

# Impacts of Eutrophication and Global Warming on the Emergence of Toxic Cyanobacteria blooms

Raju Potharaju<sup>1\*</sup> and M. Aruna<sup>2</sup>

<sup>1\*</sup>Department of Botany, City Womens Degree College, Hanamkonda, Telangana, India.

<sup>2</sup>Professor & Head Department of Botany

Hydrobiology and Algal Biotechnology Laboratory, Telangana University, Dichpally, Nizamabad, Telangana, India  
rajuvarmabotany@gmail.com

**Abstract:** *Cyanobacteria, the oldest phytoplankton on the planet, cause toxic algal blooms in freshwater, estuarine, marine and fresh water habitats. According to recent study, eutrophication and climate change may contribute to the spread of dangerous cyanobacterial algae blooms. This study examines the correlation between eutrophication, climate change, and cyanobacterial taxa in freshwater (Microcystis, Anabaena, Cyndrospermopsis). Cyanobacterial genera have the capacity to compete for low inorganic phosphate concentrations and acquire organic phosphate molecules. Cyanobacteria, both diazotrophic (nitrogen (N<sub>2</sub>) fixers) and non-diazotrophic, may create blooms using a wide range of nitrogen sources. Some cyanobacterial blooms are linked to eutrophication, although others occur at low inorganic N and P concentrations. Cyanobacteria dominate phytoplankton assemblages at higher temperatures due to physiological (e.g., faster growth) and physical reasons (e.g., greater stratification), with distinct species exhibiting various temperature peaks. The impact of rising carbon dioxide (CO<sub>2</sub>) concentrations on cyanobacteria is unclear. However, some research shows that some genera of cyanobacteria thrive in low CO<sub>2</sub> environments. Future eutrophication and climate change are expected to increase the frequency and size of dangerous cyanobacterial blooms, despite their complicated interactions.*

**Keywords:** Oldest Phytoplankton, Cyanobacteria, Eutrophication, Cyanobacterial blooms

## I. INTRODUCTION

Cyanobacterial hazardous algal blooms have been described in the scientific literature for over 130 years (Francis, 1878), but their frequency and severity have grown in recent decades, resulting in economic loss in both fresh and marine waterways. In recent times, scientists have made new findings on cyanobacterial toxins that were previously unknown. One such toxin is amino b-methylamino-L-alanine (BMAA). Additionally, new types of cyanobacteria have been discovered that are capable of generating toxins that were already known. So far, the factors that have been identified as causing the worldwide spread of harmful cyanobacterial blooms are: higher amounts of nutrients entering the water, the movement of cyanobacterial cells or cysts through human activities, and the increase in aquaculture production and/or overfishing, which disrupts food chains and allows harmful species to take over algal communities. (Downing, J.A.et.al.,2001)

Research has shown that the rising global temperatures caused by climate change might contribute to the growth of cyanobacterial blooms in surface water. Significantly, it is widely agreed that dangerous algal blooms are intricate occurrences, usually resulting from the simultaneous interaction of numerous environmental elements rather than a single cause. At last, an Enhanced capacity to identify and track detrimental cyanobacterial blooms, along with their toxins, as well as heightened scientific and public awareness of these occurrences, has also resulted in greater record-keeping of such events. (GEOHAB 2001). Multiple assessments have been conducted on the increase and worldwide spread of detrimental cyanobacterial blooms, including their quantity, geographic range, and impact on ecosystem well-being. Additionally, the variables that may be enabling this growth have been examined. The objective of this review is to: (1) Emphasise significant discoveries made in the past ten years regarding harmful cyanobacterial blooms in freshwater, environments; and (2) Explain how factors related to eutrophication and climate change impact some of the most extensively studied harmful cyanobacterial bloom genera. (Agawin, et.al.,2000.)

**II. BACKGROUND**

Though technically prokaryotes, cyanobacteria have long been considered a kind of eukaryotic "algae" and have gone by many names in that time, including blue-greens, blue-green algae, Myxophyceae, Cyanophyceae, and Cyanophyta. The term "CyanoHABs" or "cyanobacterial blooms" has more recently been used to describe cyanobacteria that produce toxic blooms. (Carmichael, W.W., 2008).

**Harmful substances**

Cyanobacteria create many secondary metabolites, including toxins and beneficial substances. Toxins are substances that provide a health danger to animals and humans, whereas bioactive compounds have antibacterial and cytotoxic capabilities and are used in pharmaceutical and research applications. (Tonk, L., 2007). Although certain substances are known to be hazardous, their long-term consequences remain unclear.

