IJNRD.ORG ISSN : 2456-4184
INTERNATIONAL JOURNAL OF NOVEL RESEARCH AND DEVELOPMENT (IJNRD) | IJNRD.ORG
An International Open Access, Peer-reviewed, Refereed Journal

Harmful Algal Blooms in a Changing World: A View on Harmful Algal Blooms, Their Impacts, Consequences and Management in a Changing Climate and Environment

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Abstract

Autotrophic algae and some heterotrophic protist blooms are becoming more common in coastal waters around the world and are referred to as harmful algal blooms (Harmful Algal Blooms).Harmful algal blooms have arisen as a major environmental concern, affecting aquatic ecosystems and human health around the world. Alternatively, particular species in harmful algal blooms (Harmful Algal Blooms) might exert their impacts through the creation of chemicals (e.g., toxins) that can disrupt the cellular processes of other creatures ranging from plankton to humans. It is a major marine problem that has increased in frequency, intensity and geographic extent worldwide; this increase is not only a threat to global marine aquaculture but also a hazard to human health. This review paper provides a detailed analysis of the causes, consequences and mitigation techniques connected with Harmful Algal Blooms, which is critical for creating successful mitigation strategies.

Keywords- Harmful algal bloom, Paralytic shellfish poisoning, Ciguatera, Domoic acid

Introduction

The microscopic planktonic algae of the world's oceans provide crucial food for filter feeding bivalve shellfish (oysters, mussels, scallops, clams) as well as the larvae of commercially important crustaceans and finfish. In most circumstances, the expansion of plankton algae (so-called 'algal blooms up to millions of cells per litre) is consequently favourable for aquaculture and wild fishing operations. However, in other cases, algal blooms can have a negative influence, producing serious economic losses to aquaculture, fisheries and tourism industries as well as major environmental and human health consequences. Harmful algal blooms have been growing in frequency and area in Chinese coastal waterways since the 1980s, causing significant economic losses. In the current research , Harmful Algal Blooms are a severe marine hazard that has increased in frequency, intensity, and geographic area globally; this increase is a concern not only to marine aquaculture worldwide but also to human health (Anderson, (1997); Tang et al., 2003, 2004a, (2005). In 1933, *Noctiluca scintillans* and

Skeletonema costatum triggered the first known Harmful Algal Bloom incident in China in Zhejiang coastal waters.As a result, without continued public health surveillance, research and outreach into Harmful Algal Bloom related exposures and illnesses, the number of instances of Harmful Algal Bloom related illnesses is expected to climb over the next decade. With this in mind, the focus of this Special Issue of Harmful Algae is on Harmful Algal Blooms and public health.

It is thought that the first written mention of a toxic algal bloom (1000 B.C.) comes in the Bible all the waters in the river were turned to blood and the fish in the river died and the river stank and the Egyptians couldn't drink the river's water Exodus 7:20In one case, a non-toxic bloom-forming alga grew so densely concentrated that it created anoxic conditions, killing both fish and invertebrates indiscriminately. Oxygen depletion can be induced by excessive algal respiration (at night or in low light during the day), but it is most usually caused by bacterial respiration during bloom decomposition. However, even non-toxic bloom formers can have significant environmental impacts and ugly dead fish, slime and foam inhibit tourism and recreational activities.

Harmful Algal Blooms can be extremely harmful to animals, the environment, and economies. They have grown in size and frequency over the world, which many scientists ascribe to global climate change. The National Oceanic and Atmospheric Administration (NOAA) of the United States forecasts additional dangerous blooms in the Pacific Ocean. (Andersan et al., (1997). Chemical treatment, new reservoirs, sensors, and monitoring devices, lowering nutrient runoff, research and management, and monitoring and reporting are all potential solutions.

1. Global increase of algal blooms

Algal blooms are becoming larger and more common as ocean temperatures rise and circulation patterns vary. Climate change is most likely one of the causes of changes that favour phytoplankton growth. It's uncertain whether this is positive or negative. Many marine species feed on algae, and large blooms can occasionally be helpful to ocean ecosystems and fisheries. However, some algal blooms seep toxins into the water and harm the environment. When blooms die and begin to decompose, the oxygen concentrations in the water fall, causing the ecology to suffer.

Algal colonies in bloom the rapid increase in the population of algae in aquatic ecosystems has become a rising problem worldwide due to a variety of factors.These blooms have the potential to harm water quality, ecosystems and even human health. Here are some key points about the global increase in algal bloom.

