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Articles

Review of potentially harmful cianobacteria

Revisión de cianobacterias potencialmente nocivas

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Abstract

A bibliographic review was developed by consulting various sources of information (articles, books, abstracts, etc.), obtained from the Web of Science database, Scopus, biological abstracts, etc. They describe the most relevant studies of the last three decades chronologically, from historical researches, as well as current topics under various sub-themes, critically analyzing nearly 200 articles with the aim to expose simply, but in a straightforward way, the general characteristics of cyanobacteria, the main conditions that favour the formation and persistence of blooms or "CyanoHABs"; negative implications on water resources due to cyanotoxin production, emphasizing the reference limits established for the hepatotoxin Microcystin-LR in water for human consumption, in recreational systems and food products; methodologies developed for monitoring toxic strains and a summary of the research published in Mexico on cyanobacteria and their toxins. Finally, some control procedures used in the remediation of systems with cyanobacterial blooms are discussed.

Keywords: Cyanobacteria, cyanohabs, cyanotoxins, microcystins.

Resumen

Se desarrolló una revisión bibliográfica a través de la consulta de diversas fuentes de información (artículos, libros, resúmenes, etc.) obtenidas de diversas bases de datos como *Web of Science*, *Scopus* y *Biological abstracts*, entre otras. Se describen de forma cronológica los estudios más relevantes de las últimas tres décadas, partiendo de investigaciones históricas, así como tópicos actuales bajo diversos subtemas; se

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analizaron críticamente cerca de 200 de artículos con el objetivo de exponer de manera sencilla, pero explícita, las características generales de las cianobacterias; las principales condiciones que favorecen la formación y persistencia de los florecimientos o "CianoFANs"; las implicaciones negativas sobre los recursos hídricos debido a la producción de cianotoxinas, con énfasis en los límites de referencia establecidos para la hepatotoxina Microcistina-LR en agua de consumo humano, en sistemas de uso recreativo y en productos alimenticios; las metodologías desarrolladas para el monitoreo de cepas tóxicas, y un resumen de las investigaciones publicadas en México sobre cianobacterias y sus toxinas. Por último, se discuten algunos procedimientos de control usados en remediación de sistemas con proliferación de cianobacterias.

Palabras clave: cianobacteria, cianofan, cianotoxinas, microcistinas.

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Cyanobacteria: general features

Cyanobacteria or cyanoprokaryote are the first oxygenic photoautotrophs (Komárek, 2006). According to the classification based on phylogenetic

relationships, they belong to the eubacterial domain (Maddison, Schulz, & Maddison, 2007). Their age is estimated at more than 3.5 billion years through fossil records (microbialites: organosedimentary deposists formed by accretion, precipitation, and union of mineral materials) and geological data obtained from carbon isotopic samples consistent with CO_2 fixation through the Rubisco enzyme (Castle & Rodgers, 2009; Schopf, 2012). They are responsible for altering the primitive biosphere and transforming it into an oxidizing one during the Precambrian (Schirrmeister, de Vos, Antonelli, & Bagheri, 2013; Pla-García & Menor-Salván, 2017; Moss, 2018). Cyanobacteria have colonized most ecological niches due to their long evolutionary history. They are found from the poles to the tropics in aquatic and terrestrial systems, tolerating inhospitable environmental circumstances of low and high alkalinity and predominating in geothermal microbial communities (Steinberg, Schäfer, & Beisker, 1998; Miller & Castenholz, 2000). However, cyanobacterial taxa require different ecological strategies to grow in each specific habitat. Most species have ecological niches restricted by their morphological and physiological traits (Komárek, 1995; Mateo, Leganés, Perona, Loza, & Fernández-Piñas, 2015).

Among the prokaryotes and from the study of morphological characters (traditional taxonomy), cyanobacteria comprise about 24 % of them, with about 3 000 species arranged in 150 genera (Guiry, 2012; Nabout, Da-Silva-Rocha, Carneiro, & Sant'Anna, 2013). Based on a polyphasic approach that integrates phenotypic, ecophysiological and phylogenetic information, reveals that cyanobacteria are a widely diversified group. To understand their evolutionary relationships and generate a classification that does not underestimate or overestimate the

size of the populations, they have been divided into eight orders: Gloeobacterales, Synechococcales, Spirulinales, Chroococcales, Pleurocapsales, Oscillatoriales, Chroococcidiopsidales, Nostocales (Komárek, 2010; Komárek, 2014). However, using mathematical logistic models based on the species recognized so far, it has been estimated that this group must contain about 3 580 species which have not yet been described (Nabout *et al*., 2013).

Cyanobacteria have a wide range of morphological variations, unicellular organisms from 2 to 20 µm and multicellular filaments or colonies exceeding 500 µm (Whitton, 2002; Codd, Lindsay, Young, Morrison, & Metcalf, 2005b). They reproduce asexually by binary or multiple fission; however, some species can produce endospores and exospores (exocytes, baeocytes and hormocytes). Another reproductive strategy is the fragmentation of colonies or filamentous trichomes in the form of hormogonia (short trichome fragments separated by necridial zones formed by programmed cell death) (Whitton & Potts, 2012). Cell division occurs in one, two, or three perpendicular or irregular planes, resulting in a variety of three-dimensional configurations (Mazouni, Domain, Cassier-Chauvat, & Chauvat, 2004; Flores & Herrero, 2014). Furthermore, some filamentous cyanobacteria have different types of branching, which gives them a distinctive morphology used for taxonomic classification (Cirés, 2012). Unlike photosynthetic eukaryotes, they do not have a defined nucleus and lack plastids and organelles. Likewise, their cell wall is Gram-negative, free of teichoic acids, formed by three main layers composed of peptidoglycan; although some genera present a fourth protein layer, called the superficial layer or S-layer (Rippka,

Deruelles, Waterbury, Herdman, & Stanier, 1979; Hoiczyk & Hansel, 2000).

The photosynthetic pigment composition of cyanobacteria is variable, as they synthesize a wide range of accessory pigments, such as phycocyanin (maximum absorbance = 620 nm), phycoerythrin (maximum absorbance = 565 nm), allophycocyanin (maximum absorbance = 650 nm), and various carotenoids, resulting in a wide range of colorations, including red, brown, and pink; However, one of the transcendental features is their distinctive blue-green (cyan) coloration, which is due to the ubiquitous presence of the pigment chlorophyll-a hidden by phycobiliproteins (Huisman *et al*., 2018).

Cyanobacteria play an essential role in energy flow, transforming inorganic matter into organic matter in biomass. At the same time, they play an important role in both nitrogen and carbon biogeochemical cycles (Bellinger & Sigee, 2015). The growth of primary producers depends on a quota of essential inorganic nutrients; these nutritional requirements have a stoichiometric relation known as the Redfield ratio, an average proportion of the atomic composition of phytoplankton biomass, with a relatively constant ratio of 106 carbon to 16 nitrogen and 1 phosphorus atoms (Redfield, 1958; Ptacnik, Andersen, & Tamminen, 2010). Nitrogen and phosphorus are vital nutrients for primary producers, structuring the synthesis of cell membranes, DNA (deoxyribonucleic acid), amino acids, proteins, and as part of cell metabolism (Reynolds, 2006).

Cyanobacteria actively incorporate a wide range of nitrogen molecules such as ammonium (NH_4^+), nitrate (NO_3^-), nitrite (NO_2^-), urea (CH_4NO_2), etc. Depending on the nitrogen source, assimilation requires

additional enzymatic reductions (nitrate reductase and nitrite reductase). Ammonium is the least expensive nitrogen source; for glutamate synthesis, one molecule of NADPH (Nicotinamide-Adenine-Dinucleotide-Phosphate) and ATP (Adenosine triphosphate) is required (Flores & Herrero, 2005). The main phosphorus supply for cyanobacteria is orthophosphates (H_3PO_4), but they also use other organic forms (Whitton & Potts, 2012). Low N:P (nitrogen: phosphorus) ratios have been considered as one of the factors influencing the success of cyanobacteria, and conversely, a high ratio (50:1) favors their dominance in epicontinental systems (Hyenstrand, Blomqvist, & Pettersson, 1998; Bulgakov & Levich, 1999).

CyanoHABs: Factors and traits that drive your success

Cyanobacteria significantly accelerate the average population biomass in a relatively short time, generating massive growth phenomena (> 10^4 cels m l^{-1}), known as harmful algal blooms "CyanoHABs" (Carmichael, 2001; Codd, Morrison, & Metcalf, 2005a; Ger, Hansson, & Lürling, 2014). A CyanoHAB is distinguished by the dominance of a few species, which account for more than 80 % of the total biomass among primary

producers (Mihaljević & Stević, 2011; Humbert & Fastner, 2017). CyanoHAB has a severe impact on the water quality of aquatic systems caused by the organic matter accumulation that decreases the vertical transparency, causing alterations in the submerged aquatic vegetation.

Despite not being toxic to humans, cyanobacteria produce volatile organoleptic compounds such as geosmin and 2-methylisoborneol, which interfere with the recreational function of aquatic systems or their use as drinking water reservoirs by altering public perceptions of hygiene and public health and causing significant economic losses in both sectors (Liato & Aïder, 2017; Churro, Semedo-Aguiar, Silva, Pereira-Leal, & Leite, 2020).

Furthermore, due to photosynthesis and cellular respiration, dense blooms cause dramatic alterations in dissolved oxygen concentrations (Vermaas, 2001; Moss *et al*., 2011). They coexist in microenvironments with heterotrophic bacteria immersed in the phycosphere (the region surrounding a cyanobacterial cell enriched with exuded organic molecules) (Steiner *et al*., 2017), which during the senescence of a bloom promote hypoxia and anoxia periods due to degradation process, causing the death of benthic, nektonic and planktonic organisms, (fish, birds, zooplankton, phytoplankton, etc.), decreasing the biodiversity of aquatic ecosystems (Oberholster, Botha, & Cloete, 2006; Paerl & Otten, 2013).

Eutrophication increased atmospheric carbon dioxide (CO_2), and global climate change are just a few of the many environmental factors contributing to blooms frequency and intensity (Huisman *et al*., 2018). CyanoHABs have been more intense in the last 50 years as the rate of anthropogenic eutrophication has increased due to industrialization and

urbanization processes (Paerl & Paul, 2012; Deshpande, Tremblay, Pienitz, & Vincent, 2014; Paerl, 2017).

Global warming stimulates the proliferation of cyanobacteria directly or indirectly, wreaking havoc on the functioning of aquatic systems and ecological structure (Visser, Ibelings, Bormans, & Huisman, 2016a; Huisman *et al*., 2018).

Directly, global warming favors increased photosynthetic capacity and accelerated metabolic rate, presenting its maximum population growth rates above 25 °C Lürling, Eshetu, Faassen, Kosten, & Huszar, 2013; Paerl, 2014; Savadova *et al*., 2018). Thermal increase stimulates the reintegration of cells or colonies of meroplanktonic genera (Cirés, Wörmer, Agha, & Quesada, 2013), incite early akinete inoculation, and increase of the germination percentage (Carey, Ibelings, Hoffmann, Hamilton, & Brookes, 2012; Cirés *et al*., 2013; Silveira & Odebrecht, 2019). On the other hand, global warming promotes biogeographic range expansion, establishment, and dispersal of species with invasive potential such as *Raphidiopsis raciborskii* (Nostocales), *Planktothrix rubescens* (Oscillatoriales), and *Synechococcus capitatus* (Chroococcales) (Sinha *et al*., 2012; Kokociński, Akçaalan, Salmaso, Stoyneva-Gärtner, & Sukenik, 2017). Indirect effects of temperature involved higher stratification stability on the water column with vertical mixing reduction because of changes in water density (Joehnk *et al*., 2008; Paerl *et al*., 2020) and viscosity decrease, causing loss due to sedimentation of those primary producers without buoyancy regulating structures (Joehnk *et al*., 2008; O'Neil, Davis, Burford, & Gobler, 2012).

In recent decades atmospheric CO_2 emissions have increased at a rate of 3 % per year, derived from the combustion of fossil fuels (O'Neil *et al*., 2012). Due to their physiological flexibility, cyanobacteria have inorganic carbon concentration systems, which give them efficient CO_2 and HCO_3^- consumption (Huisman *et al*., 2018). Nevertheless, since high photosynthetic rates generate higher demand for CO_2, cyanobacteria with gas vesicles have a competitive advantage because they directly intercept this ion from the atmosphere (Paerl & Huisman, 2009). An increase in CO_2 concentrations in the atmosphere probably favors CyanoHABs in eutrophic waters, especially those with the possibility of regulating their vertical buoyancy along the water column and combining carbon concentration systems (Ji, Verspagen, Stomp, & Huisman, 2017).

