Brazilian Journal of Biology
ISSN 1519-6984 (Print)
ISSN 1678-4375 (Online)

https://doi.org/10.1590/1519-6984.182599
Original Article

Phytoplankton scenario and microcystin in water during extreme drought in semiarid tropical water supplies, Northeastern Brazil

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Received: July 11, 2017 – Accepted: April 5, 2018 – Distributed: February 28, 2020
(With 6 figures)

Abstract

The objective of this study was to characterize the limnological, microystin and phytoplankton community of five tropical eutrophic reservoirs located in the Brazilian northeastern semi-arid region, used for domestic use at the time of extreme drought and reduction of water volume. The study was conducted in July and August 2015, and an integrated sample of the water column was collected at three points near the dam in each reservoir. Analysis of limnological parameters, identification and quantification of phytoplankton, with emphasis on cyanobacteria were performed, as well as detection of microcystin by means of immunoassay (ELISA). The reservoirs presented ~ 90% water volume reduction. High turbidity and concentrations of nitrogen and phosphorus, as well as high cyanobacterial densities, revealed an increase in the eutrophic state for hypereutrophy. The total biovolume of phytoplankton and cyanobacterial density is high, plus an average increase in relation to previous studies of 350% and 150%, respectively. The density of cyanobacteria and microcystin concentration presented values above acceptable levels for drinking water according to Brazilian legislation. A phytoplankton community was represented by 17 functional groups, including potentially toxic cyanobacteria species such as *Planktothrix agardhii* (**S1**), *Microcystis aeruginosa* (**M**), *Anabaena planktonica* e *Anabaena spp*. (**H1**), *Cylindrospermopsis raciborskii* (**Sn**). Our results confirm that conditions of extreme drought and reduction of the volume of the reservoirs influence the composition, biovolume of phytoplankton and water quality, but not the increase of total microcystin in the analysed, although above 1µg^{-1} registered a significant decrease of water quality in used for human consumption.

Keywords: cyanobacteria, functional groups, reservoirs, heavy metals, eutrofication.

Cenário de fitoplanctônico e microcistinas na água durante extrema estiagem em reservatórios tropical semiárido de abastecimento de água, nordeste do Brasil

Resumo

O objetivo deste trabalho foi caracterizar a comunidade limnológica, microistalina e fitoplanctônica de cinco reservatórios eutróficos tropicais localizados no semi-árido nordestino brasileiro, utilizados para uso doméstico no período de seca extrema e redução do volume de água. O estudo foi realizado em julho e agosto de 2015, e uma amostra integrada da coluna de água foi coletada em três pontos próximos à barragem em cada reservatório. Análises de parâmetros limnológicos, identificação e quantificação do fitoplâncton, com ênfase em cianobactérias, foram realizadas, assim como a detecção de microcistina por meio de imunoensaio (ELISA). Os reservatórios apresentaram ~ 90% de redução do volume de água. A alta turbidez e as concentrações de nitrogênio e fósforo, bem como as altas densidades de cianobactérias, revelaram um aumento no estado eutrófico da hipereutrofia. O biovolume total de fitoplâncton e densidade de cianobactérias é alto, além de um aumento médio em relação a estudos anteriores de 350% e 150%, respectivamente. A densidade de cianobactérias e a concentração de microcistina apresentaram valores acima dos níveis aceitáveis para água de consumo, de acordo com a legislação brasileira. Uma comunidade fitoplanctônica foi representada por 17 grupos funcionais, incluindo espécies de cianobactérias potencialmente tóxicas, como *Planktothrix agardhii* (**S1**), *Microcystis aeruginosa* (**M**), *Anabaena planktonica* e *Anabaena spp*. (**H1**), *Cylindrospermopsis raciborskii* (**Sn**). Nossos resultados confirmam que condições de seca extrema e redução do volume dos reservatórios influenciam a composição, o biovolume de fitoplâncton e a qualidade da água, mas não o aumento do total de microcistina no analisado, embora acima de 1μg^{-1} tenha registrado uma diminuição significativa da qualidade da água usado para consumo humano.