The most common cyanobacterial toxins produced worldwide are hepatotoxins, which are followed by neurotoxins. Hepatotoxins include: (1) microcystins; (2) nodularins; and (3) cylindrospermopsins. The three most common types of cyanobacterial neurotoxins produced are: (1) anatoxin-a; (2) anatoxin-a (S); and (3) saxitoxins. As previously mentioned, (table no.1, fig no1) a recent study reported the presence of the neurotoxic compound, BMAA, in almost all cyanobacteria they tested. It has been theorised that BMAA could be the cause of the amyotrophic lateral sclerosis parkinsonism–dementia complex. (Bosch, K. et.al., 2007).

Table.1 Major cyanobacterial bloom toxins.

Toxin groups	Primary target organ in mammals	Cyanobacterial genera
Microcystin	Liver	Microcystis, Anabaena, Planktothrix (Oscillatoria), Nostoc, Hapalosiphon, Anabaenopsis, Trichodesmium, Synechococcus, Snowella
Nodularian	Liver	Nodularia
Cylindrospermopsin	Liver	Cylindrospermopsis, Umezakia, Aphanizomenon, Lyngbya, Raphidiopsis, Anabaena
Lyngbyatoxin-a	Skin, gatro-intestinal tract	Lyngbya, Schizothrix, Planktothrix (Oscillatoria)
BMAA	Nerve synapse	All
Saxitoxins	Nerve axons	Anabaena, Planktothrix (Oscillatoria), Aphanizomenon, Lyngbya, Cylindrospermopsis, Seytonema

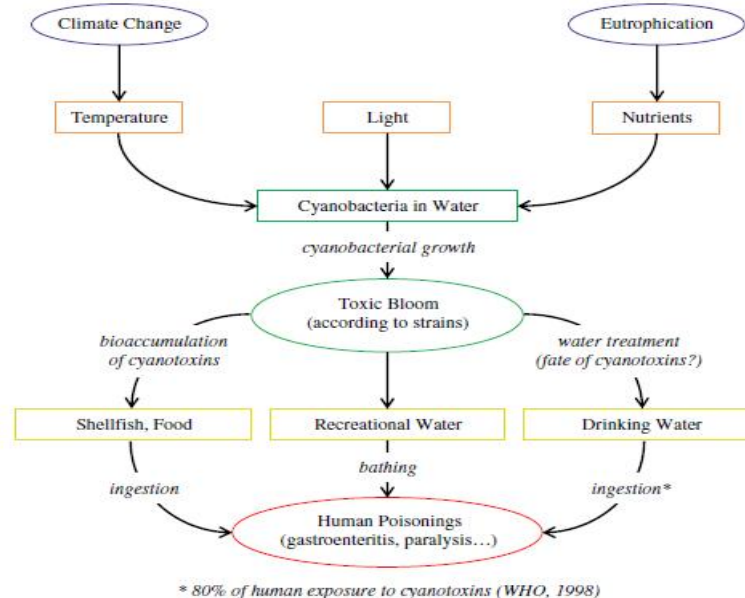


Fig-1. Origin of toxic cyanobacterial blooms and human exposure

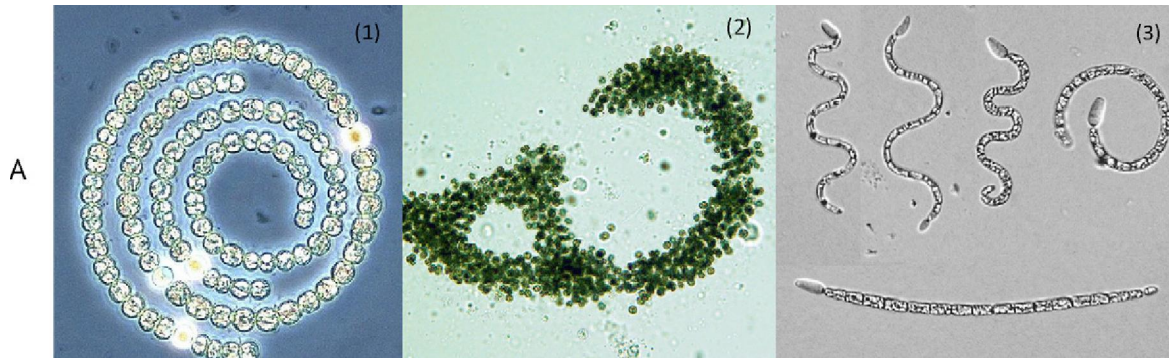


Fig. 2. Major CHAB genera from (A) freshwater: (1) *Anabaena* (2) *Microcystis* (3) *Cylandrospermopsis*