1.1 Eutrophication

Excess nutrients in water bodies can cause eutrophication, a situation in which water becomes rich in nutrients, resulting in algae blooms. This is a widespread problem in many areas. An algal bloom affects the entire ecosystem depending on the individual; it can produce beneficial outcomes such as simply feeding higher tropical levels to more harmful effects, preventing sunlight from entering other species, causing oxygen loss in the atmosphere and secreting toxins into the environment. Eutrophication is the process of fertilizer overstock that results in algae growth and oxygen deprivation.

1.2 Harmful algal blooms

When some algae species pollute drinking water or seafood, they can produce toxins that harm aquatic life and pose health risks to humans. Algal blooms are a serious cause of concern throughout the world.

At all major algal bloom conferences, the problem of global increases in dangerous algal blooms have been a frequent topic of discussion (Anderson et al., 1989; Hallegraeff et al., 1993; Smayda et al., 1990). Four explanations have been proposed for this apparent increase in algal blooms: increased scientific awareness of toxic species; increased use of coastal waters for aquaculture; stimulation of plankton blooms by cultural eutrophication and unusual climatological conditions; and transportation of *dinoflagellate* resting cysts in ship ballast water or associated with shellfish stock translocation.

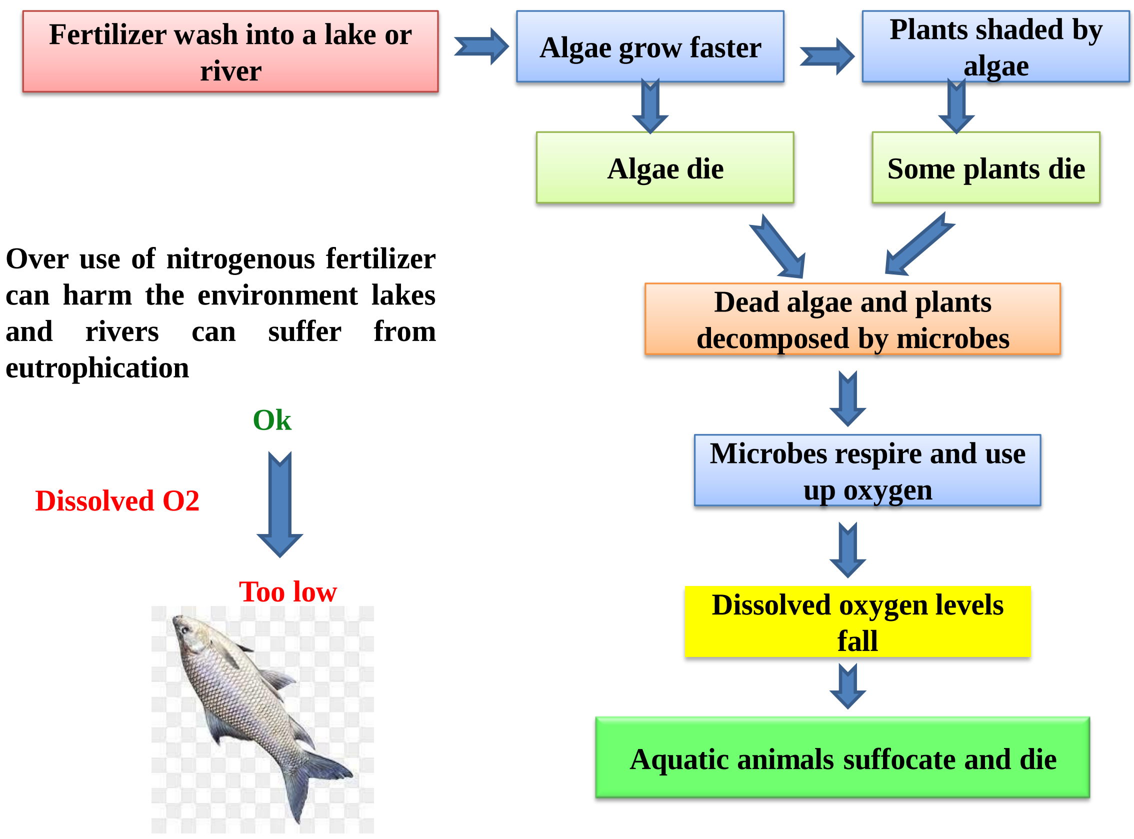

fig. 1 Eutrophication (algal blooms)

2. What Are the Reasons for Algae Bloom?

It is not always clear what causes certain harmful algal blooms, as their presence in some areas appears to be wholly natural (Adams et al., Lesoing, & Trainer, et al., 2000). In some cases, they appear to be the consequence of human activity. (Marcotte & colleagues (1989). Furthermore, there are numerous kinds of algae that can generate harmful algal blooms, each with its own set of environmental needs for maximum growth. The frequency and severity of harmful algal blooms have been linked to increased nitrogen loading from the actions of humans in several parts of the world. In some regions, harmful algal blooms are a seasonal phenomenon caused by coastal upwelling, which is caused by the passage of particular ocean currents. (Trainer, et al.).