Palavras-chave: cianobactérias, grupos funcionais, reservatório, metais pesados, eutrofização.

1. Introduction

The Brazilian semi-arid region is characterized by a peculiar hydrological regime, prolonged droughts, alternated by short periods of rain, with low annual volume (~400mm), high irradiation and evaporation rate, long residence time (Arfi, 2003; Burford and O'Donohue, 2006; Romo et al., 2013). Studies on the ecology of shallow tropical lakes in the semi-arid region have clearly shown that such climatic conditions favor the increase of turbidity, nutrient concentration and increase of algal biomass, which associated with anthropic pollution causes a decrease in water quality (Naselli-Flores, 2003) and the establishment of a permanent scenario of eutrophication in reservoirs, which may promote a dominance of bloom-forming potentially toxic cyanobacteria (Chorus and Bartram, 1999; Romo et al., 2013). Periods of seasonal drought (predictable in terms of time and duration), or supra-seasonal (not predictable as to their duration and time), require different responses from the biota of an aquatic ecosystem. In the first case, the biotic beings present adaptations to seasonal drought conditions, whereas in the second situation the biota finds difficulties of adaptation and overcoming this extreme condition (Lake, 2003; Romo et al., 2013).

The description and analysis of the limnological scenario, as well as the availability of phytoplankton nutrients, such as phosphorus and nitrogen, and attributes contribute to a better environmental ecological diagnosis of the ecosystem, besides identifying the conditions that determine water quality (Pinto and Becker, 2014). From this knowledge it is possible to draw a profile of an optimal environment for the blooms in an aquatic environment.

The phytoplankton community becomes a worrying biological variable due to the excessive growth caused by the phenomenon of eutrophication, which is a factor of loss of water quality in reservoirs, as is the case in the Brazilian Northeast (Eskinazi-Sant'Anna et al., 2006; Costa et al., 2006a, b, 2009; Vasconcelos et al., 2011). It is known that this phenomenon causes a number of negative impacts on the dynamics of aquatic ecosystems, for example, toxic blooms of cyanobacteria, that constitute the main responsible for this blooming because they present several ecological advantages over other phytoplankton groups (Chorus and Bartram, 1999). Several species of cyanobacteria indicate a potentially toxic risk to aquatic and terrestrial organisms, including human health (Van Apeldoorn et al., 2007).

Studies on the dynamics of phytoplankton in tropical regions (Calijuri et al., 2002; Crossetti and Bicudo, 2008; Soares, 2009; Soares et al., 2012; Fonseca and Bicudo, 2008), especially in the northeastern Brazilian semi-arid region (Huszar et al., 2000; Bouvy et al., 2000; Bittencourt-Oliveira et al., 2010; Bouvy et al., 2003; Dantas et al., 2011, 2012; Barbosa et al., 2012; Costa et al., 2009), report relationships among local climatic conditions and eutrophication on favoring the dominance of cyanobacteria and decreasing water quality. Further evidence of the influence of the hydrological regime of semi-arid region on the composition and dominance of cyanobacteria is shown by Medeiros et al. (2015), Braga et al. (2015) and Costa et al. (2016). Other phytoplankton studies carried out in eutrophic reservoirs in the Brazilian Northeast, reveal the occurrence of potentially toxic species bloom-forming such as *Cylindrospermopsis raciborskii, Microcystis aeruginosa* and *Planktothrix agardhii* (Medeiros et al., 2015; Costa et al., 2006a, b, 2009) and the presence of their toxins (microcystins and saxitoxins) in these environments is reported by Fonseca et al. (2015) and Costa et al. (2006a). Such studies are important because they contribute to establish conditions and make predictions of future scenarios of the phytoplankton behavior in regions affected drastically by prolonged droughts, contributing to the management of water for the population. Functional attributes allow greater generalization, where each group corresponds to species that relate to certain ecosystem functions, because grouping them is based on morphological, physiological and ecological equivalences (Reynolds et al., 2002). In this way, a study will be adopted as a classification parameter to complement the phylogenetic approach.