### Global warming

Research on the evolutionary history, ecophysiology, and in situ dynamics of cyanobacteria indicates that they will flourish under the circumstances anticipated for global climate change (Paul, 2008; Paerl and Huisman, 2009). The particular responses of some taxa of cyanobacteria to climate change remain uncertain. This study will specifically examine the impact of temperature and concurrent changes in stratification, as well as the influence of CO<sub>2</sub> and pH, on several taxa of cyanobacteria found in freshwater, estuarine, and marine environments. (Paerl, H.W., Millie, D.F., 1996)

### Temperature

The combustion of fossil fuels and resulting increase in atmospheric carbon dioxide has led to a rise in the earth's surface temperature of about 1.8 degrees Celsius throughout the course of the 20th century, with the majority of this increase occurring in the previous four decades. (IPCC, 2007) Worldwide, temperatures are projected to rise by an extra 1.5–5.8 degrees Celsius this century. Because of the high yet differential dependence of algal growth rates on temperature, these temperature rises have had and will have an impact on natural phytoplankton populations. Temperatures over 20 °C cause many cyanobacteria to develop at an accelerated pace, giving them an edge against freshwater eukaryotic phytoplankton, whose growth rates tend to stabilise or fall at this time. In addition to influencing cyanobacterial growth rates directly, increasing temperatures will alter numerous physical features of aquatic habitats in ways that might be beneficial to cyanobacteria. (Goldman, J.C., Carpenter, E.J., 1974). For example, when species compete for resources, a process known as surface water viscosity decreases and nutrient diffusion towards the cell surface increases as temperatures rise.

Cyanobacteria can regulate buoyancy to offset sedimentation, so decreasing viscosity promotes sinking of larger, non-motile phytoplankton with weak buoyancy regulation mechanisms (e.g. diatoms), giving them an advantage in these systems. Insular heating leads to more frequent, stronger, and longer-lasting stratification. This mechanism reduces the availability of nutrients in surface waters, allowing cyanobacteria that control buoyancy to get nutrients from deeper water or are diazotrophic. (Wagner, C., Adrian, R., 2009). Cyanobacteria dominate phytoplankton assemblages in eutrophic freshwater habitats during warm seasons, especially in temperate ecosystems, supporting previous studies. As global temperatures rise, it is expected that cyanobacterial blooms will spread, last longer, and become more intense.

### Carbon dioxide

Fossil fuel burning has led to a large rise in atmospheric CO<sub>2</sub> concentrations during the last two centuries, which is expected to continue in the next decades. CO<sub>2</sub> concentrations in the atmosphere are growing at a 3% annual pace, perhaps exceeding 800 ppm by the end of the century, up from a 1% annual rise in the 20th century. Rising CO<sub>2</sub> levels will significantly impact aquatic chemistry, resulting in lower pH and carbonate ion levels. Increased CO<sub>2</sub> concentrations in the atmosphere may benefit species that lack CCMs or depend heavily on CO<sub>2</sub> transport, especially in light of climate change. (Qui, B., Gao, K., 2002. ). Although increased CO<sub>2</sub> levels may reduce the severity of cyanobacterial blooms, the exact mechanism remains unknown. The concentration of CO<sub>2</sub> affects the physiology and growth rates of certain cyanobacteria taxa. Changing CO<sub>2</sub> circumstances. This may also impact the strain makeup of a

cyanobacterial colony. A research comparing toxic and non-toxic cyanobacteria strains with high CO<sub>2</sub> availability found that the non-toxic strain had a competitive advantage. (Cao, L., Caldeira, K., 2008). This article explores the impact of climate change on several dangerous cyanobacterial bloom genera, from freshwater.