- The availability of nitrates and phosphates, which can be abundant in coastal upwelling zones as well as agricultural run-off, limits the growth of marine phytoplankton (both non-toxic and toxic). The type of nitrates and phosphates available in the system are particularly important since phytoplankton can grow at varying rates depending on the relative concentration of these substances (e.g., ammonia, urea, nitrate ion). (Moore, S., et al. (2011).

- Excess nutrients—phosphorus, and nitrates—from fertilizers or sewage released into bodies of water (also known as nutrient contamination). (Amin, et al., (2017); Liang, et al., (2017); Peebles, et al., (2016).
    - Global warming. (2017) (Liang et al.)
    - Power plant and factory thermal pollution
    - Low water levels in streams and lakes, reducing flow and raising water temperatures. (2022; Sadegh et al.).
    - Invasive filter feeders, especially Zebra mussels (*Dreissena polymorpha*), which consume non-toxic algae that compete with hazardous algae. (Harke and colleagues,et al., (2016).

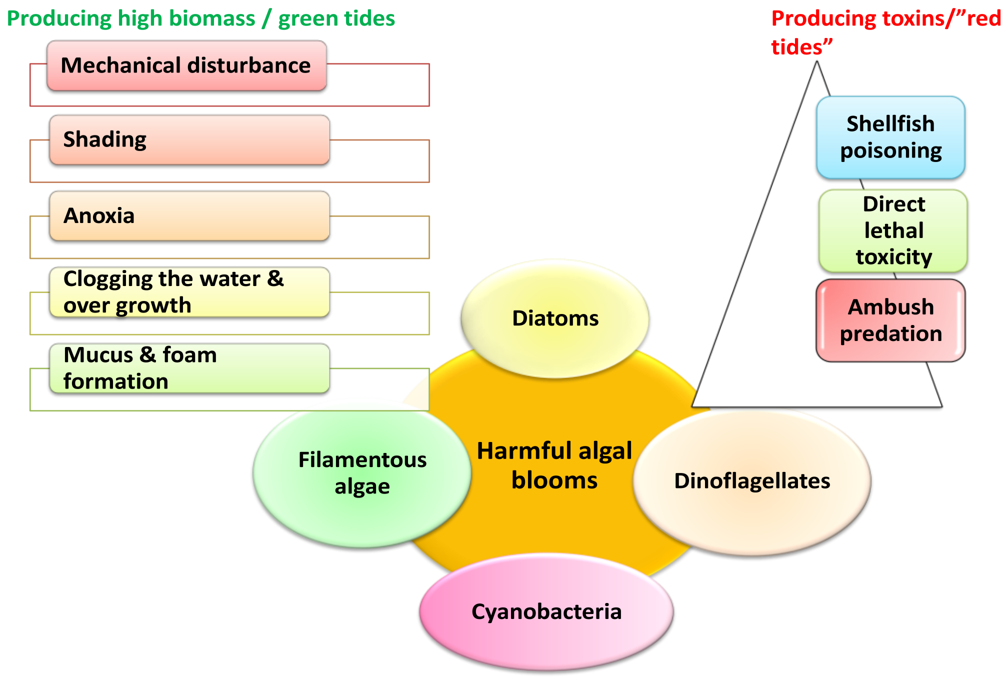

fig. 2 Gropus of organisms generating harmful algal blooms & different types of harmful algal blooms

2.1 Nutrient Overabundance

Surface runoff from agricultural pollution, urban runoff from fertilized lawns, golf courses and other manicured properties and sewage treatment plants that lack nutrient management mechanisms all contribute to nutrient contamination in freshwater and marine habitats.(Shortle and colleagues et al.,(2017). Pollution in the atmosphere introduces additional nutrients. (Crews and Howdeshell et al.,(2003). Coastal environments around the world, particularly wetlands and estuaries, coral reefs and swamps, are prone to nutrient overload. (Crews and Howdeshell, et al., (2003).These nutrients are also gathered in streams by drainage systems. Untreated raw sewage enters aquatic bodies due to poor sewage treatment, and because it contains nitrogen compounds such as ammonia and nitrates, it causes algal blooms.