In this study we want to design the scenario of the limnological conditions and the phytoplankton community of five eutrophic tropical reservoirs of the Brazilian northeastern semiarid used for domestic supply in an instant of extreme reduction of water level caused by a severe dry season. We aimed to analyze the changes in composition, biomass and functional groups of phytoplankton, with emphasis on blooming cyanobacteria, and the presence and degree of toxicity of microcystin in an instant of drastic reduction of volume of water caused by severe and prolonged drought. It is expected to find a marked increase in cyanobacterial biomass and microcystin levels, associated with decreased water quality, in comparison with other studies.

2. Material and Methods

2.1. Study area

The study was conducted in five reservoirs, all located in the Brazilian semi-arid region and intensely submitted to periodic droughts, being located in the Piancó-Piranhas-Açu Hydrographic Basin (Figure 1). The Barragem Armando Ribeiro Gonçalves - ARG (5° 40'21.4" S 36° 53'05.0" W); Boqueirão – BQ (6° 41'43.0" S 36° 37'44.4" W), Gargalheiras - GAR (6° 25'30.8" S 36° 36'08.2" W), Açude Itans - IT (6º 29'26.6" S 37° 03'57.1" W) and Passagem das

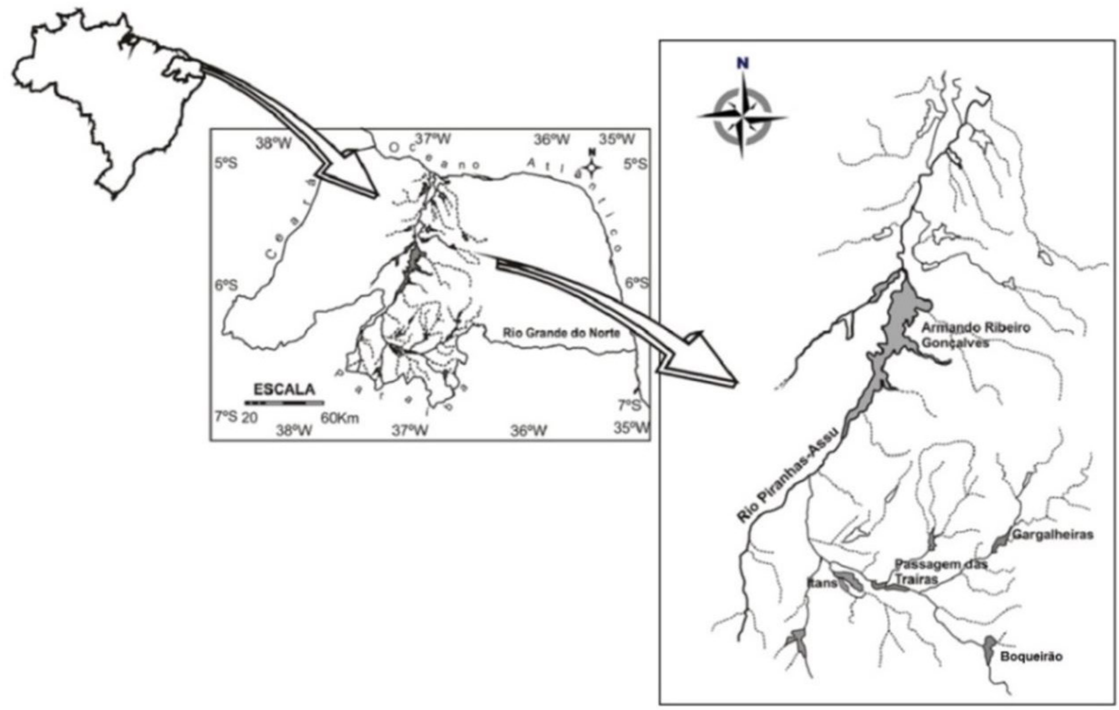

Figure 1. Location and area of study. Barragem Armando Ribeiro Gonçalves; Gargalheiras; Açude Itans; Passagem das Traíras; Açude Boqueirão. (Rio Grande do Norte, Northeast Brazil) Costa et al. (2009).

