Chapter

Eutrophication and Phytoplankton: Some Generalities from Lakes and Reservoirs of the Americas

Ernesto J. González and Gabriel Roldán

Abstract

Eutrophication is one of the most widespread problems of inland waters in the world. In many countries from North to South America, eutrophication is due to several impacts resulting from the inefficient or nonexistent wastewater treatment; the agricultural expansion with inadequate soil uses and application of chemical fertilizers; the urbanization of watersheds, the increase of intensive husbandry of cattle, pigs, and chicken; the increase of aquaculture; the construction of reservoirs; and the destruction of natural ecosystems. Basically, the increase in the internal load of nitrogen and phosphorus in lakes and reservoirs produces an increase in the biological productivity of the water bodies. As consequence, phytoplankton community in freshwater systems is mainly dominated by cyanobacteria. Despite differences in continental climate regimes, this seems to be a regular pattern along the Americas, where there are various practices related to the use of lower and upper taxonomic groups of phytoplankton for the indication of the trophic level and water quality status of freshwater systems. As was reported in numerous studies in the Americas, increase in nutrient concentrations mainly due to rich in phosphorus cause larger phytoplankton biomass and predominance of cyanobacteria such as genera *Microcystis*, *Anabaena*, *Planktothrix*, *Oscillatoria*, and *Cylindrospermopsis* than ever before.

Keywords: America, eutrophication, phytoplankton, cyanobacterial dominance

1. Introduction

Eutrophication, defined as the nutrient enrichment process (mainly nitrogen and phosphorus) of any water body which results in an excessive growth of phytoplankton and macrophytes [1–3], has become a major cause of concern in developing as well as developed countries [1]. Also, it was recognized as a pollution problem in the European and North American lakes and reservoirs in the mid-twentieth century. Since then, it has become more widespread in the whole world.

Eutrophication is due to several impacts resulting from the inefficient or nonexistent wastewater treatment; the agricultural expansion with inadequate soil uses and application of chemical fertilizers; the urbanization of watersheds; the increase of intensive husbandry of cattle, pigs, and chicken; the increase of aquaculture; the construction of reservoirs; and the destruction of natural ecosystems [4]. The eutrophication event describes formation of a set of symptoms in a lake system exposed to excessive nutrient increase [2]. Common symptoms due to eutrophication include excessive algal blooms, tremendous organic and inorganic material accumulation, and lower biodiversity, high turbidity, excessive sedimentation, and high anoxia conditions, particularly in the deeper parts of lakes. The increase in anoxia condition can cause fish deaths in midsummer. One of the first and worst symptoms of eutrophication has been formation of planktonic algal blooms. In freshwaters, former of these algal blooms are mostly nitrogen (N)-fixing cyanobacteria [5].

Eutrophic water bodies are richly supplied with plant nutrients (N, P, as well other nutrients of less acute demand), and consequences include the increase of biological productivity and turbidity of water because of dense growths of phytoplankton [6, 7]. Thus, phytoplankton community structures and their relevant participants could be used as a biological indicator of negative environmental impacts formed in lakes and reservoirs, as was eutrophication event [8].

In the Americas, as was reported in previous studies, the increase in nutrient concentrations leads to greater biomass of phytoplankton in freshwater systems. In this new region of the world, there are numerous experiences relating the effect of eutrophication on the phytoplankton community.

In this book chapter, we aimed to provide a short overview based on the sparse and scattered literature sources and fixed practices in the American continent related to the proliferation of certain groups of phytoplankton in lakes and reservoirs in terms of eutrophication. We try to depict some generalizations that have arisen from this review, in relation to dominant phytoplankton in the eutrophic lakes and reservoirs in the Americas.

2. Eutrophication and phytoplankton

Excessive nutrient accumulation in aquatic ecosystems by carrying of anthropogenic sources, mainly rich in phosphorus (P) and nitrogen (N), creates a series of changes in their structure and function in the direction of deterioration of water quality, known as eutrophication [9]. Among the structural changes caused by the eutrophication, there is the dominance of the "r" selective species in the community structure of phytoplankton known as tiny primary pelagic producers, particularly in the predominance of cyanobacteria in the freshwater ecosystems such as lakes and reservoirs.

As were reported by Bellinger and Sigee [10], the detection of excessive harmful blooms of some algae that are biological indicators of environmental pollution, particularly of nutrient pollution, reveals anthropogenic activities in freshwater systems and a rapid change in their trophic status. It is known that in the mid-twentieth century, some researchers such as Thunmark [11], Nygaard [12], and Stockner [13] developed trophic status indexes by using typical algal groups of oligotrophic (particularly desmids, a group of green algae) or typical algal groups of eutrophic conditions (chlorococcal, cyanobacterial, and euglenoid species). Although these indices provide useful information about trophic status of the lakes, generally they are not enough to indicate a lot of environmental problems since a lot of algal species have been living in both eutrophic and oligotrophic freshwater systems. In the other word, there are a lot of similarities in view of species homogeneity and seasonal succession of species for both systems. The rehabilitation of previous methods on sampling and taxonomic analysis, and development of new methods in this framework have provided the development in indices based on more specific indicator algal species from different taxonomic groups. Thus, Bellinger and Sigee

[10] revealed in their books what the indicator species of the trophic status would be in mid-summer in temperate lakes (**Table 1**).

In the Americas, there are some examples about how phytoplankton groups and species have been used for the determination of the trophic status and quality of surface waters. Some of these experiences will be presented in the following sections.

2.1 North America

2.1.1 Canada

The dominant indicator species list for trophic status of various lake types in the western region of Canada is revealed in **Table 2**. This list bases on 25 years of observations by Rawson [14].

In the Experimental Lake Area (ELA), located in Ontario, Schindler [15] and Schindler et al. [5] showed that water fertilization (N and P) causes quantitative increase of all phytoplankton groups, especially the cyanobacteria species *Aphanizomenon schindleri* Kling, Findlay and Komárek 1994, and *Limnothrix redekei* (Goor) Meffert 1988.

2.1.2 The United States of America

In 1978, the Environmental Protection Agency (EPA) published a study about eutrophication relating aquatic plant response to nutrient loading to lakes and reservoirs [16]. There was good correlation between phosphorus loading and the average chlorophyll *a* and water transparency. In general, the correlations between phosphorus-loading concentrations and eutrophication response data are better than those observed between nitrogen-loading concentrations and the same eutrophication parameters, supporting the phosphorus limitation of most of the United States water bodies. Summarizing, the characteristic algal species in relation to the phytoplankton in eutrophic lakes are represented by *Anabaena* spp., *Aphanizomenon* spp., *Microcystis* spp., and *Oscillatoria rubescens* De Candolle ex Gomont 1892.