2.2 The presence of decomposing organic matter

Bacteria of many sorts can be found in both the atmosphere and water. They are all on the lookout for appropriate growth and nutrition media. As with other bacteria, the algal bacterium is activated by the presence of dead species in water. The decaying organic matter, in conjunction with the nutrients in the water, ends up spreading the growth of algae in the water, resulting in algae blooming.

2.3 Extreme temperatures

The planet is facing ozone layer depletion as a result of global warming. This is one of the primary reasons for the rapid growth of algal bloom. A suitable temperature is required for certain bacteria to live both in and out of water. Extremely high temperatures caused by global warming have increased the degradation of nutrients such as nitrates and ammonia, which are easier to utilize and expand in abundance for bacteria.

2.4 Water that Moves Slowly

Algal blooms require massive amounts of water that have yet to develop. Their expansion in these waterways is less concerning, which is why they are restricted to fast-flowing streams and rivers.

3. Environmental consequences

3.1 Zones of no return

The presence of toxic algae blooms in a body of water can cause hypoxia or anoxia. A dead zone can form when there is a lack of oxygen in a body of water. When a body of water becomes unsuitable for organism survival, it is said to have reached a dead zone. Dead zones are caused by harmful algal blooms absorbing oxygen in these bodies of water, leaving little oxygen accessible for other marine creatures. When the Harmful Algal Blooms die, their bodies drop to the bottom of the body of water because the decomposing of their bodies (by bacteria) causes the consumption of oxygen**.** Once the oxygen levels are so low, the Harmful Algal Blooms cause hypoxia in the body of water, and the low oxygen levels will lead marine organisms to seek out better-suited regions for survival. (Joyce & colleagues et al.,(2000).

Blooms can affect the ecosystem even if they do not produce poisons by removing oxygen from the water as they grow and degrade after they die. Blooms can also block sunlight from reaching species living beneath them. A record-breaking number and size of blooms have occurred along the Pacific coast, Lake Erie, the Chesapeake Bay and the Gulf of Mexico; resulting in the formation of a number of dead zones (Toxic algal blooms threaten marine life along Florida coastlines). There were 49 dead zones in the world in the 1960s; by 2008, the number had risen to over 400. (Biello & colleagues et al.,(2008).

Warmer seas due to climate change make situations better for algae development in more places and further north. ("Algal blooms 'likely to flourish as temperatures climb'"(2016),(Climate Change and Harmful Algal Blooms"(2017). In general, quiet, warm, shallow water in lakes or rivers, along with high nitrogen levels, raises the danger of damaging algal blooms. (Sadegh et al., (2022). Summer surface temperatures in lakes climbed by 0.34 °C decade on the decade between 1985 and 2009 as a result of global warming and this will likely boost algal blooms by 20% over the next century.(O'Reilly, S. Sharma and colleagues,et al., (2015).

Although the causes of toxic algal blooms are unknown, they appear to have expanded in range and frequency in coastal areas since the 1980s. (Abram and colleagues, et al., (2022). This is due to human-caused factors like as increased fertiliser inputs (nutrient pollution) and climate change (specifically, rising water temperatures).(Abram et al., (2022).Ocean warming, marine heatwaves, oxygen depletion, eutrophication, and water pollution are all factors that influence the production of Harmful Algal Blooms. (Caretta and colleagues, et al., (2022).

3.2 Consequences

Algal blooms can decrease fish and other aquatic life's capacity to find food, causing entire populations to depart or even die.Because of the thick, green muck that impairs clean water, recreation, business, and property values, nutrient pollution encourages the establishment of harmful algal blooms, which has a severe influence on aquatic ecosystems.

3.3 Direct contact with algae

Toxins produced by harmful algal blooms are sometimes toxic to fish and other creatures. Toxins migrate up the food chain after being digested by small fish and shellfish, affecting larger creatures such as sea lions, turtles, dolphins, birds, and manatees. Even if algal blooms are not harmful, they can harm life by obstructing sunlight and clogging fish gills.

4. Management of dangerous algal

Many aspects must be examined when developing effective lake ecosystem management techniques, including inter annual variability, examination of regional differences in agents, and factors that disrupt the accessibility of nutrients to bloom (Huo, et al., (2019). Previous research has suggested that harmful algal bloom management is difficult for scientists and managers due to the world's rapid changes.Increased population is one of the primary factors that will increase nutrient enrichment in coastal waters in order to feed 40% more people over the next three decades, resulting in more harmful algal blooms in some areas and the effects of aquaculture expansion in those areas that are affected (Anderson, et al., (2014). Many studies have been conducted around the world to find a better strategy to reduce Harmful Algal Blooms. In the lab, various biotic variables have been identified to decrease the possibility of Harmful Algal Blooms.

