aerosolized or volatilized, hence human would be poisoned after they inhaled toxic vapor released by some algae. A typical example is palytoxin poisoning.

Apart from causing health problems for human by poisoning, algal toxins may also cause ecological and economic problems. Algal toxins and harmful algal blooms (HAB) are suspected to be the main causes of mass mortality of lives including fish, shellfish, marine mammals, and seabirds which dependent on the marine food web [1, 13].

Comparing with the last decades, there have been increasing cases of poisoning caused by algal toxins and ecological systems changing caused by HABs reported. There are servals reasons including more new-built monitoring stations, climate change like El Nino and global warming, more frequent international trades, as well as international interactions [1].

3.1 Cases of algal toxin poison

Toxic algae and HABs have transferred from sea to fresh water, which has more negative effects on human. In 2002 at Dane County, Wisconsin, America, children swam in a pond which was covered by blue-green algae, underwent nausea and diarrhea, and among them, one boy had epilepsy and died due to heart failure. Laboratory examinations found the possibilities of pesticides poisoning, parasitic infection as well as some other pathogens were ruled out, indicating that they contacted with algae. Importantly, the positive results of testing the algal toxins indicating an algae poisoning [10].

From May to June 2007, at Taihu Lake WuXi, China, HABs in Taihu Lake caused all the drinking water and tap water polluted, hence bottled water was in short supply in WuXi. Residents in WuXi smelt stink from their tap and the tap water was green and muddy. There were serval reasons, including the relative higher temperature in Taihu Lake compared with other years, lower water level, discharging of industrial, and agricultural wastewater which may lead to eutrophication [14]. Although government spent more than 10 billion dollars to control HABs in Taihu Lake and size of HABs have been reduced, the pollution still cannot be eradicated in a short term.

Some toxins such as palytoxin may only appear in tropical ocean and temperature ocean in theory, but Britain has reported more than one case that some residents poisoned by palytoxin in their house. The main resource might be home aquariums. Coral reefs which are contaminated by palytoxins are traded to Britain, and palytoxin can be aerosolized. Patients who inhaled contaminated coral reefs when they are cleaning their aquariums may feel ill. Palytoxin is highly toxic, while fortunately those patients were treated on time and saved their lives. However, there have been death cases reported worldwide every year [5].

In 2015-2016, there was a massive die-off of Common Murres was observed in the Gulf of Alaska was observed [10]. Caroline Van Hemerta et al tested and compared the amount of saxitoxin (STX) (one of the main toxins of PSP) and domoic acid (DA) in visceral samples separately obtained from healthy murres, healthy kittiwakes, died murres and died kittiwakes. However, there were no statistically significant differences between died murres, healthy kittiwakes and healthy murres, but the highest concentration of STX appeared in different viscera. The visceral with the highest STX concentration for healthy murres were GI samples, for died murres were liver samples, and for healthy murres were GI samples, while STX was not detected from their stool samples. In addition, 20.3% forage fish and 53.8% invertebrates from samples were detected STX. Those results indicated that seabirds and forage taxa may contact algal toxins widely, but there have not been enough evidence to support that the acute poisoning might be one of the directly reasons for the massive death of murres in Alaska from 2015-2016. The lack of testing all lives in Alaska made it difficult to qualify the effects of the algal toxins on local ecology. In 2015-2016, there was massive died-off of murres in California, and 80% died murres were detected low level DA, while the hunger was the direct cause of death [3]. Although acute poisoning does not seem to be the directly causes of death, some algal toxins such as DA and palytoxin may influence the physiological function including impaired spatial memory, thermoregulatory problems, depression, as well as lack of responsiveness and reproduction [7, 11]. Those factors may also cause the decreasing of murres amount.

3.2 Factors of poisoning

The increasing reports of algal toxins poisoning and HABs are caused by serval reasons, including human factors and natural factors.