Lake types	Algal indicators
Oligotrophic	Diatoms: *Cyclotella comensis* Grunow in Van Heurck 1882, *Rhizosolenia* spp. Green algae: *Staurodesmus* spp.
Mesotrophic	Diatoms: *Tabellaria flocculosa* (Roth) Kützing 1844 Chrysophytes: *Dinobryon divergens* O. E. Imhof 1887, *Mallomonas caudata* Iwanoff (Ivanov) 1899 Green algae: *Sphaerocystis schroeteri* Chodat 1897, *Dictyosphaerium elegans* Bachmann 1913, *Cosmarium* spp., *Staurastrum* spp. Dinoflagellates: *Ceratium hirundinella* (O. F. Müller) Dujardin 1841 Cyanobacteria: *Gomphosphaeria* spp.
Eutrophic	Diatoms: *Aulacoseira* spp., *Stephanodiscus rotula* (Kützing) Hendey 1964 Green algae: *Eudorina* spp., *Pandorina morum* (O. F. Müller) Bory 1897, *Volvox* spp. Cyanobacteria: *Anabaena* spp., *Aphanizomenon flos-aquae* Ralfs ex Bornet and Flahault 1886, *Microcystis aeruginosa* (Kützing) Kützing 1846
Hypereutrophic	Diatoms: *Stephanodiscus hantzschii* Grunow 1880 Green algae: *Scenedesmus* spp., *Ankistrodesmus* spp., *Pediastrum* spp. Cyanobacteria: *Aphanocapsa* spp., *Aphanothece* spp., *Synechococcus* spp.

Table 1.
Phytoplankton indicative species of trophic status in temperate lakes in mid-summer, modified from Bellinger and Sigee [10].

Lake types	Algal indicators
Oligotrophic	Diatoms: *Asterionella formosa* Hassall 1850, *Melosira islandica* O. Müller 1906, *Tabellaria fenestrata* (Lyngbye) Kützing 1844, *Tabellaria flocculosa* (Roth) Kützing 1844, *Fragilaria capucina* Desmazières 1830, *Stephanodiscus niagarae* Ehrenberg 1845, *Staurastrum* spp., *Melosira granulata* (Ehrenberg) Ralfs 1861 Chrysophytes: *Dinobryon divergens* O. E. Imhof 1887
Mesotrophic	Diatoms: *Fragilaria crotonensis* Kitton 1869 Green algae: *Pediastrum boryanum* (Turpin) Meneghini 1840, *Pediastrum duplex* Meyen 1829 Dinoflagellates: *Ceratium hirundinella* (O.F.Müller) Dujardin 1841 Cyanobacteria: *Coelosphaerium naegelianum* Unger 1854, *Anabaena* spp., *Aphanizomenon flos-aquae* Ralfs ex Bornet and Flahault 1886, *Microcystis aeruginosa* (Kützing) Kützing 1846
Eutrophic	Cyanobacteria: *Microcystis flos-aquae* (Wittrock) Kirchner 1898

Table 2.
The list of dominant algal indicator species for trophic status of various lake types in the western region of Canada, modified from Rawson [14].

2.1.3 Mexico

In several lakes suffering the eutrophication process, green algae and diatoms have been replaced by cyanobacteria, particularly *Anabaena* spp., *Microcystis aeruginosa* (Kützing) Kützing 1846, *Oscillatoria* spp., and *Lyngbya* spp. ([17–22], among others).

Cyanobacteria dominance in the eutrophic Lake Chapala is described by de Anda and Shear [23]. The high TN and TP concentrations contained in the large quantities of domestic, agricultural, and industrial sewage that enter to the lake through its main tributary, the Lerma river, increased the phytoplankton biomass and resulted in the dominance of *Anabaena flos-aquae* Brébisson ex Bornet and Flauhault 1886.

Tomasini-Ortiz et al. [24] reported the dominance of *Aphanizomenon gracile* Lemmermann 1907, followed by *M. aeruginosa*, *Microcystis pulverea* (HC Wood) Forti 1907, and *Anabaena affinis* Lemmermann 1898 in the eutrophic Lake Pátzcuaro, Michoacán State. The authors pointed out that many cyanobacterial blooms have been reported in eutrophic lakes along the Mexican states of Jalisco, Michoacán, Veracruz, San Luis Potosí, Querétaro, Guanajuato, Puebla, Oaxaca, and Hidalgo and in Mexico City.

Valle de Bravo reservoir (State of Mexico) provides drinking water to about 2,500,000 inhabitants in Mexico City [25]. This water body also shows frequent cyanobacterial blooms as consequence of the high nutrient load in its waters, posing health risks for human population. The common genera found during blooms are *Microcystis* sp., *Oscillatoria* sp., *Anabaena* sp., *Cylindrospermopsis raciborskii* (Woloszynska) Seenayya and Subba Raju 1972, and *Nostoc* sp.

2.2 Central America

2.2.1 Guatemala

Unregulated land use and lack of wastewater treatment have led to eutrophication in many lakes of Guatemala [26]. Some examples of this situation are the following studies.

Basterrechea [27] found the prevalence of cyanobacteria in the Lake Amatitlán due to eutrophic conditions. Similarly, Rejmánková et al. [28] recorded blooms of the *Lyngbya* species complex (cyanobacteria) as a consequence of the change in land use in the Lake Atitlán basin. Brocard et al. [26] pointed out that eutrophication has had a dramatic impact on the lake Chichój environment; among other effects, fertilization of lake waters produced severe hypoxia, massive development of the water hyacinth *Eichhornia crassipes* (Mart.) Solms 1883, and "blue-green" algae dominance.

2.2.2 Honduras

The Lake Yojoa is the largest natural lake in the country and represents an important natural resource for Hondurans [29]. The lake is used extensively for commercial production of tilapia fish; fishes are raised to full maturity in floating cages in the lake, and subsequently, high nutrient load is directly supplied to the water body. Other sources of nutrients are: (a) significant amount of wastewater from the ineffective product of water treatment plant, (b) wastewater from restaurants around the lake, and (c) agricultural practices in the neighboring lands, where fertilizers are commonly used, thus contributing with nutrients to the system, having an impact on water quality [29].

Because of the high input of nutrients, cyanobacteria are the dominant phytoplankton group that accounted for 59.0% of total phytoplankton in the lake [30]. Dominant species in the lake are *M. aeruginosa*, *Aphanocapsa delicatissima* West and GS West 1912, and *Oscillatoria limosa* C. Agardh ex Gomont 1892, all of them common in eutrophic tropical and temperate lakes. Other species that present high densities in lake are the green algae *Staurastrum leptocladum* Nordstedt 1870 and *Sphaerocystis schroeteri* Chodat 1897 and the diatom *Aulacoseira granulata* (Ehrenberg) Simonsen 1979.

2.2.3 El Salvador

Wastewater effluents and similar runoffs with high nutrient concentrations derived from agricultural fertilizers, which are increased by the susceptibility to erosion, deforestation, and sediment trawling, have induced the eutrophication process and, consequently, produced the proliferation of *M. aeruginosa* (cyanobacteria) in the volcanic Lake Coatepeque [31].

The Cerrón Grande reservoir also suffered the eutrophication process, and its waters are classified as hypereutrophic. The dominant cyanobacteria species is *Microcystis* spp. [32].

2.2.4 Nicaragua

In the eutrophic Lake Xolotlán (Lake Managua), Hooker and Hernández [33] and Erikson [34] found high phosphorus concentrations (≈150 μg/L), turbid waters (0.40 m of transparency), and high algal biomass of mainly "blue-greens" (cyanobacteria). Phytoplankton community was dominated by cyanobacteria throughout the entire year [35], and *Lyngbya contorta* Lemmermann 1898 accounted for more than 35.0% of total phytoplankton in the lake, followed by the diatom *Cyclotella meneghiniana* Kützing 1844.

Vammen et al. [36] pointed out that increased eutrophication in Lake Cocibolca (Lake Nicaragua) had resulted in the increase of phytoplankton density and a marked dominance of two cyanobacterial species (*M. aeruginosa* and *C. raciborskii*). Cyanobacteria accounted for almost 99% of total phytoplankton in the lake.