Hydrological alterations are another indicator of climate change. Prolonged and heavy precipitation enhance runoff and the discharge of nutrient-rich groundwater into drainage basins, which occurs naturally because of erosion. This inflow of large volumes of water during storms favors sediment removal, subsequent release of nutrients into the water column, and reintegration of cyanobacterial cells in dormancy (Cirés *et al*., 2013; Havens, East, & Beaver, 2016). However, if storms are followed by periods of drought and long water residence stages, populations of slow growing and persistent primary producers, such as cyanobacteria, are favored (Moss *et al*., 2011; Reichwaldt & Ghadouani, 2012; Chapra *et al*., 2017).

Factors intrinsic to cyanobacterial cells also contribute to their ecological success. Cyanobacteria tend to change their unicellular to multicellular morphology into large colonies or filaments, avoiding this

way their ingestion by size or exclusion by interference from feeding appendages of filter-feeding herbivores (Porter, 1973; DeMott, Gulati, & Van Donk, 2001). Several species are embedded into a colloidal element composed of mucilage which is an extracellular polymeric substance which acts a protective boundary between cells and the surrounding environment and plays a key role in intraspecific and interspecific interactions (Kehr & Dittmann, 2015).

Under phosphorus limiting conditions, cyanobacteria form polyphosphate granules, used as a reserve, which is enough to perform several cell divisions (Whitton & Potts, 2012). Also, cyanobacteria can transform atmospheric N_2 by different enzymatic processes (diazotrophy) during nitrogen limiting conditions. a procedure that requires a significant amount of energy (10 % of total cellular proteins and 16 ATP molecules) (Berman-Frank, Quigg, Finkel, Irwin, & Haramaty, 2007). Diverse filamentous cyanobacteria (mainly of the Nostocales genus) carry out fixation in morphologically modified microaerobic cells, known as heterocytes or diazocytes, where the enzyme nitrogenase is expressed (Bergman, Sandh, Lin, Larsson, & Carpenter, 2013).

Planktonic species can benefit when exploiting water systems with dense thermal stratification, regulating buoyancy through the metalimnion, or if the systems are unstable, they occupy the surface regions of the epilimnion, which are zones with better illumination and higher nutrient concentration. This is due to the production of intracellular gas vesicles, aerotopes, which are arranged in structures that are distributed parallel to one another (Walsby, Hayes, Boje, & Stal, 1997; Mur, Skulberg, & Utkilen, 1999; Kobos *et al*., 2013).

Mechanisms behind buoyancy involve modulation of genetic expression of vesicles, their collapse by turgor pressure, and the action of ballast, such as intracellular carbohydrates the accumulation of intracellular carbohydrates produced during the respiration (Walsby, 1994; Wallace, Bailey, & Hamilton, 2000; Wörmer, Cirés, & Quesada, 2011). Larger colonies have higher ascent rates because the buoyancy rate is related to its diameter squared (Rabouille, Salençon, & Thébault, 2005; Zhao *et al*., 2016). Field studies demonstrate that colonies larger than > 300 µm resist turbulent mixing, whereas colonies smaller than < 36 µm disperse uniformly and are susceptible to sedimentation (Chien, Wu, Chen, & Chou, 2013; Zhao *et al*., 2016).

Bioactive metabolites: Cyanotoxins

Cyanobacteria can produce bioactive metabolites with varied chemical structures; more than 2 000 metabolic substances have been characterized so far (Carmichael *et al*., 2001; Jones *et al*., 2021). Due to their high complexity, these substances draw the attention of researchers for use in the field of biotechnology and are commercially exploited in the food, cosmetics, agrochemical, and pharmaceutical industries (Liu, Pohnert, & Wei, 2016).

Pharmaceutical research explores their use to combat against cancer, cardiac disorders, autoimmune and infectious diseases (Swain, Paidesetty, & Padhy, 2017). Compounds with anticancer activity derived from cyanobacteria include alkaloids, polyketides, terpenes, peptides, nucleosides, and carbohydrates. These include cytotoxic compounds targeting non-specific macromolecules expressed by cancer cells or metabolites that alter oncogenic signal transduction pathways (Nobili *et al*., 2009; Mondal *et al*., 2020).

Among the bioactive secondary metabolites, the so-called cyanotoxins stand out mainly because of their adverse effect on mammals, birds, fish, zooplankton, protozoa, bacteria, and their harmful impact on human health (Yadav, Sinha, Tyagi, & Kumar, 2011).

These substances are classified chemically as cyclic peptides (heptapeptides, such as Microcystins, and pentapeptides, such as Nodularin), alkaloids (anatoxins, saxitoxins, and cylindrospermopsin), and lipopolysaccharides (Whitton & Potts, 2012). They can also be categorized as cytotoxins or biotoxins if they affect an organ or tissue (hepatotoxins, neurotoxins, and irritant toxins) (Vasconcelos, 2001; Whitton & Potts 2012; Ibrahem, Khairy, & Ibrahim, 2012; Paerl, Otten, & Joyner, 2016; Huisman *et al*., 2018) (Table 1).

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Table 1. Scheme of cyanotoxins, characteristics and examples of the main producing genera (Adapted from Huisman *et al*., 2018).

Cyanotoxin	Chemical Structure	Classification and Mechanisms of Action	Main Producing Genera
Microcystins	Cyclic heptapeptide	Hepatotoxins: Inhibition of eukaryotic protein phosphatases (PP1 and PP2A). Hepatic and renal damage, gastroenteritis, tumor promoter.	*Microcystis* *Dolichospermum* *Planktothrix* *Nostoc* *Anabaenopsis* *Leptolyngbya* *Phormidium* *Synechococcus*
Nodularins	Cyclic pentapeptide	Hepatotoxins: Inhibition of eukaryotic protein phosphatases. Promoters of cancerous tumors, liver damage.	*Nodularia*
Anatoxin-*a*	Bicyclic alkaloid	Neurotoxin: Agonist of nicotinic acetylcholine receptors at neuromuscular junctions. Blocker of postsynaptic neuromuscular depolarization. Loss of coordination, muscle spasms and respiratory failure.	*Anabaena* *Aphanizomenon* *Cuspidothrix* *Dolichospermum* *Planktothrix* *Oscillatoria* *Phormidium*
Anatoxin-*a*(s)	Alkaloid	Neurotoxin: Acetylcholinesterase inhibitor. Salivation, muscle spasms and respiratory failure.	*Dolichospermum*
Saxitoxins	Alkaloid	Neurotoxins: Blocks sodium ion channels of eukaryotic neurons. Promotes numbness, paralysis, and respiratory failure.	*Aphanizomenon* *Cuspidothrix* *Cylindrospermopsis* *Dolichospermum* *Lyngbya* *Planktothrix*

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Cyanotoxin	Chemical Structure	Classification and Mechanisms of Action	Main Producing Genera
Cylindrospermopsin	Tricyclic guanidine alkaloid	Multiple toxicity. Neurotoxic, genotoxic and protein synthesis inhibitor potential.	*Cylindrospermopsis* *Umezakia* *Anabaena* *Oscillatoria* *Raphidiopsis*
BMAA	Beta-methylamino-L- alanine (non-encoded amino acids)	Neurotoxin: Excessive stimulation of glutamate receptors in neurons and erroneous insertion into proteins, changing their configuration. Linked to neurodegenerative diseases.	*Microcystis* *Nostoc* Possibly widespread among more cyanobacteria, but still no consensus.
LPS	Lipopolysaccharides	Dermatotoxins: Inflammation and promoters of cytokine production. Skin irritation, fever and gastrointestinal distress.	All cyanobacteria.

Over 50 % of the CyanoHAB-forming genera can produce one or more cyanotoxins (Codd *et al*., 2005a; Codd *et al*., 2005b). Cyanotoxins are endotoxins, and their release into the environment is regulated by cell membrane lysis, especially during CyanoHAB senescence (Chorus & Bartram, 1999). However, some physical or chemical agents promote its disruption and cyanotoxin release (Hoeger, Dietrich, & Hitzfeld, 2002; Dai *et al*., 2016). During the exponential growth phase, 10-20 % of the concentration is released to the surrounding water (Watanabe, Tsuji, Watanabe, Harada, & Suzuki, 1992; Negri, Jones, Blackburn, Oshima, & Onodera, 1997; Rapala, Sivonen, Lyra, & Niemelä, 1997). In some cases, dissolved cyanotoxin ratios are higher than intracellular concentrations (Bumke-Vogt, Mailahn, & Chorus, 1999; Kinnear, Duivenvoorden, &

Fabbro, 2007). Once in the environment, they have variable persistence (e.g., the half-life of microcystins is up to 10 weeks at 40 °C and pH 10) because they can be biodegraded by bacteria, which can hydrolyze the molecule and use it as a carbon or nitrogen source (strains of *Sphingomonas*, *Sphingosinicella*, *Novosphingobium*, *Sphingopyxis*, and *Stenotrophomonas*), physicochemically decomposed (e.g., by photolysis) or absorbed by sedimentary particles (Edwards & Lawton, 2009; Harada & Tsuji, 1998; Brinkman & Bourne, 2013; Schmidt, Wilhelm, & Boyer, 2014).

Microcystins

Microcystins (MCs) are the most abundant cyanotoxins in both freshwater and brackish habitats around the world (Chorus & Bartram, 1999), with approximately 280 known congeners, which are distinguished by amino acids linked to the *X* and *Z* positions of the heptapeptide structure (seven amino acids in a ring formation with a single β-amino acid side chain (ADDA group) (Chorus & Bartram, 1999; Bouaïcha *et al*., 2019). Environmental factors such as competition, predation, temperature, light intensity, and nutrition concentration influence the production of MCs (Merel *et al*., 2013).

MCs are not synthesized by the ribosomal pathway; their gene expression depends on genomic locus coding *mcy* (Microcystis and Anabaena) arranged in two divergent transcription operons. Multifunctional enzyme complexes containing nonribosomal peptide synthetase (*NRPS*) and polyketide synthase (*PKS*) domains (Tillett *et al*., 2000).

The Microcystis genus mostly produces this toxin (e.g., *Microcystis aeruginosa*, *Microcystis novacekii*, Microcystis *panniformis*, *Microcystis protocystis*). Nevertheless, because of horizontal gene transfer, about 23 planktonic and benthic taxa, including *Anabaena*, *Phormidium*, *Planktothrix*, *Nostoc*, *Limnothrix*, *Anabaenopsis*, *Aphanocapsa*, *Aphanizomenon*, *Cylindrospermopsis*, *Fischerella*, *Hapalosiphon*, *Lyngbya*, *Oscillatoria*, *Rivularia*, *Synechocystis* and *Synechococcus*, can synthesize (Rantala *et al*., 2004; Rastogi, Madamwar, & Incharoensakdi, 2015; Catherine, Bernard, Spoof, & Bruno, 2017).

Exposure to MCs represents a high risk to humans. Once ingested, they cannot be hydrolyzed by peptidase enzymes in the stomach, and due to their high molecular weight (from 900 to 1 100 Da), they do not passively diffuse across cell membranes; therefore, they are actively transported to hepatocytes by organic anion transporter proteins of the biliary system (OATP1B1 and OATP1B3) (Popovic, Zaja, & Smital, 2010; Fontanillo & Köhn, 2018). MCs have an inhibitory effect on serine and threonine enzymes responsible for catalyzing phosphorylation. The toxicity is caused by the amino acid Adda from microcystin binding to the catalytic site of protein phosphatases (PP1, PP2A, PP2B, PP4, PP5, and PP6), which inhibits substrate dephosphorylation (Mackintosh, Beattie,

Klumpp, Cohen, & Codd, 1990; Swingle, Ni, & Honkanen, 2007), promoting cell necrosis or apoptosis, damage to DNA repair systems, gene expression and oxidative stress (Campos & Vasconcelos, 2010; Zanchett & Oliveira-Filho, 2013). Gastroenteritis, irritations, liver disorders, including necrosis and cancer, are the most common symptoms of MC poisoning, which can lead to death (Fontanillo & Köhn, 2018).

Guiding levels and guidelines

Due to its high degree of toxicity and frequency around the world (McLellan & Manderville, 2017), different environmental authorities, including the World Health Organization (WHO), established a reference value of MCs of 1 µg l^{-1} for drinking water sources of the LR variant (Chorus & Bartram, 1999). The same level was set in Mexico under the draft standard PROY-NOM-127-SSA1-2017. Furthermore, to reduce the health risks caused by toxin-producing cyanobacteria, a guide of reference values for recreational waters has been established, based on cell density and microcystin concentration. Recommended concentrations representing low risk are 4-10 µg l^{-1} or < 20 000 cyanobacterial cells ml^{-1}, < 20 µg l^{-1}, while a concentration of 20 µg l^{-1} or between 20 000 and 100 000 cyanobacterial cells ml^{-1} is considered moderate risk, and a concentration above 20 µg l^{-1} or > 100 000 cyanobacterial cells ml^{-1}

carries a high risk of adverse health effects (Table 2) (Chorus & Bartram, 1999; Churro, Dias, & Valério, 2012; Paerl & Otten, 2013).