3.2.1 Human factors

Eutrophication is one of the most critical factors. Many areas of the world where toxic blooms have recently expanded are areas used heavily for aquaculture [1]. Industrial and agricultural wastewaters discharged in lakes or ocean may bring nutrients like nitrogen, phosphorus and silicon into water, and these nutrients may stimulate algae growth. Although most algae are non-toxic, the overgrowth algae could block the sunshine and their respiration and breaking down of died algae may cause shortage of oxygen, which in turn killing fishes and subsequently cause death of some seabirds that eat fish due to hunger. Although some countries such as America have controlled even banned discharging wastewater into lakes and ocean directly, the nutrients that have been discharged in water would stay in soil and water, and would keep stimulating the growth of algae for decades [10]. In addition, some industrial water that contains heavy metal or other chemicals will pollute the soil, in 2007, soil samples collected from Taihu Lake were black and smell.

Apart from eutrophication, international interaction might be another major reason. Recently, some algae have become to appear in different oceans. One of the reasons is ships' ballast water. Most of ships pump the local seawater into the ships as the ships' ballast water. If the water contained algae, those algae did not die during voyage, and the environments of destinations were suitable, the algae would be transferred into new environments and would cause new risks [1]. Additionally, there have been more monitoring stations used which would increase the reports rate of HABs.

3.2.2 Natural reasons

Climate change, including global warming and El Nino, is one of the most important reasons. The appearances of tropical algae higher latitude zones are normal [1, 2]. Algae especially the cyanobacteria grow fast in relative high temperature water (>20°C) [2]. El Nino is suspected as a reason for occurrence of diseases in marine species, including coral bleaching and shellfish diseases, and possibly marine mammal mortality events due to the dramatic changes in temperature, and abnormal migration of creatures [1]. In addition, oceans act as capacity of heat, hence it can recircuit nutrients, oxygen, and carbon dioxygen by thermohaline circulation [1].

Shellfish is the main carrier of algal toxin and is because when bivalves are consuming toxic algae, they may filter most of water. Hence shellfish can concentrate the algae toxins [15]. Most of human algal poisoning is caused by consuming contaminated shellfish, poisoning caused by other marine lives is less frequent and less serious [16]. Some other organisms such as cephalopods including squids, octopus, also play a role in the expanding of algae. They are in the middle of marine chain with varying diet and hunt different small and medium marine organisms while they are prey for large marine organisms like tuna and hairtail, and seabirds. Hence, algal toxins may be transferred into the whole food chain. Apart from this, cephalopods usually hunt in different oceans and different depths, which may cause migrations of algal toxins. Mostly, cephalopods do not response to the marine toxins but other organisms including mammals even their young and fetus may be affected. For example, if young artemia were contaminated by OA or diphtheria toxin (DTX), they would become nauplii and loss balance, and consequently cannot swim at last sink into the sea. PTX may also inhibit the sperm of sea urchin and PTX would cause gastropod larvae retracted viscera, settled and velum lost. Mammals including hamsters, guinea pigs, rabbits, cattle, humans' sperm will also be influenced their sperms loss in flagellar-bend amplitude, this will cause increase in beat frequency hence the forward progression is lost gradually until the completely cessation of movement [5, 11]. Moreover, cephalopods and other predators may bioaccumulate and amplify the toxins in the food chain. Some microorganisms would transfer nontoxic chemicals into toxic chemicals. For example, GTX1 toxin in Alexandrium minutum can be transformed into GTX 2 and 3 through the marine bacterium Pseudomonas sp. [4].

4. Monitor and Prevent HABs and algal toxins

Methods of monitoring HABs have been challenging. The common method is using light microscopy combined with laboratory technologies like chromatography, which has two main

disadvantages [8]. One is confusing of detecting some algae. For example, Azadinium/Heterocapsa spp have appeared in coasts of Cork and Galway, Ireland, but their analysed graph did not show obvious differences (Figure 3).