Hernández González et al. [37] also found that the most representative phytoplankton genera detected during most of the period sampled in the eutrophic lakes Cocibolca, Tiscapa, and Masaya, were cyanobacteria, among which are distinguished *Anabaenopsis*, *Merismopedia*, *Chroococcus*, and *Lyngbya*.

2.2.5 Costa Rica

Umaña et al. [38] stated that there are few long-term works in lakes in Costa Rica, which have shown a wide annual variation of their characteristics. In the Talamanca region of the province of Limón, Jones et al. [39] found a gradient of trophic states, varying from high-altitude lakes with a tendency to be oligotrophic, to lower-altitude lakes with a tendency to be eutrophic, despite being located in woodland regions where it is away from any human disturbances. These researchers express that, because they do not have a high burden of anthropic phosphorus, their planktonic communities do not show the classic dominance of cyanobacteria against other planktonic groups, but rather a higher prevalence of green algae, a few dinoflagellates and a few cryptomonadales, all of which suggest a more balanced availability between nitrogen and phosphorus. On the other hand, the Arenal reservoir, the largest water body in Costa Rica, located between the provinces of Guanacaste and Alajuela, has been classified as mesotrophic by Jones et al. [39], representing varied phytoplanktonic community that is dominated by green algae, some diatoms, and cyanobacteria (*Microcystis* spp.).

2.2.6 Panama

Reservoirs of the Panama channel show a mesotrophic status, with a predominance of diatom populations that are represented by 40.0% of total phytoplankton in Gatún reservoir, 55.1% in Alajuela reservoir, and 58.0% in Miraflores reservoir [40].

2.2.7 Cuba

Gómez Luna et al. [41] identified the phytoplankton communities in three reservoirs which are used for drinking water supply to 80.0% of the inhabitants in the City of Santiago de Cuba. High concentrations of nutrients were detected in Chalóns, Charco Mono, and Paradas reservoirs, where the phytoplankton communities were dominated by the cyanobacterial species *Microcystis* spp., *Aphanothece minutissima* (West) J. Komárková-Legnerová and G. Cronberg 1994, and *Oscillatoria chalybea* Mertens ex Gomont 1892.

2.2.8 Puerto Rico

Pantoja Agreda [42] conducted a limnological characterization of Guajataca reservoir, which was classified as mesotrophic. The dominant phytoplankton group were Euglenophyta (43.8% of total phytoplankton), followed by Pyrrhophyta (34.9%) and Chlorophyta (10.7%); cyanobacteria accounted for less than 5.00% of total algal density. This fact is common in water bodies with high content of organic matter.

2.3 South America

2.3.1 Colombia

According to Roldán [43] and Roldán and Ramírez [44], water bodies with more signs of eutrophication (Porce II, El Peñol, Prado, and Tominé) have a predominance of cyanobacteria, especially of the genera *Anabaena* spp. and *Oscillatoria* spp. The main source of eutrophication is domestic wastewater that reaches the rivers and streams without any treatment. The use of agrochemicals also contributes to eutrophication. The most outstanding case of eutrophication is that of the Porce II reservoir, which receives the waters of the Medellín river, carrying pollutants of a city of about 3,000,000 inhabitants. Currently, there are two wastewater treatment plants, one of which has started process a short time ago. It is expected that this reservoir will begin to recover in the future. Unfortunately, more than 95.0% of the towns and cities in Colombia do not have wastewater treatment plants.

2.3.2 Ecuador

Composition of phytoplankton in the Lake Yahuarcocha is dominated by the following species: *Cylindrospermopsis* sp., *Anabaena* sp., *Microcystis* sp. (cyanobacteria), *Monoraphidium* sp. (chlorophyta), and *Fragilaria* sp. (diatom) [45]. Eutrophication in this lake is due to the entrance of wastewater caused by the tourism industry around the lake.

2.3.3 Peru and Bolivia

In the Lake Titicaca, in the corresponding Bolivian basin, Fonturbel and Castaño-Villa [46] considered nutrient concentrations and phytoplankton groups as a whole to determine that the families Oscillatoriaceae and Nostocaceae (cyanobacteria) respond positively to the increase in pH (alkalinization) and negatively to the increasing nutrients, while the families Naviculaceae (diatoms), Closteriaceae, and partly Zygnemataceae (green algae) showed an inverse tendency with proliferating in acidic water enriched with nutrients. The diatoms seem to respond negatively, both to the acidification of the water and to the excessive nutrient enrichments. Studies revealed that they are the most sensitive groups to the eutrophication of waters.

Between the 1970s and 1990s, both sections of the Lake Titicaca, deep Lago Mayor and large part of shallow Lago Menor, were oligotrophic with high water transparency and strong nitrogen limitation. Chlorophyta and cyanobacteria (particularly *Anabaena* spp.) dominated the phytoplankton with low biomass and primary production, except for diatoms during the dry season [47]. Currently, the deep pelagic areas of the Lake Lago Mayor remain oligotrophic. However, shallow littoral areas of the Lake Lago Mayor and the Lago Menor turn to eutrophic from mesotrophic. In the northern littoral area of the Lago Menor, there are a lot of villages which have domestic pollution sources, while El Alto is responsible for the heavy contamination of the Cohana bay. In 2015, the extended rainy season produced the first major phytoplankton bloom event in dominance of *Carteria* sp., which is a harmless unicellular green algae in the northern part of the Lago Menor in the period of March–April. Phytoplankton blooms in the region have been spotted since the 2000s. Cyanobacteria *Limnoraphis* (syn. *Lyngbya*) predominates in the Puno bay.

2.3.4 Brazil

Numerous studies on eutrophication of freshwater ecosystems have been conducted along the Brazilian territory. Prevalence of cyanobacteria under this eutrophic condition has also been reported.

Tundisi [48] reported blooms of the cyanobacteria *Microcystis* spp. and *Anabaena* spp. in the reservoirs of the State of São Paulo, where they are characterized by a severe eutrophication in their waters due to industrial and agricultural wastewater.

Huszar et al. [49] and Dantas et al. [50] also found the dominance of *Microcystis* in highly eutrophic shallow lakes and small reservoirs.

Lake Vaca Brava, in the State of Goiás (Central Western Brazil), is an urban water body that suffers the eutrophication process as a consequence of the human settlement in its neighboring areas [51]. Increased cyanobacterial density accompanies the eutrophication process, where *Planktolyngbya limnetica* (Lemmermann) Komárková-Legnerová and Cronberg 1992 is the dominant species.

Likewise, Chellappa et al. [52] studied the dynamics of phytoplankton in the Armando Ribeiro Gonçalves reservoir, located in the state of Rio Grande do Norte (Northern Brazil), which is used for drinking water supply; this reservoir was classified as eutrophic due to its high nutrient concentrations, and the toxic cyanobacteria dominated the phytoplankton composition, particularly *Planktothrix agardhii* (Gomont) Anagnostidis and Komárek 1988 in drought period and *M. aeruginosa* in rainy season.

Due to inadequate treatment, sewage with high levels of P and N reaches to Pampulha and Ibirité reservoirs in South-Eastern Brazil [53, 54], causing changes in the composition and diversity of the plankton community. *Microcystis* spp. were the main species registered during the blooms in these reservoirs.