### **Economic effects of cyanobacterial blooms**

Cyanobacterial blooms in surface water may have a significant influence on local economy. Restricting recreational activities like bathing or shellfish harvesting in contaminated water can harm tourism. Additionally, blooms across different latitudes can have a significant impact on the industry, but the associated costs are often underestimated. (Chan, F., Pace, M.L. 2004). Cyanobacterial blooms have a worldwide economic effect, and preventive and corrective strategies play an important role. (Codd, G.A., Morrison, L.F., Metcalf, J.S., 2005). To inhibit cyanobacterial development in lakes or reservoirs, pumps must be installed at precise areas and maintained regularly. Eliminating algal blooms may be costly. Monitoring the progress of a bloom in surface water requires repeated costly examination over many months. The economic effect of cyanobacterial blooms is still not fully understood. Further study is needed to address the impact of global warming on public health and water treatment.

## **III. RESULTS AND DISCUSSION**

### **Freshwater environments**

As noted above, freshwater harmful algal blooms are predominantly caused by pelagic cyanobacteria. (Carmichael, W.W., 2008.) As such, this review will focus on the role of eutrophication and climate change in the occurrence of three of the most prevalent pelagic cyanobacterial bloom forming genera in this environment, *Anabaena*, *Microcystis*, and *Cylindrospermopsis*. (Fig 2)

#### **Anabaena**

*Anabaena* is a common freshwater genus found worldwide, particularly in lentic water bodies including lakes, reservoirs, cease-to-flow rivers, and weir pools. *Anabaena* is a diazotroph of the Nostocales order that produces filaments and akinetes. Some species in this genus generate toxins such as microcystins (MCYs), anatoxin-a (S), and cylindrospermopsin (CYN), whereas *Anabaena circinalis* produces saxitoxin. (Rouhiainen, L., et al., 2004). *Anabaena*'s anatoxin biosynthesis gene cluster was recently identified.

#### **Potential nutritional effects**

*Anabaena* is diazotrophic in low dissolved inorganic nitrogen environments. *Anabaena*'s physiological ability allows it to outcompete non-nitrogen fixers in nitrogen-depleted waters, as proved by several investigations in both field and laboratory settings. *Anabaena*, a diazotroph, relies heavily on P as a limiting nutrient for its surface bloom. Limitation by P may Promote akinete production to ensure population recovery when P becomes accessible again. An agent-based model of *Anabaena*'s life cycle found that the sediment bed provides the majority of nutrients to populations shortly after they germinate. *Anabaena* may have a competitive edge against nonakinete-forming taxa in the early phases of bloom production, until P depletes or cells relocate to surface waters. (Wood, S.A., Prentice, M.J., Smith, J., Hamilton, D.P., 2010.)

#### **The potential implications of climate change**

Increasing temperature has been shown to benefit cyanobacteria via thermal stratification, notably promoting *Anabaena*. Diazotrophs like *Anabaena* benefit from strong stratification, which reduces the availability of remineralized nutrients in surface waters. Additionally, *Anabaena*'s capacity to modulate buoyancy in the water column further enhances its physiology. *Anabaena* blooms in thermally stratified circumstances owing to its capacity to control buoyancy and obtain adequate light for development. (Paerl, H.W., Huisman, J., 2009). Studies have shown that stable conditions, such as diurnal stratification, stimulate the growth of *A. circinalis*.

#### **Microcystis**

*Microcystis* is a prevalent bloom-forming organism in freshwater systems on all continents except Antarctica. This genus may create potentially hazardous substances such MCYs, anatoxin-(a), and BMAA. *Microcystis* bloom populations are divided into MCY-producing (MCY+) and non-MCY-producing (MCY-) strains, which can only be identified through molecular quantification of the MCY synthetase gene operon and as a marker for the overall

Microcystis population, such as the 16S rRNA gene.( Fristachi, A., Sinclair, J.L., 2008). Over the last decade, this approach of identifying sub-populations has been applied in both lab and field settings.Global changes to aquatic ecosystems, including increasing temperatures, nutrient loads, and CO<sub>2</sub> concentrations, may impact the dominance and toxicity of Microcystis.

#### **Potential nutritional effects**

Historically, P has been seen as the key limiting nutrient in freshwater ecosystems. Evidence suggests that harmful, non-diazotrophic cyanobacteria blooms, such as Microcystis, may be influenced by N as much as P. Laboratory studies indicate that increasing N concentrations enhances the proliferation and toxicity of Microcystis. Experiments show a favourable correlation between DIN supply, MCY production, and MCY content in hazardous strains of Microcystis.( Frangeul, L., Quillardet, P., 2008). Microcystis blooms are generally linked to excessive quantities of nitrogen in the environment.