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Table 2. Guidelines for safe practice in recreational water management (modified from WHO, 2003; Chorus & Bartram, 1999; Churro *et al*., 2012).

Guideline or risk level	Orientation status	Human health hazards	Recommended actions
Low	<20 000 cyanobacterial cells per ml^{-1} < 10 µg l^{-1} chlorophyll-a with cyanobacterial dominance <2.5 mm^3 l^{-1} cyanobacterial biomass 4-10 µg l^{-1} of microcystins-LR	Low probability of adverse health effects	Continue monitoring
Moderate	20 000-100 000 cyanobacterial cells per ml^{-1} 10-50 µg l^{-1} chlorophyll-a with cyanobacterial dominance 2.5-12.5 mm^3 l^{-1} cyanobacterial biomass 10-20 µg l^{-1} of microcystin-LR	Short-term adverse health effects, such as skin irritations and gastrointestinal diseases	Add signs to indicate MODERATE warning level, indicating increased health risk when swimming or performing activities involving contact with water
High	>100 000 cyanobacterial cells per ml^{-1} >50 µg l^{-1} chlorophyll-a with cyanobacterial dominance >12.5 mm^3 l^{-1} cyanobacterial biomass >20 µg l^{-1} of microcystin-LR	Short-term adverse effects on human health, such as skin irritations or gastrointestinal illness following accidental contact or ingestion Severe acute poisoning is possible in the worst cases of ingestion	Immediate action to prevent contact with the bloom Add signs to indicate HIGH alert level, warning of danger when swimming or other activities involving contact with water Inform relevant authorities. Follow-up public health investigation

Most reports of human poisoning by MCs assess direct exposure through drinking water supply (Liu *et al*., 2011; Tian *et al*., 2013); clinical failures in patients undergoing renal hemodialysis with diluted cyanotoxins (Jochimsen *et al*., 1998; Azevedo *et al*., 2002); cyanobacterial cell contact and ingestion during recreational activities (Pilotto *et al*., 1997; Stewart, Schluter, & Shaw, 2006), and consumption of oral dietary supplements from cultures contaminated with toxin-producing strains of cyanobacteria (Saker, Welker, & Vasconcelos, 2007; Costa *et al*., 2018). However, vectors accumulating these secondary metabolites provide indirect routes of cyanotoxin uptake.

The main routes through ingestion of contaminated products include consumption of agricultural products irrigated with treated water containing cyanotoxin (Drobac *et al*., 2013) and eating seafood from sites where toxin-producing cyanobacteria are prevalent (Ibelings & Chorus, 2007; Ferrão-Filho & Kozlowsky-Suzuki, 2011), which represents a recurrent problem in aquaculture ponds worldwide (Mohamed, Carmichael, & Hussein, 2003; Drobac *et al*., 2016). Fish ingest and accumulate cyanotoxins directly through water intake or consumption cyanoprokaryote cells as part of their normal diet (omnivores and phytoplanktivores) (Ibelings *et al*., 2005). The indirect route develops when epithelial cells are exposed with the diluted fraction (skin and gills) or by accumulation and transfer through foodweb (Zamora-Barrios, Nandini, & Sarma, 2019).

Under laboratory conditions, MCs are molecules resistant to denaturation by boiling and preserving their stability at temperatures above 300 °C (Wannemacher, 1989). Cooking food contaminated with

MCs does not favor their degradation; on the contrary, it increases their bioavailability by breaking the covalent bonds with the catalytic subunits of phosphatases, increasing the risk during the eating of broths or seafood soups (Morais, Augusto, Carvalho, Vale, & Vasconcelos, 2008; Zhang, Xie, & Chen, 2010). Additionally, to toxic components, fish fed with cyanobacteria present a deficit of protein and lipid nutrients as well as a bad taste due to the accumulation of organoleptic compounds (Liang, Zhou, Zhang, Qiao, & Zhang, 2015).

WHO has also established a provisional guideline level for the tolerable daily intake of contaminated foods with microcystin, which was set at 0.04 μg^{-1} kg^{-1} d^{-1}, and is derived from the no-observed adverse effect level (NOAEL) of 40 μg kg^{-1} of microcystin-LR, based on a histopathological study in mouse, and supported by the lowest observed adverse effect level (LOAEL) obtained from a chronic study of the effect of crude extracts of Microcystis in the drinking water of pigs; however, due to interspecies variability an uncertainty value of 1 500 is applied (Fawell, James, & James, 1994; Chorus & Bartram, 1999).

Detection, identification, and evaluation methods

Due to the worldwide interest in solving public health problems and early detection of water safety difficulties, several methodologies have been

developed to determine, identify, and evaluate cyanotoxin concentrations, as well as to know the risk potential of cyanobacteria (Codd *et al*., 2001).

High performance liquid chromatography (HPLC) is the most extensively used chemical method along with UV-Visible, PDA (photodiode array detection) and FLD (fluorescence detection) detectors. These methods are based on the separation of each component of a mixture, according to different types of chemical interactions, such as polarity (extraction) and unequivocally identifying the analyte (Berry, 2013). Enzymatic approaches such as inhibiting serine/threonine phosphatases (microcystins and nodularin), cholinesterases (anatoxins), or binding to specific receptors were also developed (Vogiaz *et al*., 2019).

The immunological ELISA test is one of the most sensitive and is widely used to identify and quantify cyanotoxins in raw or drinking water, as well as in complex matrices including animal or plant tissues, sediments, urine, and human plasma (Foss & Aubel 2013; Moreira, Ramos, Azevedo, & Vasconcelos, 2014). Monoclonal kits are based on competition between the antigen diluted in the sample (specific cyanotoxin) and the peroxidase enzyme labeled (H_2O_2; conjugated enzyme) for the limited binding sites of a specific antibody (Ueno *et al*., 1996; Adamovský *et al*., 2007). The USEPA (United States Environmental Protection Agency) (USEPA, 2015) recommends the ELISA immunoassay kit as the preferred analytical screen for quantification of these secondary metabolites in aquatic systems because of the rapidity with which results can be acquired (~2h).

On the other hand, bioassays provide information on effects on biological entities such as populations, organisms, cell cultures, purified molecules, specific genetic effects, and physiological conditions (depending on the degree of sensitivity to be assessed) (Meriluoto, Metcalf, & Codd, 2017). Thus, studies have been conducted on crustaceans, protozoa, insects, rotifers, cnidaria, nematodes, oligochaetes, plants, etc. (Maršálek & Bláha, 2004).

Cyanobacteria toxicity has been evaluated using monoclonal strain cultures (Hughes, Gorham, & Zehnder, 1958; Watanabe & Oishi, 1985; Zamora-Barrios, Nandini, & Sarma, 2015); purified cyanotoxins (DeMott, Zhang, & Carmichael, 1991; Ghadouani, Pinel-Alloul, Plath, Codd, & Lampert, 2004; Huang, Xi, Xu, & Wen, 2012), and crude extracts of cyanobacterial consortia (Zamora-Barrios, Nandini, & Sarma, 2017; Pawlik-Skowrońska, Toporowska, & Mazur-Marzec, 2019; Janssen, 2019); it is suitable to evaluate their toxicological effect through bioassays, when there are consortia of strains producing several biotoxins or if blooms are dominated by poorly studied species that might contain unknown metabolites with variable toxicity (Bláha *et al*., 2017).

Molecular detection techniques are based on amplifying specific regions, using primers of genomic DNA and ribosomal RNA by polymerase chain reaction (PCR), which allows the comparison of copies of nucleotide sequences of coding genetic regions. One universally used marker for taxonomic identification in cyanobacteria is the small-subunit ribosomal called 16S rRNA (Nübel, Garcia-Pichel, & Muyzer, 1997; Albrecht, Pröschold, & Schumann, 2017). Nevertheless, due to the limited variability between genera, amplification of genes encoding enzymes

involved in metabolic activities or intergenic space usage, such as the phycocyanin operon (*PC-IGS*) or dinitrogenase reductase (*nifH* and *nifD*), is occasionally necessary (Teneva, Dzhambazov, Mladenov, & Schirmer, 2005; Hartmann & Barnum, 2010). Toxin-producing strains are detected by amplification of genes involved in their biosynthesis (e.g., the *mcy* group for microcystin and *cyr* for cylindrospermopsin). This absence provides a qualitative tool to discriminate potentially harmful strains from non-toxic strains ((Baker *et al*., 2013; Salmaso *et al*., 2016). Moreover, fluorescent markers (qPCR) have been developed to provide a quantitative real-time estimation of the number of cells containing encoding genes or transcript levels implicated in cyanotoxin biosynthesis (Humbert, 2017; Kurmayer, Sivonen, Wilmotte, & Salmaso, 2017).

Main evaluations in Mexico

CyanoHABs have been recorded in Mexico for more than three decades, and it is recognized that genera with toxicological potential, such as *Microcystis*, *Planktothrix*, and *Anabaenopsis*, have dominated the biomass of primary producers (Ortega, 1984; Alcocer, Kato, Robles, & Vilaclara, 1988); however, the first reports of cyanotoxin detection in Mexican water bodies were published 20 years later (Berry & Lind, 2010a; Vasconcelos *et al*., 2010). Cyanotoxin presence has focused on detecting microcystins, with concentrations ranging from 0.03 to more than 70 g l^{-1}. The

occurrence of cylindrospermopsin and saxitoxins accumulated in the tissues and organs of fish and the snail *Pomacea patula catemacensis* has also been confirmed, all of which are commercially important in Lake Catemaco, Veracruz (Berry & Lind, 2010b; Berry, Jaja-Chimedza, Dávalos-Lind, & Lind, 2012). A recent study (Zamora-Barrios *et al*., 2019) shows that fish ingested whole as *Chirostoma* sp. represent a higher health risk than tilapia, where only the muscules are consumed. In the latter, organs such as the liver and digestive tract, where most cyanotoxins bioaccumulate, are discarded. Each of the epicontinental systems evaluated provides ecosystem services to the surrounding human populations.

Most evaluations in Mexican laboratories focus on experiments with cyanobacterial strains from natural systems to assess their potential use in biomanipulation, considering the ability of the organisms to consume the cells (Nandini, Sarma, & Ramírez-García, 2000; Fernández, Nandini, Sarma, & Castellanos-Páez, 2014; Figueroa-Sánchez, Nandini, Castellanos-Páez, & Sarma, 2019). The synergistic impact of environmental stressors (predation and competition) experienced by filter-feeding species commonly found in water bodies with the presence of CyanoHABs; in addition to the evaluation of environmental factors (herbivory, nutrient concentration, temperature, and light intensity) that trigger gene expression and microcystin synthesis (Pineda-Mendoza, Zúñiga, & Martínez-Jerónimo, 2014; Pérez-Morales, Sarma, & Nandini, 2015; Pineda-Mendoza, Zúñiga, & Martínez-Jerónimo, 2016), also the antibacterial effect of bioactive compounds isolated from cyanobacteria (Gutiérrez, Flores, Solís, & Jimenez, 2008), the deleterious effects of exudates, crude extracts of monoclonal strains, and mixtures of

cyanobacteria from natural systems on zooplankton organisms (Arzate-Cárdenas, Olvera-Ramirez, & Martinez-Jeronimo, 2010; Olvera-Ramírez, Centeno-Ramos, & Martínez-Jerónimo, 2010; Pineda-Mendoza, Olvera-Ramírez, & Martínez-Jerónimo, 2012; Zamora-Barrios *et al*., 2015; Zamora-Barrios *et al*., 2017; Nandini, Sánchez-Zamora, & Sarma, 2019; Nandini, Zamora-Barrios, & Sarma, 2020) or by mixed diets, composed of different proportions of *Microcystis aeruginosa* and green algae (Alva-Martínez, Sarma, & Nandini, 2007a; Alva-Martínez, Sarma, & Nandini, 2007b; Alva-Martínez, Fernández, Sarma, & Nandini, 2009); and the development of techniques to remove *Microcystis* and microcystins by coagulation and flocculation of organic matter (Sandoval-Reyes & Ramírez-Zamora, 2019).

Restoration methods

The importance of determining the underlying causes of poor water quality and resolving them through a combination of methodologies to control external and internal nutrient loading is evident in the successful instances of lake restoration impaired by CyanoHABs. (Lürling & Van Oosterhout, 2013; Ibelings, Bormans, Fastner, & Visser, 2016; Lürling, Waajen, Engels, & Van Oosterhout, 2017).