Despite resulting in known impacts, such as loss of aquatic biodiversity, the emergence of potentially toxic cyanobacterial blooms, overgrowth of aquatic macrophytes, anoxia and fish mortality, increased eutrophication of Brazilian reservoirs has also, as an additional consequence, the increase of greenhouse gas emission that aggravates the global warming process [55, 56].

2.3.5 Chile

In this country, it has also been reported that the increase in the concentration of nitrogen and phosphorus leads to an increase in phytoplankton biomass and to the dominance of cyanobacteria [57]. In lakes which have heavy eutrophication process, the dominant cyanobacteria which occur blooms are usually of *Anabaena* spp., *Microcystis* spp., and *Oscillatoria* spp. [58–60], some of them presenting toxic strains [58]. On the other hand, Parra et al. [61] found that green algae (Chlorophyta), particularly Desmidiaceae family members, are the group more sensitive to negative changes in environmental conditions, especially to those associated with pollution and eutrophication.

2.3.6 Argentina

Quirós [62], analyzing the empirical relationships between nutrient concentrations and biological communities in more than 100 Argentine lakes and reservoirs, found that total phosphorus concentration is the main factor in the control of the phytoplankton biomass. Likewise, he also found that the applied empirical order grouped lakes in two groups which are the lakes located in the lower latitudes which are shallow, warm, and eutrophic where phytoplankton are limited by nitrogen, and the lakes located in higher latitude, temperate-cold, and oligotrophic where phytoplankton are limited by phosphorus [63]. Also, Quirós et al. [64] found that nutrient enrichment of the Pampa's surface water and its multiple negative effects on its lagoons have increased the internal phosphorus load allowing the increase in the frequency of cyanobacterial blooms, especially during relatively dry years.

2.3.7 Uruguay

The largest reservoirs (Salto Grande, Bonete, Baygorria, and Palmar) have suffered the process of eutrophication, which has led to an intense growth of phytoplankton [65]. De León and Chalar [66], Chalar et al. [67], and Chalar [68, 69] studied the phytoplankton dynamics of the Salto Grande reservoir and recorded the dominance of typical diatoms in eutrophic environments and high densities of cyanobacteria which are predominant with *M. aeruginosa* during algal blooms.

Vidal et al. [70] had detected cyanobacterial blooms, mainly supported by *C. raciborskii* in many eutrophic water bodies of the country, as were the artificial lakes in Canelones, the lake Laguna Blanca in Maldonado, and small dam lakes in Rocha.

RAP-AL [71] also detected that in the eutrophic system of Laguna del Sauce which has a predominance of cyanobacteria throughout the year, there was a marked increase in the frequency and duration of microalgae blooms, particularly of *M. aeruginosa*.

2.3.8 Paraguay

The rapid growth of anthropogenic or human sourced activities has led to the environmental degradation of the Lake Ypacaraí, the most renowned water body in Paraguay [72]. Increasing nutrient concentrations over the last decades have recently resulted in intense cyanobacterial blooms; dominant species in the lake are *C. raciborskii*, *M. aeruginosa*, and *Anabaena* spp.

2.3.9 Venezuela

González and Quirós [73], when they considered trends in 16 reservoirs that have different trophic status, found both linear relationship, between total phosphorus (TP) and total nitrogen (TN) with the phytoplankton biomass, and empirical relationship, between total phosphorus concentration and the nitrate/ammonia quotient which determine the dominance of cyanobacteria. According to the authors' empirical ordination, Venezuelan reservoirs were separated in three groups: group 1 includes reservoirs with low TP (<20 μg/L), while groups 2 and 3 include those reservoirs with moderate to high TP concentrations (>20 μg/L) (**Figure 1**). In group 1, green algae (chlorophyta) are dominant. Group 2 is composed by those reservoirs where nitrate is the dominant inorganic nitrogen compound over ammonia (high nitrate/ammonia quotient), with short water residence time, and the dominant phytoplankton taxa are different from cyanobacteria, while

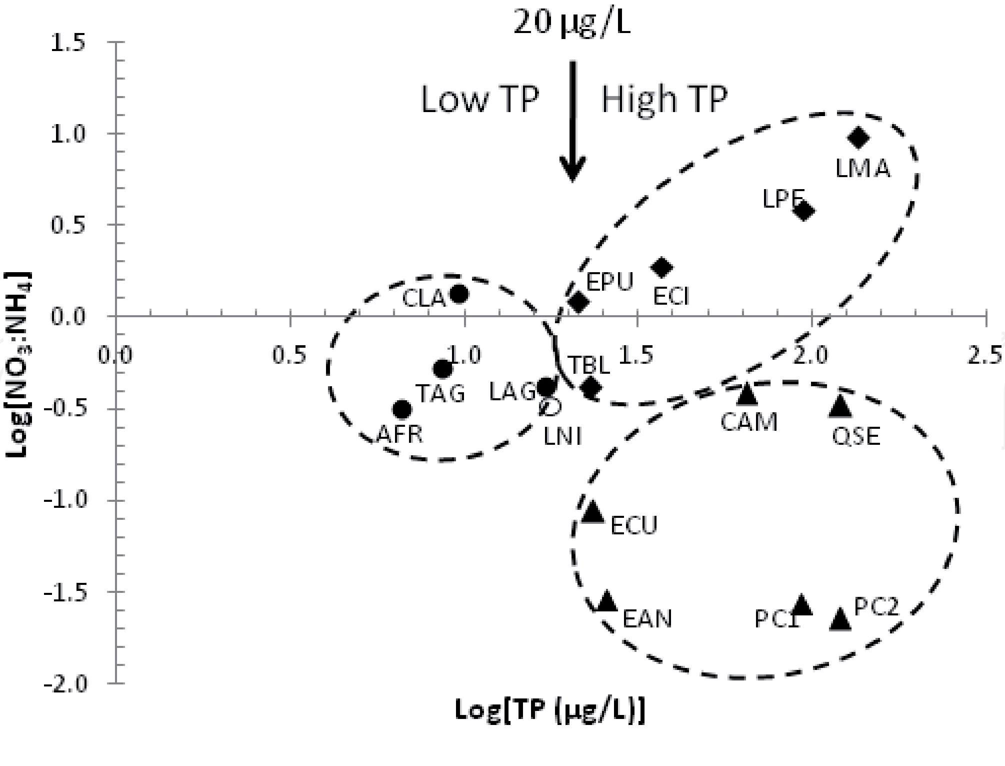

Figure 1.
Relationships between TP and the NO_3:NH_4 ratio in Venezuelan reservoirs: group 1—TP < 20 μg/L—black circles; group 2—TP > 20 μg/L and non-cyanobacteria dominance—black diamonds; and group 3—TP > 20 μg/L and cyanobacteria dominance—black triangles. The Loma de Níquel reservoir is represented by a white circle, because it represented an intermediate situation between groups. Abbreviation of reservoir names: AFR: Agua Fría, TAG: Taguaza, LAG: Lagartijo, CLA: Clavellinos, TBL: Tierra Blanca, LNI: Loma de Níquel, ECI: El Cigarrón, EPU: El Pueblito, ECU: El Cují, EAN: El Andino, LMA: La Mariposa, LPE: La Pereza, CAM: Camatagua, QSE: Quebrada Seca, PC1: Pao-Cachinche—western wing with uptake point and outlet, and PC2: Pao-Cachinche—eastern wing without outlet, modified from González and Quirós [73].

group 3 is composed by those reservoirs with low nitrate/ammonia quotient, high residence time of their waters, and the dominant phytoplankton is cyanobacteria.