#### **The potential implications of climate change**

Microcystis thrives at temperatures over 25°C and may compete with eukaryotic algae in ecosystems. Temperature-induced stratification may further promote this genus. Microcystis, like other bloom-forming cyanobacteria, may adjust its location in the water column by controlling gas vesicle generation and negatively buoyant carbohydrate reserves. Strong stratification promotes the growth of buoyancy-regulating cyanobacteria.( Mitrovic, S.M., Chessman, B.C., 2008). As water temperatures rise, cyanobacteria like Microcystis become more dominant. Warmer temperatures reduce water viscosity, perhaps increasing the sedimentation rate of eukaryotic algae and enhancing Microcystis' competitive edge.

#### **Cylindrospermopsis**

The Cyanobacterium Cylindrospermopsis is a single, filamentous diazotroph. Originally assumed to be a tropical/subtropical species, it was discovered in Java in 1912 (Koma'rkova', 1998). Over the last decade, it has expanded across all continents. Cylindrospermopsis was identified as a dangerous bloom species during a toxic bloom episode in 1979. Acute hepato-enteritis and kidney damage affected over 150 persons on Palm Island, located off the coast of North Queensland, Australia (Hawkins et al., 1985; Carmichael 2001). In 1992, Ohtani et al. identified the structure of cylindrospermisin (CYN), the toxin responsible for "Palm Island disease," resolving the riddle.

#### **Potential nutritional effects**

Despite being a diazotroph, *C. raciborskii* does not need low DIN conditions to bloom. A microcosm experiment compared *C. raciborskii* against *Anabaena* spp. and showed that *C. raciborskii* was more competitive for DIN. In waters dominated by *C. raciborskii*, DIN absorption rates outperformed N fixation rates in DIN replete circumstances, according to studies. Given the high energy cost of diazotrophy, it's understandable that ammonium is preferred when available. Laboratory investigations show that *C. raciborskii* grows best when nitrogen is provided as ammonium, followed by nitrate and urea. The activation of N<sub>2</sub>-fixation may be influenced by the cell's nitrogen content. *C. raciborskii* has a variable nitrogen strategy, using DIN when adequate and N<sub>2</sub>-fixation when depleted. Little is known about the influence of nitrogen on CYN synthesis.( Spro' ber, P., Shafik, H 2003). Several studies found that Australian isolates of *C. raciborskii* had the highest intracellular CYN content (reported as% of freeze-dried weight) in cultures without a fixed N source and the lowest in cultures with saturating ammonium concentrations. Growth rates were greatest in the presence of ammonium and lowest in the absence of a fixed nitrogen supply. In *C. raciborskii*, the CYN biosynthetic gene cluster is flanked by hyp gene homologs involved in hydrogenase maturation, leading to higher intracellular CYN levels in the absence of fixed N.( Seifert, M., McGregor, G.,2007).

#### **The potential implications of climate change**

*C. raciborskii* blooms were severe in a subtropical reservoir amid low rainfall and steady water column conditions. Vertical stratification gave *C. raciborskii* a competitive advantage over other algae species, perhaps because to its greater DIP scavenging capabilities at low concentrations. Installing a destratification device in a reservoir to remove stratification did not lower *C. raciborskii* blooms, but rather increased bloom start and duration.( Chonudomkul, D., Yongmanitchai, W 2004). Cells may photoadapt to dim and changing light conditions, which may explain this. Laboratory studies indicate that *C. raciborskii* requires low light levels for optimum development. *C. raciborskii* is not positively buoyant but sinks at a modest rate, which is consistent with previous findings. (Chorus, J., Bartram, J., 1999.) These data indicate that *C. raciborskii* blooms may occur without substantial stratification.

#### IV. CONCLUSION AND RECOMMENDATIONS

This review found that greater temperatures and large anthropogenic nutrient loads, especially Phosphates, increase cyanobacterial blooms. Cyanobacteria compete for low quantities of inorganic P and have improved techniques for getting it from organic molecules. In temperate ecosystems, cyanobacteria blooms are preceded by non-cyanobacterial phytoplankton blooms, which lower orthophosphate concentrations and promote cyanobacterial growth. As non-cyanobacteria phytoplankton die or are grazed, their biomass is remineralized into organic forms, which cyanobacteria can easily utilise. Large temperatures in tropical habitats enhance quick microbial digestion of orthophosphate, even with large P loads, resulting in low concentrations and cyanobacterial blooms. (Hudnell, K.H., 2008). Low nitrogen levels favour diazotrophic cyanobacteria with variable N acquisition mechanisms. Future CO<sub>2</sub> rises from climate change may reduce harmful cyanobacterial blooms, since they normally develop under low CO<sub>2</sub>. However, research on this issue is still in its early stages.