Preventing or controllingeutrophication is the most sustainable approach to reduce cyanobacteria, and at least three strategies have been considered to decrease eutrophication conditions in a system. The chemical methodology includes artificial aeration and flocculation or precipitation of nutrients by adding aluminum and calcium salts or commercial products such as Phoslock (bentonite clay) (Visser *et al*., 2016b). The physical technique decreases water residence time and removes nutrient-rich sediments (dredging) (Wang *et al*., 2018; Waajen, Lürling, & Van de Sande, 2019). Manipulation of the trophic cascade by top-down management is one of the most acknowledged paradigms in aquatic ecology (Carpenter *et al*., 1987; Lampert & Sommer, 2007), this being widely used regulation processes in temperate systems where the effect of removing planktivorous fish, decreasing predation and allowing the recovery of filter-feeding herbivore populations with the ability to consume cyanobacteria has been evaluated (Triest, Stiers, & Van Onsem, 2016).

However, several assessments demonstrated the low effectiveness of top-down control in aquatic ecosystems with dense CyanoHAB (Gliwicz, 1990; Dickman, Newell, González, & Vanni, 2008; Rondel *et al*., 2008; Lacerot, Kruk, Lürling, & Scheffer, 2013). Even, suggesting that zooplankton facilitate cyanobacterial dominance by eliminating eukaryotic competitors (Lynch & Shapiro, 1981; Mitra & Flynn, 2006; Ger, Naus-Wiezer, De-Meester, & Lürling, 2019). On the other hand, it has been classified as a success in systems with a strong relationship between primary producers and zooplankton (Havens *et al*., 1996; Jeppesen *et al*., 2012; Urrutia-Cordero, Ekvall, & Hansson, 2016). Because of their generalist feeding habits, cladocerans like *Daphnia magna* are considered

effective models in controlling cyanobacteria; however, this species is restricted to temperate climate zones. Other crustaceans such as *Simocephalus mixtus* and *Hyalella azteca* show a great capacity to consume cyanobacterial cells at feeding rates higher than those obtained with a eukaryotic primary producer and in combination with the zooplanktivorous fish remotion would be a model for cyanoprokaryote control (Figueroa-Sánchez *et al*., 2019).

Conclusions

The dominance of CyanoHABs in Mexican reservoirs has been well documented during the last decades through limnological studies or research on phytoplankton diversity analysis (Gaytan-Herrera, Martinez-Almeida, Oliva-Martinez, Duran-Diaz, & Ramirez-Garcia, 2011; Oliva-Martínez, Godínez-Ortega, & Zuñiga-Ramos, 2014). Experimental ecology since the 1990s showed that certain rotifer and cladoceran species can feed and grow on mixed or pure cyanobacterial diets (Alva-Martínez *et al*., 2007a; Alva-Martínez *et al*., 2009). Likewise, some novel species such as amphipods and ostracods were studied, quantifying their filtration rates, and assessing their ability to decrease cyanobacterial cells from the medium in laboratory experiments (Fernández, Nandini, Sarma, & Castellanos-Páez, 2016; Figueroa-Sánchez *et al*., 2019). Several studies

indicate that continuous predation pressure from zooplanktivorous fish in the tropics significantly reduces herbivory of large cladocerans. Current studies also show the accumulation of cyanotoxins in various trophic levels, including food supplies such as snails and fish, which represents a significant risk to human health, especially when are eaten whole without removing the digestive tract where most cyanotoxins accumulate (Berry & Lind, 2010a; Zamora-Barrios *et al*., 2019). It is well established that many waterbodies in Mexico are supplied with or receive partially treated wastewater. However, limited research has been done on nutrient control in the watershed. CyanoHAB control actions on a large scale have also been rarely examined (Waajen *et al*., 2019). Likewise, cyanobacteria in saline and sodic lakes have been evaluated in select waterbodies, but further research is needed across the country. We hope that the scientific information contained in this review will be helpful to promote a management model that follows the water safety guidelines proposed by the World Health Organization.

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References

Adamovský, O., Kopp, R., Hilscherová, K., Babica, P., Palíková, M., Pašková, V., & Bláha, L. (2007). Microcystin kinetics (bioaccumulation and elimination) and biochemical responses in common carp (*Cyprinus carpio*) and silver carp (*Hypophthalmichthys molitrix*) exposed to toxic cyanobacterial blooms. *Environmental Toxicology and Chemistry: An International Journal*, 26(12), 2687-2693. DOI: https://doi.org/10.1897/07-213.1

Albrecht, M., Pröschold, T., & Schumann, R. (2017). Identification of Cyanobacteria in a eutrophic coastal lagoon on the Southern Baltic Coast. *Frontiers in Microbiology*, 8, 923. DOI: https://doi.org/10.3389/fmicb.2017.00923

Alcocer, J., Kato, E., Robles, E., & Vilaclara, G. (1988). Estudio preliminar del efecto del dragado sobre el estado trófico del Lago Viejo de Chapultepec. *Revista Internacional de Contaminación Ambiental*, 4(1), 43-56.

Alva-Martínez, A. A., Sarma, S. S. S., & Nandini, S. (2007a). Population dynamics of *Brachionus calyciflorus* and *Brachionus havanaensis* (Rotifera) on mixed diets with *Microcystis aeruginosa* and green algae. *Hidrobiológica*, 17(Su1), 59-67.

Alva-Martínez, A. F., Sarma, S. S. S., & Nandini, S. (2007b). Effect of mixed diets (cyanobacteria and green algae) on the population growth of the cladocerans *Ceriodaphnia dubia* and *Moina macrocopa*. *Aquatic Ecology*, 41(4), 579-585. DOI: https://doi.org/10.1007/s10452-007-9115-1

Alva-Martínez, A. F., Fernández, R., Sarma, S. S. S., & Nandini, S. (2009). Effect of mixed toxic diets (*Microcystis* and *Chlorella*) on the rotifers *Brachionus calyciflorus* and *Brachionus havanaensis* cultured alone and together. *Limnologica*, 39(4), 302-305. DOI: https://doi.org/10.1016/j.limno.2009.06.002

Arzate-Cárdenas, M. A., Olvera-Ramirez, R., & Martinez-Jeronimo, F. (2010). *Microcystis* toxigenic strains in urban lakes: A case of study in Mexico City. *Ecotoxicology*, 19(6), 1157-1165. DOI: https://doi.org/10.1007/s10646-010-0499-7

Azevedo, S. M., Carmichael, W. W., Jochimsen, E. M., Rinehart, K. L., Lau, S., Shaw, G. R., & Eaglesham, G. K. (2002). Human intoxication by microcystins during renal dialysis treatment in Caruaru-Brazil. *Toxicology*, 181, 441-446. DOI: https://doi.org/10.1016/S0300-483X(02)00491-2

Baker, L., Sendall, B. C., Gasser, R. B., Menjivar, T., Neilan, B. A., & Jex, A. R. (2013). Rapid, multiplex-tandem PCR assay for automated detection and differentiation of toxigenic cyanobacterial blooms. *Molecular and Cellular Probes*, 27(5-6), 208-214. DOI: https://doi.org/10.1016/j.mcp.2013.07.001.

Bellinger, E. G., & Sigee, D. C. (2015). *Freshwater algae: Identification, enumeration and use as bioindicators*. Hoboken, USA: John Wiley & Sons.

Bergman, B., Sandh, G., Lin, S., Larsson, J., & Carpenter, E. J. (2013). *Trichodesmium*–A widespread marine cyanobacterium with unusual nitrogen fixation properties. *FEMS Microbiology Reviews*, 37(3), 286-302. DOI: https://doi.org/10.1111/j.1574-6976.2012.00352.x

Berman-Frank, I., Quigg, A., Finkel, Z. V., Irwin, A. J., & Haramaty, L. (2007). Nitrogen-fixation strategies and Fe requirements in cyanobacteria. *Limnology and Oceanography*, 52(5), 2260-2269. DOI: https://doi.org/10.4319/lo.2007.52.5.2260

Berry, J. (2013). Cyanobacterial toxins in food-webs: implications for human and environmental health. In: *Current Topics in Public Health*. London, UK: IntechOpen. DOI: 10.5772/55111

Berry, J. P., & Lind, O. (2010a). First evidence of "paralytic shellfish toxins" and cylindrospermopsin in a Mexican freshwater system, lago Catemaco, and apparent bioaccumulation of the toxins in "tegogolo" snails (*Pomacea patula catemacensis*). *Toxicon*, 55(5), 930-938. DOI: https://doi.org/10.1016/j.toxicon.2009.07.035

Berry, J. P., & Lind, O. (2010b). First evidence of "paralytic shellfish toxins" and cylindrospermopsin in a Mexican freshwater system, Lago Catemaco, and apparent bioaccumulation of the toxins in "tegogolo" snails (*Pomacea patula catemacensis*). *Toxicon*, 55(5), 930-938. DOI: https://doi.org/10.1016/j.toxicon.2009.07.035

Berry, J. P., Jaja-Chimedza, A., Dávalos-Lind, L., & Lind, O. (2012). Apparent bioaccumulation of cylindrospermopsin and paralytic shellfish toxins by finfish in Lake Catemaco (Veracruz, Mexico). *Food Additives & Contaminants: Part A*, 29(2), 314-321. DOI: https://doi.org/10.1080/19440049.2011.597785

Bláha, L., Cameán, A. M., Fessard, V., Gutiérrez-Praena, D., Jos, Á., Marie, B., & Žegura, B. (2017). Bioassay use in the field of toxic cyanobacteria. In: *Handbook of Cyanobacterial Monitoring and Cyanotoxin Analysis* (pp. 272-279). Chichester, UK: John Wiley & Sons, Ltd.

Bouaïcha, N., Miles, C. O., Beach, D. G., Labidi, Z., Djabri, A., Benayache, N. Y., & Nguyen-Quang, T. (2019). Structural diversity, characterization and toxicology of microcystins. *Toxins*, 11(12), 714.

Brinkman, D. L., & Bourne, D. G. (2013). Microcystinase. In: *Handbook of Proteolytic Enzymes* (pp. 1726-1731). Cambridge, USA: Academic Press. DOI: https://doi.org/10.3390/toxins11120714

Bulgakov, N. G., & Levich, A. P. (1999). The nitrogen: Phosphorus ratio as a factor regulating phytoplankton community structure. *Archiv für hydrobiologie*, 3-22. DOI: 10.1127/archiv-hydrobiol/146/1999/3

Bumke-Vogt, C., Mailahn, W., & Chorus, I. (1999). Anatoxin-a and neurotoxic cyanobacteria in German lakes and reservoirs. *Environmental Toxicology: An International Journal*, 14(1), 117-125. DOI: https://doi.org/10.1002/(SICI)1522-7278(199902)14:1<117::AID-TOX15>3.0.CO;2-V

Campos, A., & Vasconcelos, V. (2010). Molecular mechanisms of microcystin toxicity in animal cells. *International Journal of Molecular Sciences*, 11(1), 268-287. DOI: https://doi.org/10.3390/ijms11010268

Carey, C. C., Ibelings, B. W., Hoffmann, E. P., Hamilton, D. P., & Brookes, J. D. (2012). Eco-physiological adaptations that favour freshwater cyanobacteria in a changing climate. *Water Research*, 46(5), 1394-1407. DOI: https://doi.org/10.1016/j.watres.2011.12.016

Carmichael, W. W. (2001). Health effects of toxin-producing cyanobacteria: "The CyanoHABs". *Human and Ecological Risk Assessment: An International Journal*, 7(5), 1393-1407. DOI: https://doi.org/10.1080/20018091095087

Carmichael, W. W., Azevedo, S. M., An, J. S., Molica, R. J., Jochimsen, E. M., Lau, S., & Eaglesham, G. K. (2001). Human fatalities from cyanobacteria: chemical and biological evidence for cyanotoxins. *Environmental Health Perspectives*, 109(7), 663-668. DOI: https://doi.org/10.1289/ehp.01109663

Carpenter, S. R., Kitchell, J. F., Hodgson, J. R., Cochran, P. A., Elser, J. J., Elser, M. M., & von Ende, C. (1987). Regulation of lake primary productivity by food web structure. *Ecology*, 68(6), 1863-1876. DOI: https://doi.org/10.2307/1939878

Castle, J. W., & Rodgers, J. H. (2009). Hypothesis for the role of toxin-producing algae in Phanerozoic mass extinctions based on evidence from the geologic record and modern environments. *Environmental Geosciences*, 16(1), 1-23. DOI: https://doi.org/10.1306/eg.08110808003

Catherine, A., Bernard, C., Spoof, L., & Bruno, M. (2017). Microcystins and nodularins. In: Meriluoto, J., Spoof, L., & Codd, J. (eds.). *Handbook of cyanobacterial monitoring and cyanotoxin analysis* (pp. 109-126). DOI:10.1002/9781119068761

Chapra, S. C., Boehlert, B., Fant, C., Bierman Jr., V. J., Henderson, J., Mills, D., & Strzepek, K. M. (2017). Climate change impacts on harmful algal blooms in US freshwaters: a screening-level assessment. *Environmental Science & Technology*, 51(16), 8933-8943. DOI: https://doi.org/10.1021/acs.est.7b01498

Chien, Y. C., Wu, S. C., Chen, W. C., & Chou, C. C. (2013). Model simulation of diurnal vertical migration patterns of different-sized colonies of Microcystis employing a particle trajectory approach. *Environmental Engineering Science*, 30(4), 179-186. DOI: https://doi.org/10.1089/ees.2012.0318

Chorus, I., & Bartram, J. (eds.). (1999). *Toxic cyanobacteria in water: A guide to their public health consequences, monitoring and management*. Boca Raton, USA: CRC Press.