3. Discussion

Surveys have shown that more than 40.0% of lakes and reservoirs in the Americas are in eutrophic trophic level [1, 74], and this is a major cause of concern in the developing as well as developed countries.

According to Pratts et al. [75], one of the main problems that affect lakes and reservoirs is the eutrophication. It induces undesirable ecological consequences for the water bodies [1, 3], such as excessive phytoplankton and macrophyte growth. This reduces light penetration and restricts the reoxygenation of water, therefore generating anoxic conditions in the hypolimnetic layers of lakes and reservoirs, as well as high decomposition rates of organic matter that produces a foul smell and makes the water more turbid. Other negative consequences are the proliferation of algal blooms and toxic phytoplankton, fish mortality by suffocation due to drastic oxygen concentration drop during the overturning of waters, proliferation of adequate habitats for vectors of tropical diseases, and loss of biodiversity. These problems are especially important if the water bodies are used for drinking water supply: if these problems are inadequately treated, they may involve serious health risks for human populations.

Regarding the main primary producers in lakes and reservoirs, phytoplankton communities respond quickly to environmental change (as the fertilization of waters with nitrogen and phosphorus) and are indicators of eutrophication [76]. They also show different community dynamics in ecosystems with contrasting trophic states, where high nutrient levels generally favor species belonging to cyanobacteria group.

In most of the studies on lakes and reservoirs in the Americas discussed in the present work, and despite their regional, latitudinal, altitudinal, and climatic differences, eutrophic conditions have led to be dominated by specific species of cyanobacteria. Then, species from the genera *Microcystis*, *Anabaena*, *Planktothrix*, *Oscillatoria*, and *Cylindrospermopsis* seem to be the more widespread dominant organisms under eutrophic conditions in lakes and reservoirs in the American continent. Thus, the cyanobacteria dominance in anthropogenically eutrophic water bodies is an increasing problem that impacts recreation, ecosystem integrity, and human and animal health [77, 78], by deterioration of water quality [79, 80]. The cyanobacterial dominance, on the other side, is under effect of several interacting abiotic (temperature, N/P ratio, other factors) and biotic (intraspecies and interspecific competition in community) factors that usually show different reactions in different environments [81, 82].

According to Reynolds et al. [83] and Bellinger and Sigee [10], cyanobacteria adapts to all types of freshwater environment, including extreme conditions and frequently have the ability to compete with other phytoplankton groups under eutrophic conditions in surface waters. Shapiro [84] and Dokulil and Teubner [81] stated that the ability of "blue-greens" to outcompete other freshwater algae has been attributed to a range of characteristics, including:

- increasing trend in temperature due to climate change;
- optimum growth at high temperatures not preferred by other phytoplankton groups, as in diatoms;
- high survival ability in the water column compared to other species under low light tolerance caused by extensive algal bloom;

- tolerance to low N/P ratios, which is the characteristic for eutrophic lakes—allowing continued growth when N becomes limited;
- depth regulation by buoyancy—avoiding photoinhibition during the early phase of population increase, and allowing algae to obtain inorganic nutrients from the hypolimnion layer when the nutrients decrease in the epilimnion layer from mid- to late-summer;
- resistance to zooplankton grazing by both mechanical and chemical interference;
- tolerance to high pH and low CO_2 concentrations, allowing continued growth of "blue-greens" (but not other algae) at the lake surface during the extensive bloom formation; and
- symbiotic association with aerobic bacteria—bacterial symbionts at the heterocyst surface provide the local reducing atmosphere required for nitrogen fixation that causes inorganic nutrients accumulation in surface waters, poor in nutrients.

The dominance of cyanobacteria in eutrophic water bodies can also be explained according to the main meaningful functional groups proposed by Reynolds [85, 86] and Reynolds et al. [87], based on nutrient availability and stability of the water column. Thus, cyanobacteria can dominate in the phytoplanktonic community in an array of warm, mixed, and fertilized (mainly phosphorus) water bodies, with low transparency values and limitation in C and N [87, 88].

4. Conclusions

In most of the eutrophic lakes and reservoirs in the Americas, as were in various researches on freshwater systems in the temperate regions, there are important increases in level of nutrients, mainly in level of phosphorus, which leads to excessive phytoplankton biomass firstly in a predominance of cyanobacteria. Likewise, in most cases, the dominant cyanobacterial species belong to the genera *Microcystis*, *Anabaena*, *Planktothrix*, *Oscillatoria*, and *Cylindrospermopsis*, which have toxic strains that can cause potential health problems, particularly if the water bodies are used for drinking water supply.

Acknowledgements

Authors would like to thank the Inter American Network of Academic of Sciences (IANAS) for all its help in gathering the information.

We also thank Dr. Diego Rodríguez and an anonymous reviewer for improving the language translation.

Conflict of interest

The authors declare no conflict of interest.

Author details

Ernesto J. González[1]* and Gabriel Roldán[2]

1 Central University of Venezuela, Institute of Experimental Biology, Caracas, Venezuela

2 Colombian Academy of Exact, Physical and Natural Sciences, Medellín, Colombia

*Address all correspondence to: ernesto.gonzalez@ciens.ucv.ve

References

[1] Ansari AA, Gill SS, Khan FA. Eutrophication: Threat to aquatic ecosystems. In: Ansari AA, Gill SS, Lanza GR, Rast W, editors. Eutrophication: Causes, consequences and control. Dordrecht: Springer; 2011. pp. 143-170. DOI: 10.1007/978-90-481-9625-8_7

[2] Hutchinson GE. Eutrophication. American Scientist. 1973;**61**:269-279

[3] Ryding SO, Rast W. The Control of Eutrophication of Lakes and Reservoirs. Paris: Unesco, The Parthenon Publishing Group; 1989. p. 314

[4] González EJ, Challar G, Bicudo DC, Silva e Souza AT, Luzia AP, Sidagis Galli C, et al. Eutrophication in South America: Synthesis. In: Tundisi JG, Matsumura-Tundisi T, Sidagis Galli C, editors. Eutrofização na América do Sul: Causas, Conseqüências e Tecnologias de Gerenciamento e Controle. São Carlos: Instituto Internacional de Ecologia, Instituto Internacional de Ecologia e Gerenciamento Ambiental, Academia Brasileira de Ciências, Conselho Nacional de Desenvolvimento Científico e Tecnológico, InterAcademy Panel on International Issues, InterAmerican Network of Academies of Sciences; 2006. pp. 529-531

[5] Schindler DW, Hecky RE, Findlay DL, Stainton MP, Parker BR, Paterson MJ, et al. Eutrophication of lakes cannot be controlled by reducing nitrogen input: Results of a 37-year whole-ecosystem experiment. Proceedings of the National Academy of Sciences of the United States of America. 2008;**105**:11254-11258. DOI: 10.1073/pnas.0805108105

[6] Salameh E, Harahsheh S. Eutrophication processes in arid climates. In: Ansari AA, Gill SS, Lanza GR, Rast W, editors. Eutrophication: Causes, Consequences and Control. Dordrecht: Springer; 2011. pp. 69-90. DOI: 10.1007/978-90-481-9625-8_3

[7] Wetzel RG. Limnology: Lake and River Ecosystems. 3rd ed. San Diego: Academic Press; 2001. p. 1006

[8] Vázquez Silva G, Castro Mejía G, González Mora I, Pérez Rodríguez R, Castro BT. Bioindicadores como herramientas para determinar la calidad del agua. ContactoS. 2006;**60**:41-48