Traíras - PT (6° 30'52.5" S 36° 56'32.9" W). IT, BQ, PT and GAR are medium-sized reservoirs, whereas ARG is large in size, although in the sample period all were presented as small and shallow operating below dead volume, except for ARG. All of them are used for domestic and industrial supplies and recreational activities, fish farming and fruit irrigation. As a consequence, they are impacted by intense diffuse loads of nutrients, resulting from multiple-use wastes, intense bare soil erosion, and urban and agricultural runoff, resulting in alternation of eutrophic to hypereutrophic periods (Costa et al., 2009).

2.2. Limnetical sampling and analysis

The samples were collected in July and August 2015 at the height of a severe prolonged and progressive drought for the last five years, where the reservoirs were with levels of water well below the dead volume. Three of them (GAR, IT and PT) presented less than 1% of their volumetric capacity, while ARG and BQ with 20% or less. Water samples were obtained with a bottle of Van Dorn in the limnetic and central region (near the dam) at three equidistant points. At each point of the limnetic region of the reservoirs with depths greater than 3 meters (ARG and BOQ), sub samples of 5 liters were collected at each depth of the water column (subsurface, middle and bottom) and integrated in a bucket, totaling 15 liters. Later, in the same way, the samples of the water column of each point of the limnetic region were again integrated, totaling 45 liters, in which it was used for analyzes of nutrients, metals, phytoplankton and microcystins. In the IT and PT reservoirs with depth of approximately 3m, samples were integrated only from the subsurface and bottom of the column, totaling 30 liters. In the GAR reservoir, which had depth of approximately 1 meter, the integrated sample was obtained from three subsurface points, totaling 15 liters. Data from the monthly precipitation in the five environments were obtained by the Rio Grande do Norte Agricultural Research and Development Company (EMPARN, 2016). Monthly precipitation data from the last five years, including the period of this study, were considered.

In each reservoir the water transparency was estimated by the depth measurement of the Secchi disk. Vertical profiles of turbidity, temperature, hydrogen ionic potential (pH), dissolved oxygen and conductivity were obtained through the Horiba multiparameter probe. The concentrations of nitrogen and total phosphorus in the water were estimated by spectrophotometry according to the recommendations of APHA (2000). The determination of the total phosphorus was done by the Ascorbic Acid Method after digestion of the samples in potassium persulfate and the total nitrogen by the oxidation of the nitrogenous compounds to nitrate, according to Valderrama (1981). Concentrations of heavy metals (Arsenic, Barium, Cadmium, Lead, Copper, Chromium, Mercury and Nickel) were detected in the water and sediment by internal procedure PLIE01R00, according to Official USEPA 6010 standard, carried out at the Primary Processing and Reused Water Reactor and Residue (NUPPRAR) of the Federal University of Rio Grande do Norte (UFRN).

2.3. Phytoplankton sampling, analysis and microcystin

Samples for identification of phytoplankton species were collected in vertical and horizontal trawls with plankton net (20 μm) and fixed with 4% formalin. The taxonomic identification of Cyanobacteria was made using the Komárek System (Komárek and Anagnostidis 2000, 2005; Komárek and Jankovská, 2001); Round (1971) for Chlorophyceae and Simonsen (1979) for Diatoms.