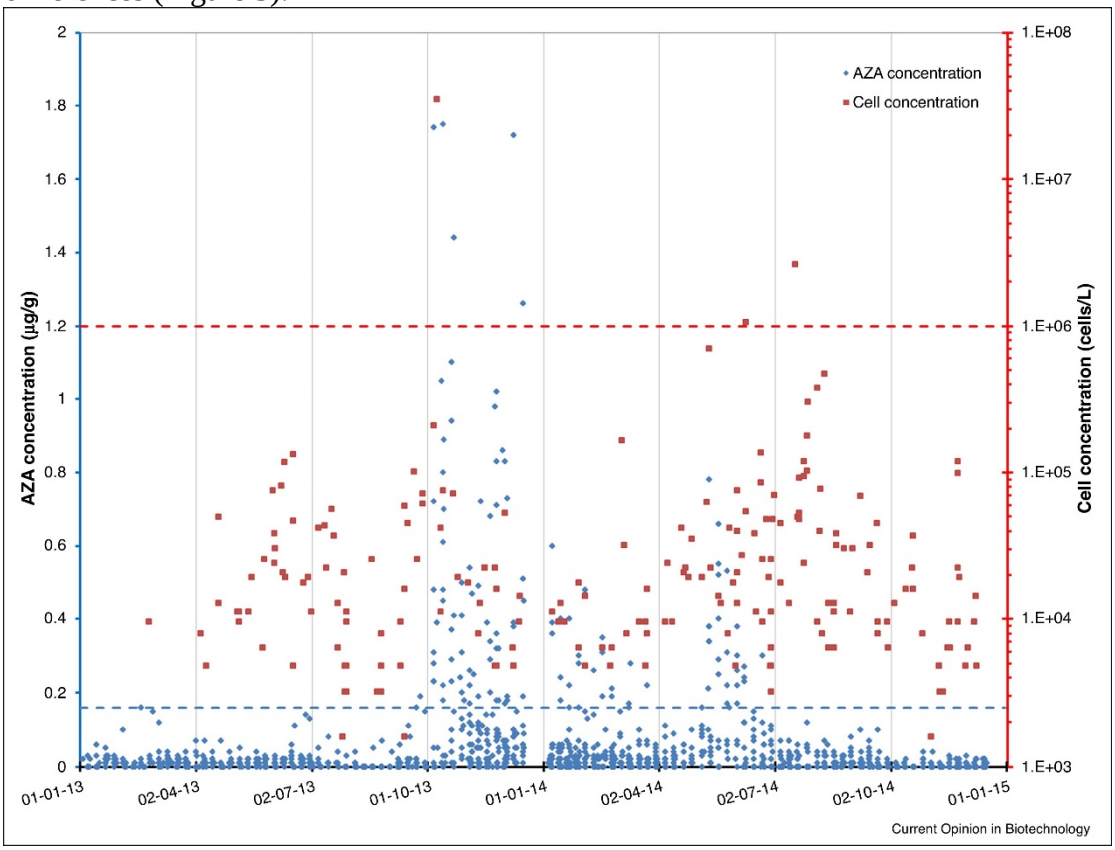

Figure 3 Occurrences of Axadinium/Heterocapsa spp. and AZA toxins (in shellfish) off the Cork coast from 2013 to 2014 [15].

The second disadvantage is that technology development, transferring, as well as staff training, could increase the cost of monitoring and detection of HABs and toxic algae [8]. Nowadays the technology of monitoring HABs by biosensor are come up, but this technology is still in development and testing stage. Biosensors have serval types, however, all of them cannot be used in large size right now due to complex preparation before using, limited spectrum of detected species, inaccurate, variability, as well as high detection threshold, and are only suitable in early term of HABs. Even so, biosensor is relative cheaper and convenient [8].

Unfortunately, there have not been effective methods to prevent HABs and algal toxins poisoning in a short term. Firstly, most of the algal toxins are water-insoluble, but many algal cells are unarmed which may make algal cells easily to break and die. Hence, the toxins saved in cells would be released into water [3], such as leakage of cylindrospermopsin from the cells [4]. Thus, salvage algae cannot remove algal toxins. Early studies carried out by Hoffman et al. demonstrated that common methods, such as flocculation/sedimentation, sand filtration, and chlorination, all failed to eliminate the toxicity associated with the peptide toxins released by cyanobacteria [4]. Activated carbon and reverse osmosis (RO) technologies can be used to treat water contaminated by algal toxins through directly absorbing toxins effectively. However, the amount of toxins removed is depended on the dose used for activated carbon. After using activated carbon for a while, there would be a biofilm formed on the surface of activated carbon and prevent activate carbon to absorb more toxins [4]. RO is similar to the filtration method in its separation of a liquid from a mixture of suspended or dissolved solids [4]. RO has been used to purified urban drinking water in many countries. Seubert et al. carried out a 5-year monitoring (2005-2009) of the intake and desalinated water at the pilot RO desalination plant of El Segundo (California) to explore the potential of extracellular algal toxin contaminating the RO products [4]. These results indicated that algal toxins could be filtered effectively. Nevertheless, both 2 methods can