[9] Quirós R. Cianobacterias en lagos y embalses de Argentina: Década de los 80. Serie de documentos de trabajo del área de Sistemas de Producción Acuática. Documento No 2. Buenos Aires: Departamento de Producción, Facultad de Agronomía, Universidad de Buenos Aires; 2004. p. 23

[10] Bellinger EG, Sigee DC. Freshwater Algae: Identification and Use as Bioindicators. Chichester: Wiley-Blackwell; 2010. p. 271

[11] Thunmark S. Zur Soziologie des susswasserplanktons: Eine methodologisch-okologische Studie. Folia Limnologica Scandinavia. 1945;**3**:1-66

[12] Nygaard G. Hydrobiological studies on some Danish ponds and lakes, II: The quotient hypothesis and some little known or new phytoplankton organisms. Kunglige Danske Vidensk, Selskab. 1949;**7**:1-242

[13] Stockner J. Paleolimnology as a means of assessing eutrophication. Verhandlungen des Internationalen Verein Limnologie. 1972;**18**:1018-1030

[14] Rawson DS. Algal indicators of trophic lakes types. Limnology and Oceanography. 1956;**1**:18-25

[15] Schindler DW. Eutrophication and recovery in experimental lakes: Implications for lake management. Science. 1974;**184**:897-899

[16] Environmental Protection Agency (EPA). Summary analysis of the North American (U.S. portion) OECD Eutrophication Project: Nutrient loading—Lake response relationships and trophic state indices. In: Ecological Research Series EPA-600/3-78-008. Corvallis: Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency; 1978. p. 455

[17] Alcócer DJ, Lugo A. The urban lakes of Mexico City (Lago Viejo de Chapultepec). Lakeline. 1995;**15**:14-31

[18] Bravo-Inclán LA, Saldaña-Fabela MP, Sánchez-Chávez JJ. Long-term eutrophication diagnosis of a high altitude body of water, Zimapan Reservoir, Mexico. Water Science and Technology. 2018;**57**:1843-1849

[19] Díaz-Pardo E, Vázquez G, López-López E. The phytoplankton community as a bioindicator of health conditions of Atezca Lake, México. Aquatic Ecosystem Health and Management. 1998;**1**:257-266

[20] López-López E, Sedeño-Díaz JE, Ortiz-Ordóñez E, Rosas Colmenárez M, Abeja Pineda O. Health condition assessment in Lake Xochimilco (Mexico). Romanian Journal of Biology-Zoology. 2010;**55**:69-80

[21] Oliva Martínez MG, Rodríguez Rocha A, Lugo Vázquez A, Sánchez Rodríguez MR. Composición y dinámica del fitoplancton en un lago urbano hipertrófico. Hidrobiologica. 2008;**18**:1-13

[22] Quiroz Castelán H, Mora Zúñiga LM, Molina Astudillo I, García RJ. Variación de los organismos fitoplanctónicos y la calidad del agua en el Lago de Chapala, Jalisco, Mexico. Acta Universitaria. 2004;**14**:47-58

[23] de Anda J, Shear H. Nutrients and Eutrophication in Lake Chapala. In: Hansen AM, van Afferden M, editors. The Lerma-Chapala Watershed. Boston, MA: Springer; 2001. pp. 183-198

[24] Tomasini-Ortiz AC, Moellez-Chávez G, Sánchez Chávez JJ, Bravo Inclán LA. Cianobacterias y cianotoxinas en el Lago de Pátzcuaro, Michoacán, México. Revista AIDIS de Ingeniería y Ciencias Ambientales: Investigación, Desarrollo y Práctica. 2012;**5**:93-101

[25] Figueroa-Sánchez MA, Sarma N, Sarma SSS. Zooplankton community structure in the presence of low levels of cyanotoxins: A case study in a high altitude tropical reservoir (Valle de Bravo, Mexico). Journal of Limnology. 2014;**73**:157-176. DOI: 10.4081/jlimnol.2014.784

[26] Brocard G, Bettini A, Pfeifer HR, Adatte T, Morán-Ical S, Gonneau C, et al. Chronology of eutrophication and chromium contamination in Lake Chichój, Guatemala. Revista Guatemalteca de Ciencias de la Tierra. 2016;**3**:20-43

[27] Basterrechea M. Enfoque global del lago de Amatitlán y su cuenca. In: Estudios Recientes Sobre la Contaminación del Lago de AMATITLÁN. Ciudad de Guatemala: Centro Agronómico Tropical de Investigación y Enseñanza (CATIE). 1987. pp. 9-31

[28] Rejmánková E, Komárek J, Dix M, Komárková J, Girón N. Cyanobacterial blooms in Lake Atitlán, Guatemala. Limnologica. 2010;**41**:296-302. DOI: 10.1016/j.limno.2010.12.003

[29] Trate TM. Nutrient load analysis of Lake Yojoa, Honduras [thesis].

Massachuset: Massachuset Institute of Technology; 2006

[30] Hernández Oviedo AI, Marín M, Henríquez L, Gray M. Variación espacial y temporal de la diversidad y abundancia del fitoplancton del Lago de Yojoa en un año hidrológico 2014-2015. Revista de Ciencia y Tecnología. 2016;**19**:40-77

[31] Espinoza-Navarrete JJ, Amaya Monterrosa OA, Rivera Torres WE, Ruíz Rodríguez GA, Escobar Muñoz JD. Intensa proliferación de cianobacterias en el Lago de Coatepeque, Santa Ana; ensayos de toxinas paralizantes y organismos causantes. Bioma. 2013;**2**:43-46

[32] Universidad Centroamericana "José Simeón Cañas" (UCA). Monitorización de Variables Físico-Químicas en Humedales RAMSAR de El Salvador. San Salvador: Universidad Centroamericana; 2013

[33] Hooker E, Hernandez S. Phytoplankton biomass in Lake Xolotlán (Managua): Its seasonal and horizontal distribution. Hydrobiological Bulletin. 1991;**25**:125-131

[34] Erikson R. Algal respiration and the regulation of phytoplankton biomass in a polymictic tropical lake (Lake Xolotlán, Nicaragua). Hydrobiologia. 1999;**382**:17-25

[35] Erikson R, Pum M, Vammen K, Cruz A, Ruíz M, Zamora H. Nutrient availability and the stability of phytoplankton biomass and production in Lake Xolotlán (Lake Managua, Nicaragua). Limnologica. 1997;**27**:157-164

[36] Vammen K, Pitty Tercero J, Montenegro Guillén S. Evaluación del proceso de eutroficación del Lago Cocibolca, Nicaragua y sus causas en la Cuenca. In: Tundisi JG, Matsumura-Tundisi T, Sidagis Galli C, editors. Eutrofização na América do Sul: Causas, Conseqüências e Tecnologias de Gerenciamento e Controle. São Carlos: Instituto Internacional de Ecologia, Instituto Internacional de Ecologia e Gerenciamento Ambiental, Academia Brasileira de Ciências, Conselho Nacional de Desenvolvimento Científico e Tecnológico, InterAcademy Panel on International Issues, InterAmerican Network of Academies of Sciences; 2006. pp. 35-58

[37] Hernández González SE, Ahlgreen E, Ahlgreen G. Fluctuaciones temporales en el fitoplancton y contenido de microcistinas intracelulares en cuatro lagos Nicaragüenses. Revista Científica Agua y Conocimiento. 2018;**3**:1-9