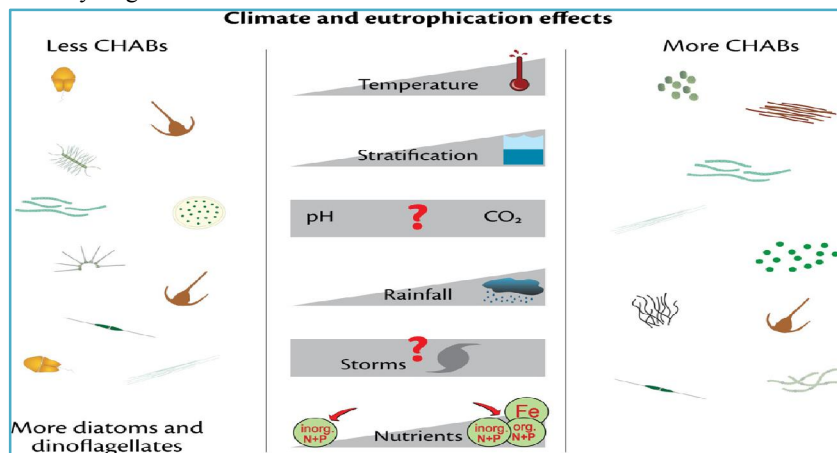


Fig. 3. Eutrophication and potential effects of climate change on Cyanobacterial Harmful Algal bloom (CHAB) abundance

Future study should concentrate on how cyanobacteria respond to eutrophication and global climate change (Fig. 2). Water management agencies must consider changing physical and chemical conditions of watersheds in remediation strategies, as cyanobacterial blooms may become more frequent and toxic due to changing climatic conditions (Fig. 2). Previously, remediation strategies have primarily focused on nutrient reduction. As mentioned in the review, increased Warming of surface waters affects viscosity and stratification in water columns. This will have a direct influence on the duration. Hypoxic conditions in bottom waters (e.g., Baltic Sea and Lake Erie, USA) affect nutrient cycling, nutrient cycling (e.g., P, Fe), and plankton competition in surface waters. (Huisman, J., Hulot, F.D., 2005). Future management plans should take these factors into account. Climate change may impact rainfall patterns and fertiliser delivery to aquatic habitats. In different regions, storms and rainfall may lead to increased freshwater delivery and decreased residence time, which may or may not stimulate harmful cyanobacterial blooms or other HAB species, depending on physical factors like light and temperature. Alternatively, increased flow may initially suppress blooms due to decreased residence times, increased turbidity, and reduced stratification. This tendency has been seen in many systems globally (Paerl and Husman, 2009). Water management must consider the influence of shifting rainfall patterns. Dissolved organic nutrients are often overlooked in management and remediation techniques, despite the fact that cyanobacteria have versatile N and P acquisition mechanisms that include organic compound absorption and utilization. As global nutrient loads rise, management agencies should consider lowering organic nutrient loads in remediation techniques. Future research should examine how climate changes affect higher trophic levels, including the influence of cyanobacterial blooms. In addition to impacting biogeochemical cycles, food web dynamics, and ecosystem function, cyanobacterial blooms may have a substantial impact on human health. The potential for widespread development of novel poisons like BMAA, (Paul, V.J., 2008.) as well as the capacity of more species to create established toxins, encourages more investigation and control of these organisms.

**Compliance with ethical standards:**

**Acknowledgments**

We are grateful to Prof. Vidyavati, former Vice Chancellor of Kakatiya University, Warangal for her valuable suggestions and constant encouragement.

**Disclosure of conflict of interest**

The authors (Dr Raju Potharaju, Prof M. Aruna) declare no conflict of interest.