For the quantification of phytoplankton, water samples integrated in the water column (250 mL) were preserved with acetic acid and quantified under inverted microscopy, following the method of Ütermohl (1958) and counting the individuals through random fields. The error less than 20%, at a 95% confidence level according to the criterion of Lund et al. (1958). The number of fields varied between the samples and the conclusion of the count was performed taking as a criterion the count of at least 100 individuals of a dominant species. For samples with apparent blooms we used the criterion of 400 for a 10% environment error (Chorus and Bartram, 1999). The biovolume was obtained by geometric approximation, multiplying the density of each species by the average volume of its cells, considering, when possible, the average size of 30 individual samples of each species (Hillebrand et al., 1999). Phytoplankton functional groups were defined according to Reynolds et al. (2002) and Pádisak et al. (2009) from the species that contributed with at least 5% of the relative biovolume in at least one sample, being considered dominant.

For analysis of total microcystin (particulate and dissolved), integrated samples of water in the water column are obtained in each reservoir. The extraction was done by ice-defrost (three times), followed by the sonication process of the sample for disruption of cells and filtration through Whatman GF / C, glass fiber filters. Microcystin total detection was performed using the Enzyme Linked Immunoadsorbent Assay (ELISA), using a Microcystin Plate Kit ELISA (ENVIROLOGIX INC.) and microplate reader. Descriptive statistics were applied to the data by means of calculating the mean aritimética as measure of central tendency and of the standard deviation and frequency of occurrence of the species (%) (Matteucci and Colma, 1982).

3. Results

3.1. Limnological scenario

The levels of precipitation and volume of the reservoirs in the sample period were extremely low as a consequence of severe drought in the last five years. Rainfall in the year 2015 in the five reservoirs ranged from 261 mm (BQ) to 449 mm (ARG), where all dams were below average annual precipitation in that year (Figure 2). GAR, IT and PT presented only 0.05%, 0.69% and 0.52% of the volumetric capacity, respectively, denoting an operating character below the dead volume. While ARG presented a volume of 26.8% and BOQ, 11.5% (Table 1).

Transparency in IT and PT was below 0.5m, indicating high turbidity, while BQ and ARG exceeded the mark above. The euphotic zone (Zeu) was lower in PT (0.7m) and IT (0.6) and reached a maximum depth of 1.83 m in ARG. The percentage of light in the euphotic zone was lower than 20% in ARG and PT, reaching 26% in BQ and 28% in IT (Table 1). The dissolved oxygen profile showed a clinograde-positive pattern, presenting low concentrations ranging from 2.5 to 5.5 mg.L^{-1} up to 15 meters deep, decreasing to concentrations below 1 mg.L^{-1} in the hypolimonium.

Thermal microstratification were recorded in the reservoirs in IT and PT, showing a variation of 29.8 °C in the surface to 25 °C in the bottom. ARG and BQ showed a homogeneous temperature profile ranging from 24 °C on the surface to 23.5 °C at the bottom (Figure 2). The water column presented clinigrade-positive oxygen profiles with oxygen deficiency at the bottom from 1 m depth of the IT and PT reservoirs (1 mg.L-1). Oxicline from 2m depth occurred in ARG and BQ (Figure 3). Surface dissolved oxygen concentrations ranged from 9.9 mg.L^{-1} in ARG; 9.6 mg.L^{-1} in BQ to 7.4 mg.L^{-1} (IT); 4.2 mg.L $^{-1}$ (PT); and 5.1 mg.L^{-1} (GAR). At the bottom they were very low in IT (1.1 mg.L^{-1}), PT (1.2 mg.L^{-1}) (Figure 3).

The total nitrogen levels were minimum of 763 μg.L^{-1} in BQ and maximum of 29059 μg.L^{-1} in IT (Table 1). Taking

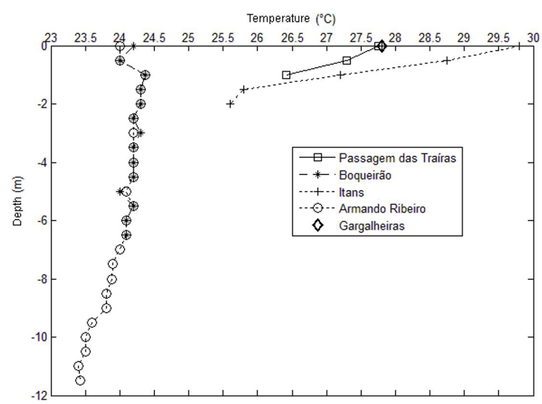

Figure 2. Vertical Temperature Profile.