[38] Umaña G, Haberyan KA, Horn SP. Limnology in Costa Rica. In: Wetzel RG, Gopal B, editors. Limnology in Developing Countries 2. New Delhi: International Association of Theoretical and Applied Limnology (SIL), International Scientific Publications; 1999. pp. 33-62

[39] Jones JR, Lohman K, Umaña G. Water chemistry and trophic state of eight in Costa Rica. Verhandlungen des Internationalen Verein Limnologie. 1993;**25**:899-905

[40] Autoridad del Canal de Panamá, Universidad de Panamá. Diatomeas del Canal de Panamá: Bioindicadores y otros Estudios Pioneros. Panamá: Facultad de Ciencias Exactas, Matemáticas y Tecnología, Departamento de Botánica y Centro de Ciencias del Mar y Limnología, Departamento de Ambiente, Agua y Energía, División de Agua, Unidad de Calidad de Agua; 2012. p. 253

[41] Gómez Luna CLM, Álamo Díaz B, Rodríguez Tito JC. Riesgo de contaminación con cianobacterias en tres embalses de Santiago de Cuba. Medisan. 2010;**14**:175-183

[42] Pantoja AF. Dinámica fisicoquímica y fitoplanctónica del embalse Guajataca, Puerto Rico [thesis]. Mayagüez: University of Puerto Rico; 2006

[43] Roldán G. Limnología y eutrofización de embalses en Colombia. In: Fernández-Cirelli A, Chalar-Marquisá G, editors. El agua en Iberoamérica. De la Limnología a la Gestión en Sudamérica. Buenos Aires: Programa Iberoamericano de Ciencia y Tecnología para el Desarrollo, CYTED XVII. Aprovechamiento y Gestión de Recursos Hídricos, Centro de Estudios Transdisciplinarios del Agua, Facultad de Ciencias Veterinarias de la Universidad de Buenos Aires; 2002. pp. 107-122

[44] Roldán G, Ramírez JJ. Fundamentos de Limnología Neotropical. 2nd ed. Medellín: Editorial Universidad de Antioquia; 2008. p. 440

[45] Saelens P. Ecological functioning of a eutrophic, high-altitude shallow lake in Ecuador, Laguna Yahuarcocha [thesis]. K.U. Leuven: Kulak; 2015

[46] Fonturbel FE, Castaño-Villa GJ. Relationships between nutrient enrichment and the phytoplankton community at an Andean oligotrophic lake: A multivariate assessment. Ecología Aplicada. 2011;**10**:75-81

[47] Lazzaro X, Rybarczyk H, Meziane T, Hubas C, Lamy D, Point D, et al. Accelerated eutrophication in Lake Titicaca: Historical evolution, mechanisms, monitoring, and observatory approach. In: Proceedings of the Coloquio internacional sobre la contaminación actual e histórica en los ecosistemas acuáticos andinos; 3-5 May 2016. La Paz: Universidad Mayor de San Andrés; 2016. pp. 23-24

[48] Tundisi JG. Management of reservoirs in Brazil. In: Jorgensen SE, Vollenweider RA, editors. Guidelines of Lake Management. Vol. 1. Principles of Lake Management. Shiga: International Lake Environment Committee (ILEC), United Nations Environment Programme (UNEP); 1988. pp. 155-169

[49] Huszar VLM, Silva LHS, Marinho M, Domingos P, Sant'Anna CL. Cyanoprokaryote assemblages in eight productive tropical Brazilian waters. Hydrobiologia. 2000;**424**:67-77

[50] Dantas EW, Moura AN, Bittencourt-Oliveira MC, Arruda Neto JDT, Cavalcanti ADC. Temporal variation of the phytoplankton community at short sampling intervals in the Mundau reservoir, Northeastern Brazil. Acta Botânica Brasílica. 2008;**22**:970-982. DOI: 10.1590/S0102-33062008000400008

[51] Nardini MJ, De Souza Nogueira I. O processo antrópico de um lago artificial da eutrofização e florações e o desenvolvimento de algas azuis em Goiânia. Estudos. 2008;**35**:23-52

[52] Chellappa NT, Camara FRA, Rocha O. Phytoplankton community: Indicator of water quality in the Armando Ribeiro Gonçalves Reservoir and Pataxó Channel, Rio Grande do Norte, Brazil. Brazilian Journal of Biology. 2009;**69**:241-251

[53] Barbosa FAR, García FC, Marques MMGSM, Nascimento FA. Nitrogen and phosphorus balance in a eutrophic reservoir in Minas Gerais: A first approach. Brazilian Journal of Biology. 1998;**58**:233-239

[54] García FC, Barbosa FAR, Braz S, Petrucio MM, Faria B. Water quality of an urban reservoir subjected to periodic applications of copper sulphate: The case of Ibirité reservoir, Southeast Brazil. Acta Limnologica Brasiliensia. 2009;**21**:235-243

[55] Abe DS, Tundisi JG, Matsumura-Tundisi T, Tundisi JEM, Sidagis Galli C, Teixeira-Silva V, et al.

Monitoramento da qualidade ecológica das águas interiores superficiais e do potencial trófico em escala continental no Brasil com o uso de tecnologias inovadoras. In: Tundisi JG, Matsumura Tundisi T, Sidagis Galli C, editors. Eutrofização na América do Sul: Causas, Conseqüências e Tecnologias de Gerenciamento e Controle. São Carlos: Instituto Internacional de Ecologia, Instituto Internacional de Ecologia e Gerenciamento Ambiental, Academia Brasileira de Ciências, Conselho Nacional de Desenvolvimento Científico e Tecnológico, InterAcademy Panel on International Issues, InterAmerican Network of Academies of Sciences; 2006. pp. 225-239

[56] Sidagis Galli C, Abe DS. Disponibilidade, poluição e eutrofização das águas. In: Scheuenstuhl MC, editor. Águas do Brasil: Análises Estratégicas. São Paulo: Instituto de Botânica; 2010. pp. 165-174

[57] Almanza-Marroquín V, Figueroa R, Parra O, Fernández X, Baeza C, Yáñez J, et al. Bases limnológicas para la gestión de los lagos urbanos de Concepción, Chile. Latin American Journal of Aquatic Research. 2016;**44**:313-326

[58] Campos V, Muñoz D, Straube M, Lisperguer S, Weckesser J. Péptidos tóxicos y no tóxicos de cianobacterias en cuerpos de agua dulce de La V Región, Chile. Boletín Micológico. 2007;**22**:95-100

[59] Mühlhauser HA, Vila I. Eutrofización, impacto en un ecosistema acuático montañoso. Archivos de Biología y Medicina Experimentales. 1987;**20**:117-124

[60] Parra O. La eutroficación de la Laguna Grande de San Pedro, Concepción, Chile: Un caso de estudio. Ambiente y Desarrollo. 1989;**5**:117-136

[61] Parra O, Valdovinos C, Urrutia R, Cisternas M, Habit E, Mardones M. Caracterización y tendencias tróficas de cinco lagos costeros de Chile Central. Limnetica. 2003;**22**:51-83

[62] Quirós R. Empirical relationships between nutrients, phyto and zooplankton and relative fish biomass in lakes and reservoirs of Argentina. Verhandlungen des Internationalen Verein Limnologie. 1991;**24**:1198-1206