only use to remove toxins in relatively small volume water, which may be applied to protect the drinking water and tap water, while cannot purify a whole lake or ocean. There are serval chemicals that can remove the toxins in water, including ClO_2, O_3, $KMnO_4$, H_2O_2, with advantages of low-cost, environmentally friendly, and biocompatible mineral such as iron-oxide mineral maghemite [4]. However, all of them have weakness, such as the efficiency depending on the environment factors (PH value) (ClO_2 and mineral), unpredictable (O3), expensive (O_3), cannot be used in larger scale (all of them), required to be corporate with other chemicals or technologies (H_2O_2) and harmful by-products (ClO_2).

Apart from lacking effective methods to clean contaminated water, it is also challenging to prevent expanding of algal toxins and HABs. For ships' ballast water, replacing the seawater by clean water is costly and difficult, thus, clean water should be supplied during the whole voyage. The nutrients like nitrogen, phosphate and silicon may catalyse the growth of algae for decades even after stopping discharging wastewater in water immediately. Many countries or organizations like China and EU do not ban buying coral reefs into the aquariums of residents and governments do not have sufficient guidance to help residents to protect themselves from contaminated marine lives [12]. In addition, algae especially dinoflagellates and cyanobacteria have strong ability to survive. Photosynthesis of alge could occur in 1% of the light level and they can grow in 100 meters depth in ocean [17]. If the nutrient is in shortage some algae can reproduce by forming thick-walled dormant cells, called cysts [18]. As for the climate change, actually global warming and EI Nino showed no sign of stopping and preventing green gas emission cannot be achieved in a short term. Moreover, not all HABs can be observed and warned in advance, because not all HABs have colour and some HABs may occur in deep water [16]. People do not have ability to separate the symptoms of algae toxins and infection by bacteria or virus, which may cause missing the best treatment time [16].

More widely interaction between human and nature have caused new problems. Some cases caused by some algae that have rare been reported begin to appear in the world. In Japan azaspiracids which was firstly discovered in Netherlands was discovered [19]. In Italy, a palytoxin analogue was identified as the probable causative agent of a respiratory illness caused by marine aerosols [20]

5. Conclusion

Among the five kinds of algal toxins, only PSP is fatal to human, while other toxins also have serious effects on human like amnesia, confusing of feeling, diarrhea, and dyspnea, etc. Importantly, the most serious problem of algal toxins is that they are difficult to be prevented. The possible factors are that most of algal toxins cannot be removed by heating or acid and some of toxins like palytoxin can be aerogelized hence poisoning by inhalation cannot be ignored. Natural factors including global warming and El Nino, and human factors including international interaction and discharging of agricultural and industrial wastewater and building more monitoring stations, causing the increasing reports of poisoning by algal toxins and Harmful Algae Blooms. Those factors cause the expansion of the breeding area of algae, helping the transferring of algae, and catalysing the growth of algae. Apart from effects on human, algal toxins may also impact murres and fishes by destructing the food chain, thus in fact, most of deaths of murres are not due to poisoning but caused by hunger. Although some solutions of HABs are came up, including activating carbon and reversing osmosis, as well as using chemicals to react with toxins. However, these methods cannot be used to clean the lake or oceans now due to the cost, size, and their properties. Besides, developing effective methods to clean water from algae, preventing international interactions and climate change are also challenging. Nutrients that have discharged in water can still stimulating the growth of algae for decades. In addition, most of governments may not have efficient guidance on buying or feeding coral reef with potential risks. Future studies and measures are required to optimize the main reasons that caused algal toxin poisoning and HABs cannot be optimized in short time, the trends of poisoning by algal toxins and HABs are expected to increase in the future.

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