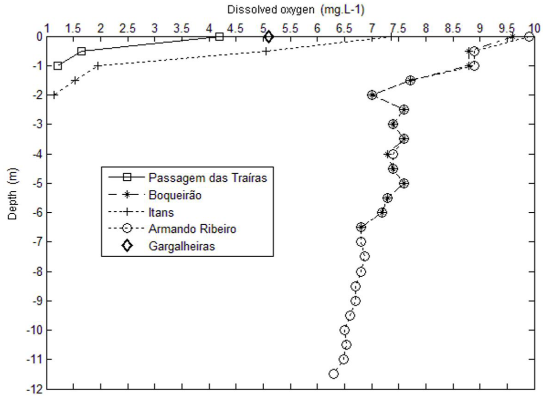

Figure 3. Vertical profile of dissolved oxygen.

Table 1. Hydrological, morphometric characteristics, Physical-chemical values, microcystin, heavy metals, phytoplanktonbiovolume increase ratio and cyanobacteria (from previous studies) and other parameters of the five reservoirs.

Reservoirs Variables	ARG	BQ	GAR	IT	PT
Vol max (m^3)	2,400,000,000.00	84,792,119.23	44,421,480.38	81,750,000.00	49,702,393.65
Vol med (m^3)	643,210,000.00	9,813,192.01	241,726.9	568,000.00	261,297.00
VMA 2015 (%)	26.8	11.5	0.05	0.69	0.52
Zmax (m)	40	29	25	23	25
Zmed (m)	11.1	4.4	4.3	5.1	3.9
Zmax 2015 (m)	13.5	7.3	-	2.6	3.5
TR (years)	2.82	6.22	1.01	2.46	0.26
Transparency (m)	0.61	0.65	-	0.25	0.21
Euphotic zone (%)	19	28	-	26	18
Cond. ($\mu S.cm^{-1}$)	1.67	1.45	-	1.21	1.35
pH (average) (Average depth; min-max)	8 (7-9)	7.9 (7.8-8)		8.1 (7.9-8.6)	8.2 (7.8-8.5)
TP ($\mu g.L^{-1}$)	56.5	52.9	901.4	203.8	413.2
TN ($\mu g . L^{-1}$)	900	763	4273	29059	1955
PO_{43-} ($\mu g.L^{-1}$)	18.9	16.4	457.5	57.6	63.2
NH_3 ($\mu g.L^{-1}$)	62.5	-25	228.9	99.8	11.2
Ba sed ($mg.Kg^{-1}$)	565.8	750.2	685.5	1372.2	836.6
Ni sed ($mg.Kg^{-1}$)	71.3	82.8	74.3	155.6	115.8
Cr sed ($mg.Kg^{-1}$)	88.4	117.9	94.4	210.3	147.1
Ba water ($mg.L^{-1}$)	0.11	0.95	0.58	0.3	0.8
MICY ($\mu g.L^{-1}$)	3.3	3.1	3.3	3.2	3.4
Phyto Biov. and Cyano dens. increase ratio (%)	437/286	543/63	530/274	90/80	89/471

ARG = Armando Ribeiro Gonçalves; BQ = Boqueirão; GAR = Gargalheiras; IT = Itans; PT = Passagem das Traíras; Vol max = Max volume; Vol med = Average volume; VMA 2015 = Average volume during collection; Zmax = Depth Maximum depth Zm = mean depth; Zmax 2015 = Mean depth during collection; TR = Time of residence; TP = Total phosphorus; Cond. = Electric conductivity; PO_{43-} = Phosphate; NH_3 = Ammonia; TN = Total Nitrogen; Ba = Barium; Ni = Nickel; Cr = Chromium; Sed = sediment; MICY = Microcystin; Phyto. Biov.= Phytoplankton biovolume; Cyano. Dens. = Cyanobacteria density). Source: EMPARN (2016).