4.1 Bacteria used to reduce Harmful Algal Blooms

Phytoplankton and bacterioplankton are numerically dominant in coastal and freshwater populations (Sarmento and Gasol, et al., (2012). Because it always produces microcystins, which are dangerous to aquatic creatures and humans, *M. aeruginosa* is the most prevalent toxic algal strain. Tumorigenesis has been connected to microcystins (Zurawell et al., 2005). Bacterial predators were found to be genus- or species-specific (Rashidan and Bird, et al., (2001), but other predators attacked a wide variety of cyanobacteria (Daft, et al., (1975).

There are two types of bacteria: predatory bacteria that are antagonistic to cyanobacteria and toxin-degrading bacteria. Predatory bacteria offer an environmentally benign answer to harmful algal blooms. Some characteristics, such as prey-predator interactions and cyanobacterial lysis mechanisms, were effective biological control measures (Gumbo, et al., 2008).

4.2 Fish species used to reduce Harmful Algal Blooms

Fish have long used an alternative for bloom eradication since some fish can absorb and digest the poison. Bio-manipulation is a promising strategy for controlling Harmful Algal Blooms in the lake ecosystem. (Shapiro & colleagues et al.,(1975). Many initiatives in China and other countries have been attempted to suppress cyanobacterial blooms by introducing filter-feeding fish like as bighead carp and silver carp, which have been found to be effective at times (Starling et al., (1993); Xie and Liu et al., (2001).

5. Harmful Algal Blooms Toxins

5.1 There are various types of dangerous algal blooms

Blooms are species that induce essentially innocuous water discolorations; yet, under extraordinary conditions in protected bays, blooms can develop so dense that they cause indiscriminate deaths of fish and invertebrates due to oxygen deprivation. *Dinoflagellates Akashiwo sanguinea*, *Gonyaulax polygramma*, *Noctiluca scintillans*, *Scrippsiella trochoidea* and *Trichodesmium erythraeum* are a few examples. Species that create severe poisons that can make their way to humans via the food chain, producing a variety of gastrointestinal and neurological disorders, such as:

5.2 Paralytic shellfish poisoning

Paralytic shellfish poisoning is caused by a group of approximately two dozen naturally occurring potent neurotoxins. These toxins specifically block the excitation current in nerve and muscle cells, finally resulting in paralysis and other illness in consumers of contaminated shellfish.(Examples: *dinoflagellates Alexandrium catenella, A. cohorticula, A. fundyense, A. fraterculus, A. leei, A. minutum, A. tamarense, Gymnodinium catenatum, Pyrodinium bahamense var. compressum).*

5.3 Diarrhetic shellfish poisoning

Diarrhetic shellfish poisoning is characterized by acute gastrointestinal symptoms triggered by the ingestion of shellfish contaminated with okadaic acid and related toxins. Mussels, clams, scallops and oysters are the most common vectors for the Diarrhetic Sshellfish Poisining toxins which are produced by a community of *dinoflagellates*, most notably, *Dinophysis spp* and *Prorocentrum spp* (James et al., (2010); Valdiglesias et al., (2011).(Examples: *dinoflagellates Dinophysis acuta, D. acuminata, D. caudata, D. fortii, D. norvegica, D. mitra, D. rotundata, D. sacculus, Prorocentrum lima.*

5.4 Amnesic shellfish poisoning

The amnesic shellfish poisoning toxin, domoic acid, was originally isolated from a red macroalga *Chondria armata* by Japanese researchers studying the insecticidal properties of algal extracts (Takemoto and Daigo et al., (1958). The structure was later revised by Ohfune and Tomita (1982). The potential risk of domoic acid to human health was discovered in 1987 in eastern Canada (Perl et al., (1990), Teitelbaum, (1990); Teitelbaum et al., (1990). Persons who ate affected blue *mussels* harvested from the Prince Edward Island region suffered serious gastrointestinal distress and, in some cases, death. Some survivors were left with a permanent and profound memory disorder, called amnesic shellfish poisoning Domoic Acid is a naturally occurring toxin produced by blooms of *Pseudonitzschia.* Shellfish and other marine organisms feed on *Pseudonitzschia* and concentrate the toxin within them. (Examples*: diatoms Pseudo-nitzschia australis, P. delicatissima, P. multiseries, P. pseudodelicatissima, P. pungens (some strains), P. seriata.*