Churro, C., Dias, E., & Valério, E. (2012). Risk assessment of cyanobacteria and cyanotoxins, the particularities and challenges of *Planktothrix* spp. monitoring. In: *Novel approaches and their applications in risk assessment*. London, UK: IntechOpen

Churro, C., Semedo-Aguiar, A. P., Silva, A. D., Pereira-Leal, J. B., & Leite, R. B. (2020). A novel cyanobacterial geosmin producer, revising Geo A distribution and dispersion patterns in Bacteria. *Scientific Reports*, 10(1), 1-18. DOI: https://doi.org/10.1038/s41598-020-64774-y

Cirés, G. S. (2012) *Ecofisiología, ciclos de vida anual y cianotoxinas de las cianobacterias planctónicas* Anabaena, Aphanizomenon *y* Microcystis *en embalses españoles* (tesis de doctorado). Universidad Autónoma de Madrid, España.

Cirés, S., Wörmer, L., Agha, R., & Quesada, A. (2013). Overwintering populations of *Anabaena*, *Aphanizomenon* and *Microcystis* as potential inocula for summer blooms. *Journal of Plankton Research*, 35(6), 1254-1266. DOI: https://doi.org/10.1093/plankt/fbt081

Codd, G. A., Metcalf, J. S., Ward, C. J., Beattie, K. A., Bell, S. G., Kaya, K., & Poon, G. K. (2001). Analysis of cyanobacterial toxins by physicochemical and biochemical methods. *Journal of AOAC International*, 84(5), 1626-1635. DOI: https://doi.org/10.1093/jaoac/84.5.1626

Codd, G. A., Morrison, L. F., & Metcalf, J. S. (2005a). Cyanobacterial toxins: Risk management for health protection. *Toxicology and Applied Pharmacology*, 203(3), 264-272. DOI: https://doi.org/10.1016/j.taap.2004.02.016

Codd, G. A., Lindsay, J., Young, F. M., Morrison, L. F., & Metcalf, J. S. (2005b). Harmful Cyanobacteria. In: Huisman, J., Matthijs, H. C., Visser, P. M. (eds.). *Harmful Cyanobacteria*. Aquatic Ecology Series, vol 3. Dordrecht, The Netherlands: Springer. Recovered from https://doi.org/10.1007/1-4020-3022-3_1

Costa, M. L., Rodrigues, J. A., Azevedo, J., Vasconcelos, V., Eiras, E., & Campos, M. G. (2018). Hepatotoxicity induced by paclitaxel interaction with turmeric in association with a microcystin from a contaminated dietary supplement. *Toxicon*, 150, 207-211. DOI: https://doi.org/10.1016/j.toxicon.2018.05.022

Dai, R., Wang, P., Jia, P., Zhang, Y., Chu, X., & Wang, Y. (2016). A review on factors affecting microcystins production by algae in aquatic environments. *World Journal of Microbiology and Biotechnology*, 32(3), 51. DOI: https://doi.org/10.1007/s11274-015-2003-2

DeMott, W. R., Gulati, R. D., & Van Donk, E. (2001). *Daphnia* food limitation in three hypereutrophic Dutch lakes: Evidence for exclusion of large-bodied species by interfering filaments of cyanobacteria. *Limnology and Oceanography*, 46(8), 2054-2060. DOI: https://doi.org/10.4319/lo.2001.46.8.2054

DeMott, W. R., Zhang, Q. X., & Carmichael, W. W. (1991). Effects of toxic cyanobacteria and purified toxins on the survival and feeding of a copepod and three species of Daphnia. *Limnology and Oceanography*, 36(7), 1346-1357. DOI: https://doi.org/10.4319/lo.1991.36.7.1346

Deshpande, B. N., Tremblay, R., Pienitz, R., & Vincent, W. F. (2014). Sedimentary pigments as indicators of cyanobacterial dynamics in a hypereutrophic lake. *Journal of Paleolimnology*, 52(3), 171-184. DOI: https://doi.org/10.1007/s10933-014-9785-3

Dickman, E. M., Newell, J. M., González, M. J., & Vanni, M. J. (2008). Light, nutrients, and food-chain length constrain planktonic energy transfer efficiency across multiple trophic levels. *Proceedings of the National Academy of Sciences*, 105(47), 18408-18412. DOI: ttps://doi.org/10.1073/pnas.0805566105

Drobac, D., Tokodi, N., Lujić, J., Marinović, Z., Subakov-Simić, G., Dulić, T., & Svirčev, Z. (2016). Cyanobacteria and cyanotoxins in fishponds and their effects on fish tissue. *Harmful Algae*, 55, 66-76. DOI: https://doi.org/10.1016/j.hal.2016.02.007

Drobac, D., Tokodi, N., Simeunović, J., Baltić, V., Stanić, D., & Svirčev, Z. (2013). Human exposure to cyanotoxins and their effects on health. *Arhiv za Higijenu Rada i Toksikologiju*, 64(2), 305-315. DOI: https://doi.org/10.2478/10004-1254-64-2013-2320

Edwards, C., & Lawton, L. A. (2009). Bioremediation of cyanotoxins. Advances in Applied Microbiology, 67, 109-129. DOI: https://doi.org/10.1016/S0065-2164(08)01004-6.

Fawell, J. K., James, C. P., & James, H. A. (1994). Toxins from blue-green algae: Toxicological assessment of microcystin-LR and a method for its determination in water. *Foundation for Water Research*. DOI: https://doi.org/10.1177/096032719901800305

Fernández, R., Nandini, S., Sarma, S. S. S., & Castellanos-Páez, M. E. (2016). Demographic responses of *Heterocypris incongruens* (Ostracoda) related to stress factors of competition, predation and food. *Journal of Limnology*, 75(s1), 31-38. DOI: 10.4081/jlimnol.2016.1367

Fernández, R., Nandini, S., Sarma, S. S. S., & Castellanos-Páez, M. E. (2014). Effects of cyanobacteria, fish kairomones, and the presence of ostracods on the demography of *Simocephalus vetulus* (Cladocera). *Invertebrate Biology*, 133(4), 371-380. DOI: https://doi.org/10.1111/ivb.12069

Ferrão-Filho, A. D. S., & Kozlowsky-Suzuki, B. (2011). Cyanotoxins: Bioaccumulation and effects on aquatic animals. *Marine Drugs*, 9(12), 2729-2772. DOI: https://doi.org/10.3390/md9122729

Figueroa-Sánchez, M. A., Nandini, S., Castellanos-Páez, M. E., & Sarma, S. S. S. (2019). Effect of temperature, food quality and quantity on the feeding behavior of *Simocephalus mixtus* and *Hyalella azteca*: Implications for biomanipulation. *Wetlands Ecology and Management*, 27(2-3), 353-361. DOI: https://doi.org/10.1007/s11273-019-09664-5

Flores, E., & Herrero, A. (2005). Nitrogen assimilation and nitrogen control in cyanobacteria. *Biochemical Society Transactions*, 33(1), 164-167. DOI: https://doi.org/10.1042/BST0330164

Flores, E., & Herrero, A. (2014). *The cell biology of cyanobacteria*. Wymondham, UK: Caister Academic Press.

Fontanillo, M., & Köhn, M. (2018). Microcystins: Synthesis and structure–activity relationship studies toward PP1 and PP2A. *Bioorganic & Medicinal Chemistry*, 26(6), 1118-1126. DOI: https://doi.org/10.1016/j.bmc.2017.08.040

Foss, A. J., & Aubel, M. T. (2013). The extraction and analysis of cylindrospermopsin from human serum and urine. *Toxicon*, 70, 54-61. DOI: https://doi.org/10.1016/j.toxicon.2013.04.007

Gaytan-Herrera, M. L., Martinez-Almeida, V., Oliva-Martinez, M. G., Duran-Diaz, A., & Ramirez-Garcia, P. (2011). Temporal variation of phytoplankton from the tropical reservoir Valle de Bravo, Mexico. *Journal of Environmental Biology*, 32(1), 117-126.

Ger, K. A., Hansson, L. A., & Lürling, M. (2014). Understanding cyanobacteria-zooplankton interactions in a more eutrophic world. *Freshwater Biology*, 59(9), 1783-1798. DOI: https://doi.org/10.1111/fwb.12393

Ger, K. A., Naus-Wiezer, S., De-Meester, L., & Lürling, M. (2019). Zooplankton grazing selectivity regulates herbivory and dominance of toxic phytoplankton over multiple prey generations. Limnology and *Oceanography*, 64(3), 1214-1227. DOI: https://doi.org/10.1002/lno.11108

Ghadouani, A., Pinel-Alloul, B., Plath, K., Codd, G. A., & Lampert, W. (2004). Effects of *Microcystis aeruginosa* and purified microcystin-LR on the feeding behavior of *Daphnia pulicaria*. *Limnology and Oceanography*, 49(3), 666-679. DOI: https://doi.org/10.4319/lo.2004.49.3.0666

Gliwicz, Z. M. (1990). Why do cladocerans fail to control algal blooms? In: *Biomanipulation Tool for Water Management* (pp. 83-97). Dordrecht, The Netherlands: Springer. DOI: https://doi.org/10.1007/978-94-017-0924-8_8

Guiry, M. D. (2012). How many species of algae are there? *Journal of Phycology*, 48(5), 1057-1063. DOI: https://doi.org/10.1111/j.1529-8817.2012.01222.x

Gutiérrez, R. M. P., Flores, A. M., Solís, R. V., & Jimenez, J. C. (2008). Two new antibacterial norabietane diterpenoids from cyanobacteria, *Microcoleous lacustris*. *Journal of Natural Medicines*, 62(3), 328-331. DOI: https://doi.org/10.1007/s11418-008-0238-z

Harada, K. I., & Tsuji, K. (1998). Persistence and decomposition of hepatotoxic microcystins produced by cyanobacteria in natural environment. *Journal of Toxicology: Toxin Reviews*, 17(3), 385-403. DOI: https://doi.org/10.3109/15569549809040400

Hartmann, L. S., & Barnum, S. R. (2010). Inferring the evolutionary history of Mo-dependent nitrogen fixation from phylogenetic studies of *nifK* and *nifDK*. *Journal of Molecular Evolution*, 71(1), 70-85.

Havens, K., East, T., & Beaver, J. (1996). Experimental studies of zooplankton–phytoplankton–nutrient interactions in a large subtropical lake (Lake Okeechobee, Florida, USA). *Freshwater Biology*, 36(3), 579-597. DOI: https://doi.org/10.1046/j.1365-2427.1996.00122.x

Hoeger, S. J., Dietrich, D. R., & Hitzfeld, B. C. (2002). Effect of ozonation on the removal of cyanobacterial toxins during drinking water treatment. *Environmental Health Perspectives*, 110(11), 1127-1132. DOI: https://doi.org/10.1289/ehp.021101127

Hoiczyk, E., & Hansel, A. (2000). Cyanobacterial cell walls: news from an unusual prokaryotic envelope. *Journal of Bacteriology*, 182(5), 1191-1199. DOI: DOI: 10.1128/JB.182.5.1191-1199.2000

Huang, L., Xi, Y., Xu, X., & Wen, X. (2012). Responses in population growth and reproduction of the freshwater rotifer *Brachionus calyciflorus* to microcystin-LR at different temperatures. In: *Annales de Limnologie-International Journal of Limnology*, 48(4), 383-390. EDP Sciences. DOI: https://doi.org/10.1051/limn/2012029

Hughes, E. O., Gorham, P. R., & Zehnder, A. (1958). Toxicity of a unialgal culture of *Microcystis aeruginosa*. *Canadian Journal of Microbiology*, 4(3), 225-236. Recovered from: https://doi.org/10.1139/m58-024

Huisman, J., Codd, G. A., Paerl, H. W., Ibelings, B. W., Verspagen, J. M., & Visser, P. M. (2018). Cyanobacterial blooms. *Nature Reviews Microbiology*, 16(8), 471-483. DOI: https://doi.org/10.1038/s41579-018-0040-1

Humbert, J. F. (2017). Molecular tools for the detection of toxigenic Cyanobacteria in natural ecosystems. In: Meriluoto, J., Spoof, L., Codd, G. A. (eds.). *Handbook of cyanobacterial monitoring and cyanotoxin analysis* (pp. 280-283). Recovered from DOI:10.1002/9781119068761.ch28