into account the total phosphorus amounts, which were used to characterize eutrophic environments in semi-arid zones, values of phosphorus concentrations higher than 100 $\mu g.L^{-1}$ were obtained in three reservoirs (GAR, IT, PT) according to Table 1. Reservoirs operating below the dead volume, GAR, IT and PT, presented very high total phosphorus amounts: 901.44 $\mu g.L^{-1}$, 203.88 $\mu g.L^{-1}$ and 413.29 $\mu g.L^{-1}$, respectively. The pH in all the reservoirs ranged from 7 to 9, thus showing to be neutral-alkaline. The electrical conductivity was 1.67$\mu S.cm^{-1}$ (ARG); 1.45 $\mu S.cm^{-1}$ (BQ); 1.21 $\mu S.cm^{-1}$ (IT); and 1.35 $\mu S.cm^{-1}$ (PT).

The analysis of heavy metals in the sediment revealed the presence of Barium, Chromium and Nickel while in the water only Barium was detected, whose concentration in the sediment of the reservoirs ranged from 565 $mg.Kg^{-1}$ (ARG) to 1372 $mg.Kg^{-1}$ (IT). The change in nickel concentrations was 71 $mg.Kg^{-1}$ (ARG) at 155 $mg.Kg^{-1}$ (IT). Chromium showed values of 88 $mg.Kg^{-1}$ (ARG) at 210 $mg.Kg^{-1}$ (IT). The concentration of Barium in the water presented values of 0.32 $mg.L^{-1}$ (IT); 0.95 $mg.L^{-1}$ (BQ); 0.11 $mg.L^{-1}$ (ARG); 0.58 $mg.L^{-1}$ (GAR); 0.81 $mg.L^{-1}$ (PT) (Table 1).

3.2. Phytoplankton scenario and microcystin

The phytoplankton community was represented by 17 functional groups according to Reynolds et al. (2002) and Padisák et al. (2009): **C, D, MP, W1, S1, F, B, K, J, Lo, H1, P, W2, Z, Sn, X1** and **M**. Five taxonomic classes of phytoplankton (Cyanobacteria, Cryptophyceae, Chlorophyceae, Bacillariophyceae and Euglenophyceae), totaling 45 taxa were found in the five reservoirs. The total biovolume of the phytoplankton for the five environments was 166.47 $mm^3.L^{-1}$ (ARG); 38.22 $mm^3.L^{-1}$ (BQ); 344.18 $mm^3.L^{-1}$ (GAR); 69.53 $mm^3.L^{-1}$ (IT) and 85.58 $mm^3.L^{-1}$. Cyanobacteria represented 90% of the total phytoplankton biomass in GAR and BQ, and 99% in ARG, IT and PT. The second group with the highest biomass of phytoplankton in all environments was the chlorophyceae, corresponding to 11% of the total phytoplankton biomass, 8% in GAR and BQ (Figure 4). The other groups represent 1% or less.

A total of 22 taxa of cyanobacteria were identified, of which the potentially toxic ones stand out, being 7 of the group Nostocales, 5 Oscillatoriales and 9 Chroococcales. Potentially toxic cyanobacteria comprised 45%