**REFERENCES**

- [1]. Agawin, N.S.R., Duarte, C.M., Agusti, S., (2000). Nutrient and temperature control of the contribution of picoplankton to phytoplankton biomass and production. *Limnol. Oceanogr.* 45, 591–600.
- [2]. Bosch, K., Visser, P.M., Huisman, J., (2007). Salt tolerance of the harmful cyanobacterium *Microcystis aeruginosa*. *Aquat. Microb. Ecol.* 46, 117–123.
- [3]. Cao, L., Caldeira, K., (2008). Atmospheric CO<sub>2</sub> stabilization and ocean acidification. *Geophys. Res. Lett.* 35, L19609.
- [4]. Carmichael, W.W., (2001). Health effects of toxin-producing cyanobacteria: “The CyanoHABs”. *Hum. Ecol. Risk Assess.* 7 (5), 1393–1407
- [5]. Carmichael, W.W., (2008). A world view—One-hundred twenty-seven years of research on toxic cyanobacteria—Where do we go from here? In: Hudnell, K.H. (Ed.), *Cyanobacterial Harmful Algal Blooms: State of the Science and Research Needs*. *Advances in Experimental Medicine and Biology*, vol. 619, vol. XXIV. pp.105–120.
- [6]. Carmichael, W.W., (2008). A world view—One-hundred twenty-seven years of research on toxic cyanobacteria—Where do we go from here? In: Hudnell, K.H. (Ed.), *Cyanobacterial Harmful Algal Blooms: State of the Science and Research Needs*. *Advances in Experimental Medicine and Biology*, vol. 619, vol. XXIV. pp. 105–120.
- [7]. Chan, F., Pace, M.L., Howarth, R.W., Marino, R.M., (2004). Bloom formation in heterocystic nitrogen-fixing cyanobacteria: the dependence on colony size and zooplankton grazing. *Limnol. Oceanogr.* 49, 2171–2178
- [8]. Chonudomkul, D., Yongmanitchai, W., Theeragool, G., Kawachi, M., Kasai, F., Kaya, K., Watanabe, M.M., (2004). Morphology, genetic diversity, temperature tolerance and toxicity of *Cylindrospermopsis raciborskii* (Nostocales, Cyanobacteria) strains from Thailand and Japan. *FEMS Microbiol. Ecol.* 48, 345–355.
- [9]. Chorus, I., Bartram, J., (1999). *Toxic Cyanobacteria in Water: A Guide to their Public Health Consequences, Monitoring and Management*. World Health Organization, E&FN Spon, Routledge, London, UK.
- [10]. Codd, G.A., Morrison, L.F., Metcalf, J.S., (2005). Cyanobacterial toxins: risk management for health protection. *Toxicol. Appl. Pharmacol.* 203, 264–272.
- [11]. Downing, J.A., Watson, S.B., McCauley, E., (2001). Predicting cyanobacteria dominance in lakes. *Can. J. Fish. Aquat. Sci.* 58, 1905–1908.
- [12]. Francis, G., (1878). Poisonous Australian Lake. *Nature* 18, 11–12.
- [13]. Frangeul, L., Quillardet, P., Castets, A.-M., Humbert, F., Matthijs, H.C.P., Cortez, D., et al., (2008). Highly plastic genome of *Microcystis aeruginosa* PCC 7806, a ubiquitous toxic freshwater cyanobacterium. *BMC Genomics* 9, 274–294
- [14]. Fristachi, A., Sinclair, J.L., (2008). Occurrence of cyanobacterial harmful algal blooms workgroup report. In: Hudnell, K.H. (Ed.), *Cyanobacterial Harmful Algal Blooms: State of the Science and Research Needs*. Springer, New York, pp. 45–103.
- [15]. GEOHAB (Global Ecology and Oceanography of Harmful Algal Blooms Programme), (2001). In: Glibert, P., Pitcher, G. (Eds.), *Science Plan*. SCOR and IOC, Baltimore, MD/Paris, France.
- [16]. Goldman, J.C., Carpenter, E.J., (1974). A kinetic approach to the effect of temperature on algal growth. *Limnol. Oceanogr.* 19, 756–766.
- [17]. Hawkins, P.R., Runnegar, M.T.C., Jackson, A.R.B., Falconer, I.R., (1985). Severe hepatotoxicity