Humbert, J. F., & Fastner, J. (2017). Ecology of cyanobacteria. In: *Handbook on cyanobacterial monitoring and cyanotoxin analysis* (pp. 11-18). Hoboken, USA: John Wiley & Sons, Ltd. DOI: 10.1002/9781119068761

Hyenstrand, P., Blomqvist, P., & Pettersson, A. (1998). Factors determining cyanobacterial success in aquatic systems: A literature review. *Archiv für Hydrobiologie Spec. Iss. Advances in Limnology*, 51, 41-62. DOI: http://oceanrep.geomar.de/id/eprint/40367

Ibelings, B. W., & Chorus, I. (2007). Accumulation of cyanobacterial toxins in freshwater "seafood" and its consequences for public health: A review. *Environmental Pollution*, 150(1), 177-192. DOI: https://doi.org/10.1016/j.envpol.2007.04.012

Ibelings, B. W., Bormans, M., Fastner, J., & Visser, P. M. (2016). CYANOCOST special issue on cyanobacterial blooms: Synopsis—A critical review of the management options for their prevention, control and mitigation. *Aquatic Ecology*, 50(3), 595-605. DOI: https://doi.org/10.1007/s10452-016-9596-x

Ibelings, B. W., Bruning, K., De-Jonge, J., Wolfstein, K., Pires, L. D., Postma, J., & Burger, T. (2005). Distribution of microcystins in a lake foodweb: No evidence for biomagnification. *Microbial Ecology*, 49(4), 487-500. DOI: https://doi.org/10.1007/s00248-004-0014-x

Ibrahem, M. D., Khairy, H. M., & Ibrahim, M. A. (2012). Laboratory exposure of *Oreochromis niloticus* to crude microcystins (containing microcystin-LR) extracted from Egyptian locally isolated strain (*Microcystis aeruginosa* Kützing): Biological and biochemical studies. *Fish Physiology and Biochemistry*, 38(3), 899-908. DOI: https://doi.org/10.1007/s10695-011-9577-x

Janssen, E. M. L. (2019). Cyanobacterial peptides beyond microcystins–A review on co-occurrence, toxicity, and challenges for risk assessment. *Water Research*, 151, 488-499. DOI: https://doi.org/10.1016/j.watres.2018.12.048

Jeppesen, E., Søndergaard, M., Lauridsen, T. L., Davidson, T. A., Liu, Z., Mazzeo, N., & Starling, F. (2012). Biomanipulation as a restoration tool to combat eutrophication: Recent advances and future challenges. In: *Advances in Ecological Research*, 47, 411-488. Academic Press. DOI: https://doi.org/10.1016/B978-0-12-398315-2.00006-5

Ji, X., Verspagen, J. M., Stomp, M., & Huisman, J. (2017). Competition between cyanobacteria and green algae at low versus elevated CO2: who will win, and why? *Journal of Experimental Botany*, 68(14), 3815-3828. DOI: https://doi.org/10.1093/jxb/erx027

Jochimsen, E. M., Carmichael, W. W., An, J., Cardo, D. M., Cookson, S. T., Holmes, C. E., & Azevedo, S. M. (1998). Liver failure and death after exposure to microcystins at a hemodialysis center in Brazil. *New England Journal of Medicine*, 338(13), 873-878. DOI: 10.1056/NEJM199803263381304

Joehnk, K. D., Huisman, J. E. F., Sharples, J., Sommeijer, B. E. N., Visser, P. M., & Stroom, J. M. (2008). Summer heatwaves promote blooms of harmful cyanobacteria. *Global Change Biology*, 14(3), 495-512. DOI: https://doi.org/10.1111/j.1365-2486.2007.01510.x

Jones, M. R., Pinto, E., Torres, M. A., Dörr, F., Mazur-Marzec, H., Szubert, K., & Janssen, E. M. L. (2021). CyanoMetDB, a comprehensive public database of secondary metabolites from cyanobacteria. *Water Research*, 196, 117017. DOI: https://doi.org/10.1016/j.watres.2021.117017

Kehr, J. C., & Dittmann, E. (2015). Biosynthesis and function of extracellular glycans in cyanobacteria. *Life*, 5(1), 164-180. DOI: https://doi.org/10.3390/life5010164

Kinnear, S. H., Duivenvoorden, L. J., & Fabbro, L. D. (2007). Growth and Bioconcentration in *Spirodela oligorrhiza* Following Exposure to *Cylindrospermopsis raciborskii* Whole Cell Extracts. *Australasian Journal of Ecotoxicology*, 13(1), 19.

Kobos, J., Błaszczyk, A., Hohlfeld, N., Toruńska-Sitarz, A., Krakowiak, A., Hebel, A., & Messyasz, B. (2013). Cyanobacteria and cyanotoxins in Polish freshwater bodies. *Oceanological and Hydrobiological Studies*, 42(4), 358-378. DOI: https://doi.org/10.2478/s13545-013-0093-8

Kokociński, M., Akçaalan, R., Salmaso, N., Stoyneva-Gärtner, M. P., & Sukenik, A. (2017). Expansion of alien and invasive cyanobacteria. In: *Handbook on Cyanobacterial Monitoring and Cyanotoxin Analysis* (pp. 28-39). DOI: 10.1002/9781119068761

Komárek, J. (1995). Current trends and species delimitation in the cyanoprokaryote taxonomy. *Algological Studies/Archiv für Hydrobiologie*, Supplement Volumes, 11-29. DOI: 10.1127/algol_stud/75/1995/11

Komárek, J. (2006). Cyanobacterial taxonomy: Current problems and prospects for the integration of traditional and molecular approaches. *Algae*, 21(4), 349-375. DOI: https://doi.org/10.4490/algae.2006.21.4.349

Komárek, J. (2010). Recent changes (2008) in cyanobacteria taxonomy based on a combination of molecular background with phenotype and ecological consequences (genus and species concept). *Hydrobiologia*, 639(1), 245-259. DOI: https://doi.org/10.1007/s10750-009-0031-3

Komárek, J. (2014). Modern classification of cyanobacteria. In: Sharma, N. K., Rai, A. K., & Stal, L. J. (eds.). *Cyanobacteria: An economic perspective* (pp. 21-39). Chichester, UK: John Wiley & Sons, Ltd. DOI: 10.1002/9781118402238

Kurmayer, R., Sivonen, K., Wilmotte, A., & Salmaso, N. (eds.). (2017). *Molecular tools for the detection and quantification of toxigenic cyanobacteria*. Chichester, UK: John Wiley & Sons, Ltd.

Lacerot, G., Kruk, C., Lürling, M., & Scheffer, M. (2013). The role of subtropical zooplankton as grazers of phytoplankton under different predation levels. *Freshwater Biology*, 58(3), 494-503. DOI: https://doi.org/10.1111/fwb.12075

Lampert, W., & Sommer, U. (2007). *Limnoecology: The ecology of lakes and streams*. Oxford, UK: Oxford University Press. DOI: https://doi.org/10.1093/plankt/fbn013

Liang, H., Zhou, W., Zhang, Y., Qiao, Q., & Zhang, X. (2015). Are fish fed with cyanobacteria safe, nutritious and delicious? A laboratory study. *Scientific Reports*, 5, 15166. DOI: https://doi.org/10.1038/srep15166

Liato, V., & Aïder, M. (2017). Geosmin as a source of the earthy-musty smell in fruits, vegetables and water: Origins, impact on foods and water, and review of the removing techniques. *Chemosphere*, 181, 9-18. DOI: https://doi.org/10.1016/j.chemosphere.2017.04.039

Liu, L., Pohnert, G., & Wei, D. (2016). Extracellular metabolites from industrial microalgae and their biotechnological potential. *Marine Drugs*, 14(10), 191. DOI: https://doi.org/10.3390/md14100191

Liu, Y., Chen, W., Li, D., Huang, Z., Shen, Y., & Liu, Y. (2011). Cyanobacteria-/cyanotoxin-contaminations and eutrophication status before Wuxi drinking water crisis in Lake Taihu, China. *Journal of Environmental Sciences*, 23(4), 575-581. DOI: https://doi.org/10.1016/S1001-0742(10)60450-0

Lürling, M., & Van Oosterhout, F. (2013). Controlling eutrophication by combined bloom precipitation and sediment phosphorus inactivation. *Water Research*, 47(17), 6527-6537. DOI: https://doi.org/10.1016/j.watres.2013.08.019

Lürling, M., Eshetu, F., Faassen, E. J., Kosten, S., & Huszar, V. L. (2013). Comparison of cyanobacterial and green algal growth rates at different temperatures. *Freshwater Biology*, 58(3), 552-559. DOI: https://doi.org/10.1111/j.1365-2427.2012.02866.x

Lürling, M., Waajen, G., Engels, B., & Van Oosterhout, F. (2017). Effects of dredging and lanthanum-modified clay on water quality variables in an enclosure study in a hypertrophic pond. *Water*, 9(6), 380. DOI: https://doi.org/10.3390/w9060380

Lynch, M., & Shapiro, J. (1981). Predation, enrichment, and phytoplankton community structure. *Limnology and Oceanography*, 26(1), 86-102. DOI: https://www.jstor.org/stable/2835809

MacKintosh, C., Beattie, K. A., Klumpp, S., Cohen, P., & Codd, G. A. (1990). Cyanobacterial microcystin-LR is a potent and specific inhibitor of protein phosphatases 1 and 2A from both mammals and higher plants. *FEBS Letters*, 264(2), 187-192. DOI: https://doi.org/10.1016/0014-5793(90)80245-E

Maddison, D. R., Schulz, K. S., & Maddison, W. P. (2007). The tree of life web project. *Zootaxa*, 1668(1), 19-40.

Maršálek, B., & Bláha, L. (2004). Comparison of 17 biotests for detection of cyanobacterial toxicity. *Environmental Toxicology: An International Journal*, 19(4), 310-317. DOI: https://doi.org/10.1002/tox.20020

Mateo, P., Leganés, F., Perona, E., Loza, V., & Fernández-Piñas, F. (2015). Cyanobacteria as bioindicators and bioreporters of environmental analysis in aquatic ecosystems. *Biodiversity and Conservation*, 24(4), 909-948. DOI: https://doi.org/10.1007/s10531-015-0903-y

Mazouni, K., Domain, F., Cassier-Chauvat, C., & Chauvat, F. (2004). Molecular analysis of the key cytokinetic components of cyanobacteria: FtsZ, ZipN and MinCDE. *Molecular Microbiology*, 52(4), 1145-1158. DOI: https://doi.org/10.1111/j.1365-2958.2004.04042.x

McLellan, N. L., & Manderville, R. A. (2017). Toxic mechanisms of microcystins in mammals. *Toxicology Research*, 6(4), 391-405. DOI: https://doi.org/10.1039/c7tx00043j

Merel, S., Walker, D., Chicana, R., Snyder, S., Baurès, E., & Thomas, O. (2013). State of knowledge and concerns on cyanobacterial blooms and cyanotoxins. *Environment International*, 59, 303-327. DOI: https://doi.org/10.1016/j.envint.2013.06.013

Meriluoto, J., Metcalf, J. S., & Codd, G. A. (2017). Selection of analytical methodology for cyanotoxin analysis. In: Meriluoto, J., Spoof, L., & Codd, G. A. (eds.). *Handbook of cyanobacterial monitoring and cyanotoxin analysis* (pp. 309-312). Hoboken, USA: John Wiley & Sons, Ltd.

Mihaljević, M., & Stević, F. (2011). Cyanobacterial blooms in a temperate river-floodplain ecosystem: The importance of hydrological extremes. *Aquatic Ecology*, 45(3), 335-349. DOI: https://doi.org/10.1007/s10452-011-9357-9

Miller, S. R., & Castenholz, R. W. (2000). The evolution of thermotolerance in hot spring cyanobacteria of the genus *Synechococcus*. *Journal of Phycology*, 36, 48-48. DOI: https://doi.org/10.1046/j.1529-8817.1999.00001-143.x

Mitra, A., & Flynn, K. J. (2006). Promotion of harmful algal blooms by zooplankton predatory activity. *Biology Letters*, 2(2), 194-197. DOI: https://doi.org/10.1098/rsbl.2006.0447

Mohamed, Z. A., Carmichael, W. W., & Hussein, A. A. (2003). Estimation of microcystins in the freshwater fish *Oreochromis niloticus* in an Egyptian fish farm containing a *Microcystis* bloom. *Environmental Toxicology: An International Journal*, 18(2), 137-141. DOI: https://doi.org/10.1002/tox.10111

Mondal, A., Bose, S., Banerjee, S., Patra, J. K., Malik, J., Mandal, S. K., & Bishayee, A. (2020). Marine cyanobacteria and microalgae metabolites—A rich source of potential anticancer drugs. *Marine Drugs*, 18(9), 476. DOI: https://doi.org/10.3390/md18090476

Morais, J., Augusto, M., Carvalho, A. P., Vale, M., & Vasconcelos, V. M. (2008). Cyanobacteria hepatotoxins, microcystins: Bioavailability in contaminated mussels exposed to different environmental conditions. *European Food Research and Technology*, 227(3), 949.