5.5 Ciguatera fish poisoning

It is generally well-accepted that ciguatera fish poisoning is the most frequently reported seafood-related disease in the United States and most common foodborne illness related to finfish consumption in the world (Isbister and Kiernan, 2005; Lynch et al., (2006); Friedman et al., (2008); Kumar-Roine´ et al., (2011).Ciguatera is caused by heat-stable sodium-channel activating toxins that cause a wide array of gastrointestinal and neurological symptoms (Gillespie et al., 1986; Lewis and Ruff, 1993; Lewis et al., 2000). This disease follows consumption of fishes that have accumulated a number of ciguatoxins derived from the benthic *dinoflagellate*, *Gambierdiscus toxicus* through the marine food chain. (Lewis and Holmes, et al., (1993). (Examples: *dinoflagellate Gambierdiscus toxicus, Coolia spp., Ostreopsis spp., Prorocentrum spp.)*

5.6 Neurotoxic shellfish poisoning

Neurotoxic shellfish poisoning is typically caused by ingesting bivalve shellfish (e.g., clams, oysters and mussels) that are contaminated with brevetoxins. The risk for Neurotoxic Shellfish Poisoning toxins in shellfish is associated with Harmful Algal Blooms or ‘‘red tides’’ along the Gulf of Mexico. The greatest number of cases appears to come from the west coast of Florida, although this may be due to differences in surveillance rather than actual differences in occurrence (Daranas et al., 2001; Watkins et al., 2008). Harmful algal blooms and associated outbreaks of Neurotoxic Shellfish Poisoning have also been reported in New Zealand and Mexico (Ishida et al., (1996); Sim and Wilson, (1997); Herna´ndez-Becerril et al., (2007). (Examples: *dinoflagellate Karenia brevis (Florida), K. papilionacea, K. selliformis, K. bicuneiformis (New Zealand)).*Whether the apparent global increase in harmful algal blooms represents a real increase is a question that we will probably not be able to answer conclusively for some time to come.

table 1. toxic syndromes, toxins and the phytoplankton source of toxins

	Paralytic shellfish poisoning	**Diarrhetic shellfish poisoning**	**Amnesic shellfish poisoning**	**Ciguatera fish poisoning**	**Neurotoxic shellfish poisoning**
Toxin produced organism	*Dinoflagellates Gymonodinium catenatum,*	*Dinoflagellates Dinophysis species,*	*Diatoms Pseudo-nitzchia species*	*Dinoflagellates: Gambierdiscus toxicus*	*Dinoflagellates Karenia brevi*
Toxins	Saxitoxins	Okadaic acid	Domoic acid	Ciguatoxins	Brevetoxins
Food likely to be contaminated	primarily scallops, mussels, clams, oysters	Shellfish, primarily scallops, mussels, clams, oysters	primarily scallops, mussels, clams, oysters,	Reef fish, red snapper, and amberjack	Shellfish, primarily mussels, oysters, scallops
Long term symptoms	Unknown	Unknown	Possibly amnesia	Pain,weakness, Low blood pressure	Unknown
Treatment	Supportive care, Possibly respiratory support	Supportive care	Especially for older people and those with kidney disease	Supportive care (treatment of symptoms),	Supportive care

Conclusion-

We will probably not be able to say conclusively whether the apparent global increase in dangerous algal blooms is a real increase for some time. There is no doubt that increased interest in using coastal waters for aquaculture is raising awareness of harmful algae species. What we are seeing today in the field of harmful algal bloom studies is that the impacts on public health and economic impact of harmful algal blooms are indicating a genuinely global 'epidemic,' and we need to start responding to this problem. Many biological control agents existed for the mitigation of Harmful Algal Blooms, including bacteria, fungi, phages, zooplankton and others. Because each creature has a species-specific way of interaction with algal blooms, the function of selective organisms in Harmful Algal Blooms remediation has been critical. The idea to mitigate such bloom is to use the lytic substances or extracellular secretion, which is biologically derived substances released from bacteria, which in turn could not grow and disturb the environment. Finally, studies of global climate change (greenhouse gas emissions, ozone depletion) must address the effects on algal bloom episodes.

A number of new worldwide initiatives have been established to investigate and control harmful algal blooms and their links to environmental changes in a way that is compatible with the global nature of the phenomenon.

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