[63] Quirós R. La eutrofización de las aguas continentales en Argentina. In: Fernández-Cirelli A, editor. El Agua en Iberoamérica: Acuíferos, lagos y embalses. Buenos Aires: Ciencia y Tecnología para el Desarrollo (CYTED), Subprograma XVII, Aprovechamiento de Recursos Hídricos; 2000. pp. 43-47

[64] Quirós R, Boveri MB, Petracchi CA, Rennella AM, Rosso JJ, Sosnovsky A, et al. Los efectos de la agriculturización del humedal pampeano sobre la eutrofización de sus lagunas. In: Tundisi JG, Matsumura-Tundisi T, Sidagis Galli C, editors. Eutrofização na América do Sul: Causas, Conseqüências e Tecnologias de Gerenciamento e Controle. São Carlos: Instituto Internacional de Ecologia, Instituto Internacional de Ecologia e Gerenciamento Ambiental, Academia Brasileira de Ciências, Conselho Nacional de Desenvolvimento Científico e Tecnológico, InterAcademy Panel on International Issues, InterAmerican Network of Academies of Sciences; 2006. pp. 1-16

[65] Chalar G, Conde D. Antecedentes y estado actual del conocimiento científico de los embalses del Uruguay. In: Fernández-Cirelli A, editor. El Agua en Iberoamérica: Acuíferos, Lagos y Embalses. Buenos Aires: Ciencia y Tecnología para el Desarrollo (CYTED). Subprograma XVII. Aprovechamiento de Recursos Hídricos; 2000. pp. 145-147

[66] De León L, Chalar G. Abundancia y diversidad del fitoplancton en el Embalse de Salto Grande (Argentina-Uruguay). Ciclo estacional y

distribución espacial. Limnetica. 2003;**22**:103-113

[67] Chalar G, De León L, Brugnoli E, Clemente J, Paradiso M. Antecedentes y nuevos aportes al conocimiento de la estructura y dinámica del embalse Salto Grande. In: Fernández-Cirelli A, Chalar-Marquisá G, editors. El agua en Iberoamérica. De la Limnología a la Gestión en Sudamérica. Buenos Aires: Programa Iberoamericano de Ciencia y Tecnología para el Desarrollo, CYTED XVII. Aprovechamiento y Gestión de Recursos Hídricos, Centro de Estudios Transdisciplinarios del Agua, Facultad de Ciencias Veterinarias de la Universidad de Buenos Aires; 2002. pp. 123-141

[68] Chalar G. Dinámica de la eutrofización a diferentes escalas temporales: Embalse Salto Grande (Argentina-Uruguay). In: Tundisi JG, Matsumura-Tundisi T, Sidagis Galli C, editors. Eutrofização na América do Sul: Causas, Conseqüências e Tecnologias de Gerenciamento e Controle. São Carlos: Instituto Internacional de Ecologia, Instituto Internacional de Ecologia e Gerenciamento Ambiental, Academia Brasileira de Ciências, Conselho Nacional de Desenvolvimento Científico e Tecnológico, InterAcademy Panel on International Issues, InterAmerican Network of Academies of Sciences; 2006. pp. 87-101

[69] Chalar G. The use of phytoplankton patterns of diversity for algal bloom management. Limnologica. 2009;**39**:200-208

[70] Vidal L, Kruk C, Aubriot L, Piccini C, Fabre A, Bonilla S. Floraciones de la especie *Cylindrospermopsis raciborskii* en Uruguay. In: Bonilla S, editor. Cianobacterias Planctónicas del Uruguay. Manual para la Identificación y Medidas de Gestión. Montevideo: Programa Hidrológico Internacional de la UNESCO para América Latina y el Caribe; 2009. pp. 81-82

[71] RAP-AL Uruguay. Contaminación y Eutrofización del Agua. Impactos del Modelo de Agricultura Industrial. Red de Acción en Plaguicidas y sus Alternativas para América Latina (RAPAL): Montevideo; 2010. p. 36

[72] López Moreira GA, Hinegk L, Salvadore A, Zolezzi G, Hölker F, Monte Domecq RA, et al. Eutrophication, research and management history of the shallow Ypacaraí Lake (Paraguay). Sustainability. 2018;**10**:1-32. DOI: 10.3390/su10072426

[73] González EJ, Quirós R. Eutrophication of reservoirs in Venezuela: Relationships between nitrogen, phosphorus and phytoplankton biomass. Oecologia Australis. 2011;**15**:458-475. DOI: 10.4257/oeco.2011.1503.03

[74] International Lake Environment Committee (ILEC). Data book of world lake environments. A survey of the state of world lakes. 3. The Americas. Kusatsu: International Lake Environment Committee and United Nations Environment Programme; 1995. p. 868

[75] Pratts J, Morales-Baquero R, Dolz J, Armengol J. Aportaciones de la Limnología a la gestión de embalses. Ingeniería del Agua. 2014;**18**:83-97. DOI: 10.4995/ia.2014.3145

[76] Baho DL, Drakare S, Johnson RK, Allen CR, Angeler DG. Is the impact of eutrophication on phytoplankton diversity dependent on volume/ecosystem size? Journal of Limnology. 2017;**76**:199-210. DOI: 10.4081/jlimnol.2016.1562

[77] Downing JA, Watson SB, McCauley E. Predicting cyanobacteria dominance in lakes. Canadian Journal of Fisheries and Aquatic Sciences. 2001;**58**:1905-1908. DOI: 10.1139/cjfas-58-10-1905

[78] Fernández C, Estrada V, Parodi ER. Factors triggering cyanobacteria dominance and succession during blooms in a hypereutrophic drinking water supply reservoir. Water, Air, and Soil Pollution. 2015;**226**:73-85. DOI: 10.1007/s11270-014-2290-5

[79] Pizzolon L. Importancia de las cianobacterias como factor de toxicidad en las aguas continentales. Interciencia. 1996;**21**:239-245

[80] Vasconcelos V. Eutrophication, toxic cyanobacteria and cyanotoxins: When ecosystems cry for help. Limnetica. 2006;**25**:425-432

[81] Dokulil MT, Teubner K. Cyanobacteria dominance in lakes. Hydrobiologia. 2000;**438**:1-12

[82] Kim S, Chung S, Park H, Cho Y, Lee H. Analysis of environmental factors associated with cyanobacterial dominance after River Weir installation. Water. 2019;**11**:1-24. DOI: 10.3390/w11061163

[83] Reynolds CS, Oliver RL, Walsby AE. Cyanobacterial dominance: The role of buoyancy regulation in dynamic lake environments. New Zealand Journal of Marine and Freshwater Research. 1987;**21**:379-390. DOI: 10.1080/00288330.1987.9516234

[84] Shapiro J. Current beliefs regarding dominance by blue-greens: The case for the importance of CO_2 and pH. Verhandlungen des Internationalen Verein Limnologie. 1990;**24**:38-54

[85] Reynolds CS. The plant life of the pelagic. Verhandlungen des Internationalen Verein Limnologie. 1996;**26**:97-113

[86] Reynolds CS. The Ecology of Phytoplankton. 2nd ed. Cambridge: Cambridge University Press; 2006. p. 535

[87] Reynolds CS, Huszar VLM, Kruk C, Naselli-Flores L, Melo S. Towards a functional classification of the freshwater phytoplankton. Journal of Plankton Research. 2002;**24**:417-428

[88] Brasil J, Huszar VML. O papel dos traços funcionais na ecología do fitoplancton continental. Oecologia Australis. 2011;**15**:799-834. DOI: 10.4257/oeco.2011.1504.04