- [18]. Hudnell, K.H., 2008. Cyanobacterial harmful algal blooms: state of the science and research needs. In: Hudnell, K.H. (Ed.), *Cyanobacterial Harmful Algal Blooms: State of the Science and Research Needs*. *Advances in Experimental Medicine and Biology*, vol. 619, vol. XXIV. pp. 950.
- [19]. Huisman, J., Hulot, F.D., (2005). Population dynamics of harmful cyanobacteria. In: Huisman, J., Matthijs, H.C.P., Visser, P.M. (Eds.), *Harmful Cyanobacteria*, *Aquatic Ecology Series*. Springer, Dordrecht, The Netherlands, pp. 143–176.
- [20]. IPCC, (2007). A report of working group I of the Intergovernmental Panel on Climate Change. Summary for Policymakers and Technical Summary.
- [21]. Komařkova, J., (1998). The tropical planktonic genus *Cylindrospermopsis* (Cyanophytes, cyanobacteria). In: Azevedo, T., de Paiva, T. (Eds.), *Anais do IV Congresso Latino Americano de Ficologia*, vol. I. Secretaria do Meio Ambiente do Estado de Saõ Paulo, Brazil, pp. 327–340.
- [22]. Mitrovic, S.M., Chessman, B.C., Bowling, L.C., Cooke, R.H., (2006). Modelling suppression of cyanobacterial blooms by flow management in lowland river. *River Res. Appl.* 22, 109–114.
- [23]. Paerl, H.W., Huisman, J., (2009). Climate change: a catalyst for global expansion of harmful cyanobacterial blooms. *Eviron. Microb. Rep.* 1, 27–37
- [24]. Paerl, H.W., Huisman, J., (2009). Climate change: a catalyst for global expansion of harmful cyanobacterial blooms. *Eviron. Microb. Rep.* 1, 27–37.
- [25]. Paerl, H.W., Millie, D.F., (1996). Physiological ecology of toxic cyanobacteria. *Phycologia* 35, 160–167
- [26]. Paul, V.J., (2008). Global warming and cyanobacterial harmful algal booms. In: Hudnell, K.H. (Ed.), *Cyanobacterial Harmful Algal Blooms: State of the Science and Research Needs*. *Advances in Experimental Medicine and Biology*, vol. 619, vol. XXIV. pp. 239–257.
- [27]. Paul, V.J., (2008). Global warming and cyanobacterial harmful algal booms. In: Hudnell, K.H. (Ed.), *Cyanobacterial Harmful Algal Blooms: State of the Science and Research Needs*. *Advances in Experimental Medicine and Biology*, vol. 619, vol. XXIV. pp. 239–257
- [28]. Qui, B., Gao, K., (2002). Effects of CO<sub>2</sub> enrichment on the bloom-forming cyanobacterium *Microcystis aeruginosa* (Cyanophyceae): physiological responses and relationships with the availability of dissolved inorganic carbon. *J. Phycol.* 38, 721–729.
- [29]. Rouhiainen, L., Vakkilainen, T., Siemer, B.L., Buikema, W., Haselkorn, R., Sivonen, K., (2004). Genes coding for hepatotoxic heptapeptides (microcystins) in the cyanobacterium *Anabaena* strain 90. *Appl. Environ. Microbiol.* 70, 686–692.
- [30]. Seifert, M., McGregor, G., Eaglesham, G., Wickramasinghe, W., Shaw, G., (2007). First evidence for the production of cylindrospermopsin and deoxy-cylindrospermopsin by the freshwater benthic cyanobacterium, *Lyngbyawollei* (Farlow ex Gomont) Speziale and Dyck. *Harmful Algae* 6, 73–80.
- [31]. Sprober, P., Shafik, H.M., Preising, M., Kovacs, A.W., Herodek, S., (2003). Nitrogen uptake and fixation in the cyanobacterium *Cylindrospermopsis raciborskii* under different nitrogen conditions. *Hydrobiologia* 506–509, 169–174.
- [32]. Tonk, L., (2007). Impact of Environmental Factors on Toxic and Bioactive Peptide Production by Harmful Cyanobacteria. Department of Aquatic Microbiology, Institute for Biodiversity and Ecosystem Dynamics, Universiteit van Amsterdam NieuweAchtergracht, Amsterdam, 136 pp.
- [33]. Wagner, C., Adrian, R., (2009). Cyanobacteria dominance: quantifying the effects of climate change. *Limnol. Oceanogr.* 54, 2460–2468.
- [34]. Wood, S.A., Prentice, M.J., Smith, J., Hamilton, D.P., (2010). Low dissolved inorganic nitrogen and increased heterocyte frequency: precursors to *Anabaena planktonica* blooms in a temperate, eutrophic reservoir. *J. Plankton Res.* 32, 1315–1325.