Moreira, C., Ramos, V., Azevedo, J., & Vasconcelos, V. (2014). Methods to detect cyanobacteria and their toxins in the environment. *Applied Microbiology and Biotechnology*, 98(19), 8073-8082. DOI: https://doi.org/10.1007/s00253-014-5951-9

Moss, B. R. (2018). *Ecology of freshwaters: Earth's bloodstream*. Hoboken, USA: John Wiley & Sons. DOI: https://doi.org/10.1007/s00217-007-0779-5

Moss, B., Kosten, S., Meerhoff, M., Battarbee, R. W., Jeppesen, E., Mazzeo, N., & Paerl, H. (2011). Allied attack: Climate change and eutrophication. *Inland Waters*, 1(2), 101-105. DOI: 10.5268/IW-1.2.359

Mur, R., Skulberg, O. M., & Utkilen, H. (1999). Cyanobacteria in the environment. In: Chorus, I., & Bartram, J. (eds.). (1999). Toxic cyanobacteria in water: A guide to their public health consequences, monitoring and management. Boca Raton, USA: CRC Press.

Nabout, J. C., Da-Silva-Rocha, B., Carneiro, F. M., & Sant'Anna, C. L. (2013). How many species of Cyanobacteria are there? Using a discovery curve to predict the species number. *Biodiversity and Conservation*, 22(12), 2907-2918. DOI: https://doi.org/10.1007/s10531-013-0561-x

Nandini, S, Sarma, S. S. S., & Ramírez-García, P. (2000). Life table demography and population growth of *Daphnia laevis* (Cladocera, Anomopoda) under different densities of *Chlorella vulgaris* and *Microcystis aeruginosa*. *Crustaceana* 73(10), 1273-1286. DOI: https://doi.org/10.1163/156854000505254

Nandini, S., Sánchez-Zamora, C., & Sarma, S. S. S. (2019) Toxicity of cyanobacterial blooms from the reservoir Valle de Bravo (Mexico): A case study on the rotifer *Brachionus calyciflorus*. *Science of the Total Environment*, 688, 1348-1358. DOI: https://doi.org/10.1016/j.scitotenv.2019.06.297

Nandini, S., Zamora-Barrios, C. A., & Sarma, S. S. S. (2020). A long-term study on the effect of cyanobacterial crude extracts from lake Chapultepec (Mexico City) on Selected zooplankton species. *Environmental Toxicology and Chemistry*, 39(12), 2409-2419. DOI: ttps://doi.org/10.1002/etc.4875

Negri, A. P., Jones, G. J., Blackburn, S. I., Oshima, Y., & Onodera, H. (1997). Effect of culture and bloom development and of sample storage on paralytic shellfish poisons in the cyanobacterium *Anabaena circinalis*. *Journal of Phycology*, 33(1), 26-35. DOI: https://doi.org/10.1111/j.0022-3646.1997.00026.x

Nobili, S., Lippi, D., Witort, E., Donnini, M., Bausi, L., Mini, E., & Capaccioli, S. (2009). Natural compounds for cancer treatment and prevention. *Pharmacological Research*, 59(6), 365-378. DOI: https://doi.org/10.1016/j.phrs.2009.01.017

Nübel, U., Garcia-Pichel, F., & Muyzer, G. (1997). PCR primers to amplify 16S rRNA genes from cyanobacteria. *Applied and Environmental Microbiology*, 63(8), 3327-3332. DOI: https://doi.org/10.1128/AEM.63.8.3327-3332.1997

O'Neil, J. M., Davis, T. W., Burford, M. A., & Gobler, C. J. (2012). The rise of harmful cyanobacteria blooms: The potential roles of eutrophication and climate change. *Harmful Algae*, 14, 313-334. DOI: https://doi.org/10.1016/j.hal.2011.10.027

Oberholster, P. J., Botha, A. M., & Cloete, T. E. (2006). Toxic cyanobacterial blooms in a shallow, artificially mixed urban lake in Colorado, USA. *Lakes & Reservoirs: Research & Management*, 11(2), 111-123. DOI: https://doi.org/10.1111/j.1440-1770.2006.00297.x

Oliva-Martínez, M. G., Godínez-Ortega, J. L., & Zuñiga-Ramos, C. A. (2014). Biodiversidad del fitoplancton de aguas continentales en México. *Revista Mexicana de Biodiversidad*, 85, 54-61. DOI: https://doi.org/10.7550/rmb.32706

Olvera-Ramírez, R., Centeno-Ramos, C., & Martínez-Jerónimo, F. (2010). Efectos tóxicos de *Pseudanabaena tenuis* (Cyanobacteria) en los cladóceros *Daphnia magna* y *Ceriodaphnia dubia*. *Hidrobiológica*, 20(3), 203-212.

Ortega, M. M. (1984). Catálogo de algas continentales recientes de México (No. Sirsi i9789688372715). Ciudad de México, México: Coordinación de la Investigación Científica, Instituto de Biología, Universidad Nacional Autónoma de México.

Paerl, H. W. (2014). Mitigating harmful cyanobacterial blooms in a human-and climatically-impacted world. *Life*, 4(4), 988-1012. DOI: https://doi.org/10.3390/life4040988

Paerl, H. W. (2017). Controlling harmful cyanobacterial blooms in a climatically more extreme world: Management options and research needs. *Journal of Plankton Research*, 39(5), 763-771. DOI: https://doi.org/10.1093/plankt/fbx042

Paerl, H. W., & Huisman, J. (2009). Climate change: A catalyst for global expansion of harmful cyanobacterial blooms. *Environmental Microbiology Reports*, 1(1), 27-37. DOI: https://doi.org/10.1111/j.1758-2229.2008.00004.x

Paerl, H. W., & Otten, T. G. (2013). Harmful cyanobacterial blooms: causes, consequences, and controls. *Microbial Ecology*, 65(4), 995-1010. DOI: https://doi.org/10.1007/s00248-012-0159-y

Paerl, H. W., & Paul, V. J. (2012). Climate change: Links to global expansion of harmful cyanobacteria. *Water Research*, 46(5), 1349-1363. DOI: https://doi.org/10.1016/j.watres.2011.08.002

Paerl, H. W., Havens, K. E., Hall, N. S., Otten, T. G., Zhu, M., Xu, H., & Qin, B. (2020). Mitigating a global expansion of toxic cyanobacterial blooms: Confounding effects and challenges posed by climate change. *Marine and Freshwater Research*, 71(5), 579-592. DOI: https://doi.org/10.1071/MF18392

Paerl, H. W., Otten, T. G., & Joyner, A. R. (2016). Moving towards adaptive management of cyanotoxin-impaired water bodies. *Microbial Biotechnology*, 9(5), 641-651.

Pawlik-Skowrońska, B., Toporowska, M., & Mazur-Marzec, H. (2019). Effects of secondary metabolites produced by different cyanobacterial populations on the freshwater zooplankters *Brachionus calyciflorus* and *Daphnia pulex*. *Environmental Science and Pollution Research*, 26(12), 11793-11804. DOI: https://doi.org/10.1007/s11356-019-04543-1

Pérez-Morales, A., Sarma, S. S. S., & Nandini, S. (2015). Producción de microcistinas en *Microcystis* inducida por *Daphnia pulex* (Cladocera) y *Brachionus calyciflorus* (Rotifera). *Hidrobiológica*, 25(3), 411-415.

Pilotto, L. S., Douglas, R. M., Burch, M. D., Cameron, S., Beers, M., Rouch, G. J., & Moore, C. (1997). Health effects of exposure to cyanobacteria (blue–green algae) during recreational water–related activities. *Australian and New Zealand Journal of Public Health*, 21(6), 562-566. DOI: ttps://doi.org/10.1111/j.1467-842X.1997.tb01755.x

Pineda-Mendoza, R. M., Olvera-Ramírez, R., & Martínez-Jerónimo, F. (2012). Microcystins produced by filamentous cyanobacteria in urban lakes. A case study in Mexico City. *Hidrobiológica*, 22(3), 290-298.

Pineda-Mendoza, R. M., Zúñiga, G., & Martínez-Jerónimo, F. (2014). Infochemicals released by *Daphnia magna* fed on *Microcystis aeruginosa* affect *mcyA* gene expression. *Toxicon*, 80, 78-86. DOI: https://doi.org/10.1016/j.toxicon.2014.01.008

Pineda-Mendoza, R. M., Zúñiga, G., & Martínez-Jerónimo, F. (2016). Microcystin production in *Microcystis aeruginosa*: Effect of type of strain, environmental factors, nutrient concentrations, and N: P ratio on *mcyA* gene expression. *Aquatic Ecology*, 50(1), 103-119. DOI: https://doi.org/10.1007/s10452-015-9559-7

Pla-García, J., & Menor-Salván, C. (2017). La composición química de la atmósfera primitiva del planeta Tierra. *Anales de Química*, 113(1). Recovered from https://analesdequimica.es/index.php/AnalesQuimica/article/view/940

Popovic, M., Zaja, R., & Smital, T. (2010). Organic anion transporting polypeptides (OATP) in zebrafish (*Danio rerio*): Phylogenetic analysis and tissue distribution. *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology*, 155(3), 327-335. DOI: https://doi.org/10.1016/j.cbpa.2009.11.011

Porter, K. G. (1973). Selective grazing and differential digestion of algae by zooplankton. *Nature*, 244(5412), 179-180. DOI: https://doi.org/10.1038/244179a0

Ptacnik, R., Andersen, T., & Tamminen, T. (2010). Performance of the Redfield ratio and a family of nutrient limitation indicators as thresholds for phytoplankton N vs. P limitation. *Ecosystems*, 13(8), 1201-1214. DOI: https://doi.org/10.1007/s10021-010-9380-z

Rabouille, S., Salençon, M. J., & Thébault, J. M. (2005). Functional analysis of *Microcystis* vertical migration: A dynamic model as a prospecting tool: I—Processes analysis. *Ecological Modelling*, 188(2-4), 386-403. DOI: https://doi.org/10.1016/j.ecolmodel.2005.02.015

Rantala, A., Fewer, D. P., Hisbergues, M., Rouhiainen, L., Vaitomaa, J., Börner, T., & Sivonen, K. (2004). Phylogenetic evidence for the early evolution of microcystin synthesis. *Proceedings of the National Academy of Sciences*, 101(2), 568-573. DOI: https://doi.org/10.1073/pnas.0304489101

Rapala, J., Sivonen, K., Lyra, C., & Niemelä, S. I. (1997). Variation of microcystins, cyanobacterial hepatotoxins, in *Anabaena* spp. as a function of growth stimuli. *Applied and Environmental Microbiology*, 63(6), 2206-2212.

Rastogi, R. P., Madamwar, D., & Incharoensakdi, A. (2015). Bloom dynamics of cyanobacteria and their toxins: Environmental health impacts and mitigation strategies. *Frontiers in Microbiology*, 6, 1254. DOI: https://doi.org/10.3389/fmicb.2015.01254

Redfield, A. C. (1958). The biological control of chemical factors in the environment. *American Scientist*, 46(3), 230A-221.

Reichwaldt, E. S., & Ghadouani, A. (2012). Effects of rainfall patterns on toxic cyanobacterial blooms in a changing climate: Between simplistic scenarios and complex dynamics. *Water Research*, 46(5), 1372-1393. DOI: https://doi.org/10.1016/j.watres.2011.11.052

Reynolds, C. S. (2006). *The ecology of phytoplankton*. Cambridge, UK: Cambridge University Press.

Rippka, R., Deruelles, J., Waterbury, J. B., Herdman, M., & Stanier, R. Y. (1979). Generic assignments, strain histories and properties of pure cultures of cyanobacteria. *Microbiology*, 111(1), 1-61. DOI: https://doi.org/10.1099/00221287-111-1-1

Rondel, C., Arfi, R., Corbin, D., Le Bihan, F., Ndour, E. H., & Lazzaro, X. (2008). A cyanobacterial bloom prevents fish trophic cascades. *Freshwater Biology*, 53(4), 637-651. DOI: https://doi.org/10.1111/j.1365-2427.2007.01894.x

Saker, M. L., Welker, M., & Vasconcelos, V. M. (2007). Multiplex PCR for the detection of toxigenic cyanobacteria in dietary supplements produced for human consumption. *Applied Microbiology and Biotechnology*, 73(5), 1136-1142. DOI: https://doi.org/10.1007/s00253-006-0565-5

Salmaso, N., Bernard, C., Humbert, J. F., Akçaalan, R., Albay, M., Ballot, A., & Yéprémian, C. (2016). Basic guide to detection and monitoring of potentially toxic cyanobacteria. In: *Handbook of cyanobacterial monitoring and cyanotoxin analysis* (pp. 46-69). Hoboken, USA: John Wiley & Sons, Ltd.

Sandoval-Reyes, J. L., & Ramírez-Zamora, R. M. (2019). Simultaneous removal of dissolved organic matter, *Microcystis aeruginosa*, and microcystin-LR by pre-oxidation and coagulation-flocculation processes. *Revista Mexicana de Ingeniería Química*, 18(3), 889-900. DOI: https://doi.org/10.24275/uam/izt/dcbi/revmexingquim/2019v18n3/Sandoval

Savadova, K., Mazur-Marzec, H., Karosienė, J., Kasperovičienė, J., Vitonytė, I., Toruńska-Sitarz, A., & Koreivienė, J. (2018). Effect of increased temperature on native and alien nuisance cyanobacteria from temperate lakes: An experimental approach. *Toxins*, 10(11), 445. DOI: https://doi.org/10.3390/toxins10110445

Schirrmeister, B. E., de Vos, J. M., Antonelli, A., & Bagheri, H. C. (2013). Evolution of multicellularity coincided with increased diversification of cyanobacteria and the Great Oxidation Event. *Proceedings of the National Academy of Sciences*, 110(5), 1791-1796. DOI: https://doi.org/10.1073/pnas.1209927110

Schmidt, J. R., Wilhelm, S. W., & Boyer, G. L. (2014). The fate of microcystins in the environment and challenges for monitoring. *Toxins*, 6(12), 3354-3387. DOI: ttps://doi.org/10.3390/toxins6123354

Schopf, J. W. (2012). The fossil record of cyanobacteria. In: *Ecology of cyanobacteria II* (pp. 15-36). Dordrecht, The Netherlands: Springer. DOI: https://doi.org/10.1007/978-94-007-3855-3_2

Silveira, S. B., & Odebrecht, C. (2019). Effects of salinity and temperature on the growth, toxin production, and akinete germination of the cyanobacterium *Nodularia spumigena*. *Frontiers in Marine Science*, 6, 339. DOI: https://doi.org/10.3389/fmars.2019.00339

Sinha, R., Pearson, L. A., Davis, T. W., Burford, M. A., Orr, P. T., & Neilan, B. A. (2012). Increased incidence of *Cylindrospermopsis raciborskii* in temperate zones–is climate change responsible? *Water Research*, 46(5), 1408-1419. DOI: https://doi.org/10.1016/j.watres.2011.12.019

Steinberg, C. E. W., Schäfer, H., & Beisker, W. (1998). Do acid-tolerant cyanobacteria exist? *Acta Hydrochimica et Hydrobiologica*, 26(1), 13-19. DOI: https://doi.org/10.1002/(SICI)1521-401X(199801)26:1<13::AID-AHEH13>3.0.CO;2-V

Steiner, K., Wood, S. A., Puddick, J., Hawes, I., Dietrich, D. R., & Hamilton, D. P. (2017). A comparison of bacterial community structure, activity and microcystins associated with formation and breakdown of a cyanobacterial scum. *Aquatic Microbial Ecology*, 80(3), 243-256. DOI: https://doi.org/10.3354/ame01852

Stewart, I., Schluter, P. J., & Shaw, G. R. (2006). Cyanobacterial lipopolysaccharides and human health–a review. *Environmental Health*, 5(1), 1-23. DOI: https://doi.org/10.1186/1476-069X-5-7

Swain, S. S., Paidesetty, S. K., & Padhy, R. N. (2017). Antibacterial, antifungal and antimycobacterial compounds from cyanobacteria. *Biomedicine & Pharmacotherapy*, 90, 760-776. DOI: https://doi.org/10.1016/j.biopha.2017.04.030

Swingle, M., Ni, L., & Honkanen, R. E. (2007). Small-molecule inhibitors of Ser/Thr protein phosphatases. In: *Protein phosphatase protocols* (pp. 23-38). Totowa, USA: Springer. DOI: https://doi.org/10.1385/1-59745-267-X:23

Teneva, I., Dzhambazov, B., Mladenov, R., & Schirmer, K. (2005). molecular and phylogenetic characterization of phormidium species (*cyanoprokaryota*) using the *CPCB-IGS-CPCA* locus 1. *Journal of Phycology*, 41(1), 188-194. DOI: https://doi.org/10.1111/j.1529-8817.2005.04054.x

Tian, D., Zheng, W., Wei, X., Sun, X., Liu, L., Chen, X., & Wang, X. (2013). Dissolved microcystins in surface and ground waters in regions with high cancer incidence in the Huai River Basin of China. *Chemosphere*, 91(7), 1064-1071. DOI: https://doi.org/10.1016/j.chemosphere.2013.01.051

Tillett, D., Dittmann, E., Erhard, M., Von Döhren, H., Börner, T., & Neilan, B. A. (2000). Structural organization of microcystin biosynthesis in *Microcystis aeruginosa* PCC7806: An integrated peptide–polyketide synthetase system. *Chemistry & Biology*, 7(10), 753-764. DOI: https://doi.org/10.1016/S1074-5521(00)00021-1

Triest, L., Stiers, I., & Van Onsem, S. (2016). Biomanipulation as a nature-based solution to reduce cyanobacterial blooms. *Aquatic Ecology*, 50(3), 461-483. DOI: https://doi.org/10.1007/s10452-015-9548-x

Ueno, Y., Nagata, S., Tsutsumi, T., Hasegawa, A., Yoshida, F., Suttajit, M., & Vasconcelos, V. (1996). Survey of microcystins in environmental water by a highly sensitive immunoassay based on monoclonal antibody. *Natural Toxins*, 4(6), 271-276. DOI:https://doi.org/10.1002/(SICI)(1996)4:6<271::AIDNT4>3.0.CO;2-A

Urrutia-Cordero, P., Ekvall, M. K., & Hansson, L. A. (2016). Local food web management increases resilience and buffers against global change effects on freshwaters. *Scientific Reports*, 6, 29542. DOI: https://doi.org/10.1038/srep29542

USEPA, U.S. Environmental Protection Agency. (2015). Health effects support document for the cyanobacterial toxin microcystins. Washington, DC, USA: U.S. Environmental Protection Agency.

Vasconcelos, V. (2001). Cyanobacteria toxins: Diversity and ecological effects. *Limnetica*, 20(1), 45-58.

Vasconcelos, V., Martins, A., Vale, M., Antunes, A., Azevedo, J., Welker, M., & Montejano, G. (2010). First report on the occurrence of microcystins in planktonic cyanobacteria from Central Mexico. *Toxicon*, 56(3), 425-431. DOI: https://doi.org/10.1016/j.toxicon.2010.04.011

Vermaas, W. F. (2001). Photosynthesis and respiration in cyanobacteria. *eLS*. DOI: https://doi.org/10.1038/npg.els.0001670

Visser, P. M., Ibelings, B. W., Bormans, M., & Huisman, J. (2016a). Artificial mixing to control cyanobacterial blooms: A review. *Aquatic Ecology*, 50(3), 423-441. DOI: https://doi.org/10.1007/s10452-015-9537-0

Visser, P. M., Verspagen, J. M., Sandrini, G., Stal, L. J., Matthijs, H. C., Davis, T. W., & Huisman, J. (2016b). How rising CO2 and global warming may stimulate harmful cyanobacterial blooms. *Harmful Algae*, 54, 145-159. DOI: https://doi.org/10.1016/j.hal.2015.12.006

Vogiazi, V., De-la-Cruz, A., Mishra, S., Shanov, V., Heineman, W. R., & Dionysiou, D. D. (2019). A comprehensive review: Development of electrochemical biosensors for detection of cyanotoxins in freshwater. *ACS Sensors*, 4(5), 1151-1173. DOI: https://doi.org/10.1021/acssensors.9b00376

Waajen, G, W., Lürling, M., & Van de Sande, R. (2019). The unfulfilled promise of urban Lake Kleine Melanen (The Netherlands): Diagnostics, experiment on reduction of sediment P-release and in-lake restoration. *Lake and Reservoir Management*, 35(1), 8-24. DOI: https://doi.org/10.1080/10402381.2018.1505791

Wallace, B. B., Bailey, M. C., & Hamilton, D. P. (2000). Simulation of vertical position of buoyancy regulating *Microcystis aeruginosa* in a shallow eutrophic lake. *Aquatic Sciences*, 62(4), 320-333. DOI: https://doi.org/10.1007/PL00001338

Walsby, A. E. (1994). Gas vesicles. *Microbiology and Molecular Biology Reviews*, 58(1), 94-144.

Walsby, A. E., Hayes, P. K., Boje, R., & Stal, L. J. (1997). The selective advantage of buoyancy provided by gas vesicles for planktonic cyanobacteria in the Baltic Sea. *New Phytologist*, 136(3), 407-417. DOI: https://doi.org/10.1046/j.1469-8137.1997.00754.x

Wang, L., Sun, J., Zheng, W., Huang, T., Zhang, Y., Wu, Z., & He, F. (2018). Effects of a combined biological restoration technology on nitrogen and phosphorus removal from eutrophic water. *Polish Journal of Environmental Studies*, 27(5). DOI: https://doi.org/10.15244/pjoes/77609

Wannemacher, R. W. (1989). *Chemical stability and laboratory safety of naturally occurring toxins*. Fort Detrick, USA: US Army Medical Research Institute of Infectious Disease.

Watanabe, M. F., & Oishi, S. (1985). Effects of environmental factors on toxicity of a cyanobacterium (Microcystis aeruginosa) under culture conditions. *Applied and Environmental Microbiology*, 49(5), 1342-1344. DOI: https://doi.org/10.1128/aem.49.5.1342-1344.1985

Watanabe, M. F., Tsuji, K., Watanabe, Y., Harada, K. I., & Suzuki, M. (1992). Release of heptapeptide toxin (microcystin) during the decomposition process of *Microcystis aeruginosa*. *Natural Toxins*, 1(1), 48-53. DOI: https://doi.org/10.1002/nt.2620010110

Whitton, B. A. (2002). *Phylum cyanophyta* (cyanobacteria). In: *The freshwater algal flora of the British isles* (pp. 25-122). Cambridge, UK: Cambridge University Press.

Whitton, B. A., & Potts, M. (2012). Introduction to the cyanobacteria. In: *Ecology of cyanobacteria II* (pp. 1-13). Dordrecht, The Netherlands: Springer. DOI: https://doi.org/10.1007/978-94-007-3855-3_1

WHO, World Health Organization. (2003). *Guidelines for safe recreational water environments: Coastal and fresh waters* (vol. 1). Geneva, Switzerland: World Health Organization.

Wörmer, L., Cirés, S., & Quesada, A. (2011). Importance of natural sedimentation in the fate of microcystins. *Chemosphere*, 82(8), 1141-1146. DOI: https://doi.org/10.1016/j.chemosphere.2010.11.024

Yadav, S., Sinha, R. P., Tyagi, M. B., & Kumar, A. (2011). Cyanobacterial secondary metabolites. *International Journal of Pharmacy and Biological Sciences*, 2(1), 144-167.

Zamora-Barrios, C. A., Nandini, S., & Sarma, S. S. S. (2015). Effect of crude extracts of *Dolichospermum planctonicum* on the demography of *Plationus patulus* (Rotifera) and *Ceriodaphnia cornuta* (Cladocera). *Ecotoxicology*, 24(1), 85-93. DOI: https://doi.org/10.1007/s10646-014-1358-8

Zamora-Barrios, C. A., Nandini, S., & Sarma, S. S. S. (2017). Effect of crude extracts from cyanobacterial blooms in Lake Texcoco (Mexico) on the population growth of *Brachionus* calyciflorus (Rotifera). *Toxicon*, 139, 45-53. DOI: https://doi.org/10.1016/j.toxicon.2017.09.013

Zamora-Barrios, C. A., Nandini, S., & Sarma, S. S. S. (2019). Bioaccumulation of microcystins in seston, zooplankton and fish: A case study in Lake Zumpango, Mexico. *Environmental Pollution*, 249, 267-276. DOI: https://doi.org/10.1016/j.envpol.2019.03.029

Zanchett, G., & Oliveira-Filho, E. C. (2013). Cyanobacteria and cyanotoxins: From impacts on aquatic ecosystems and human health to anticarcinogenic effects. *Toxins*, 5(10), 1896-1917. DOI: https://doi.org/10.3390/toxins5101896

Zhang, D., Xie, P., & Chen, J. (2010). Effects of temperature on the stability of microcystins in muscle of fish and its consequences for food safety. *Bulletin of Environmental Contamination and Toxicology*, 84(2), 202-207. DOI: https://doi.org/10.1007/s00128-009-9910-6

Zhao, H., Zhu, W., Chen, H., Zhou, X., Wang, R., & Li, M. (2016). Numerical simulation of the vertical migration of *Microcystis* (cyanobacteria) colonies based on turbulence drag. *Journal of Limnology*, 76(1). DOI: https://doi.org/10.4081/jlimnol.2016.1501