occurring from 60% to 75% in the five reservoirs, being represented by the *Anabaena planctonica*; *Anabaena spp.*; *Aphanocapsa delicatissima*; *Aphanocapsa holsatica*; *Cylindrospermopsis raciborskii*; *Microcystis aeruginosa*; *Planktothrix agardhii* and *P. isothrix* presented 100% occurrence. The reservoir with the highest diversity of cyanobacteria was BQ (n = 12), followed by ARG (n = 11), while PT presented lower diversity (n = 6). GAR and IT presented 7 species each. The most representative functional group was **S1** (31%), followed by **H1** and **K**, both with 14%, and **Lo** and **M**, both with 10%. The highest total biomass of cyanobacteria was GAR with 303.89 $mm^3.L^{-1}$. The others presented biomass of 164.32 $mm^3.L^{-1}$ (ARG), 29.9 $mm^3.L^{-1}$ (BQ), 69.14 $mm^3.L^{-1}$ (IT), 84.81 $mm^3.L^{-1}$ (PT). In ARG the species *Planktothrix agardhii* represented 84% of the biovolume of cyanobacteria, followed by *Anabaena planctonica* (5%), *Sphaerocavum brasiliense* (5%) and *P. isothrix* (5%). In BQ the dominant species was *Sphaerocavum brasiliense* (52%), followed by *Planktolyngbya sp.* (28.1%) and *Anabaena planctonica* (10%). GAR had the most representative species *Sphaerocavum brasiliense* (77%) and *Microcystis aeruginosa* (12.2%). IT showed prevalence in *Anabaena sp* (89.8%). PT had as predominant species

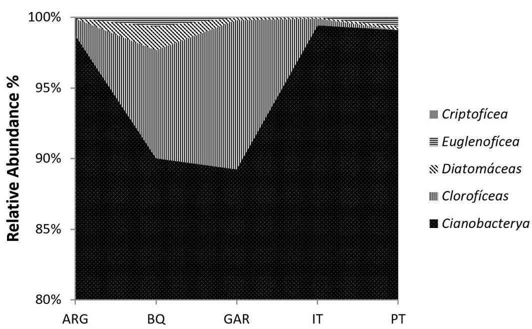

Figure 4. Relative abundance of phytoplanktonic groups (biovolume in $mm^3.L^{-1}$) in July and August 2015. ARG = Armando Ribeiro Gonçalves; BQ = Boqueirão; GAR = Gargalheiras; IT = Itans; PT = Passagem das Traíras.

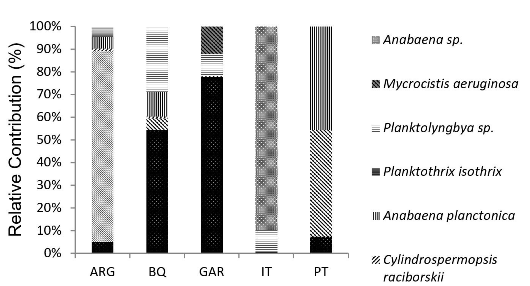

Figure 5. Relative contribution of cyanobacteria (%) in July and August 2015. ARG = Armando Ribeiro Gonçalves; BQ = Boqueirão; GAR = Gargalheiras; IT = Itans; PT = Passagem das Traíras.

Cylindrospermopsis raciborskii (45%) and *Anabaena planctonica* (44%) as indicated in Figure 5.

The functional group **S1** presented biovolume of 145.77 $mm^3.L^{-1}$ in ARG and was represented by the species *Planktothrix agardhii* that presented a relative contribution of 87%. BQ had group **M** as the most abundant with biovolume of 15.56 $mm^3.L^{-1}$, represented here by the cyanobacteria species *Sphaerocavum brasiliense*. In GAR, the **M** group also stood out due to the large number of biovolume representatives (272.49 $mm^3.L^{-1}$) of the cyanobacteria *S. brasiliense* and *Microcystis aeruginosa*. IT appears with group **H1** as more representative, being its biovolume of 62.13 mm^3.L-1 and the cyanobacteria of the genus *Anabaena*, mainly *Anabaena planktonica* were the most abundant. PT reservoir was highly representative for the **Sn** group, with a biovolume of 38.25 $mm^3.L^{-1}$, indicating a large quantity of the species *Cylindrospermopsis raciborskii*. Other groups that also stood out were the **B** in BQ, represented by the diatom *Synedra sp.*, whose contribution was 14% of the total biovolume. *Closterium sp.*, A chlorophyce belonging to the **P**-functional group, had a 10% share of the biovolume in GAR (Figure 6). The other groups were not representative. The density of cyanobacteria was very high in the five reservoirs: GAR (>11.10^6 cel/mL); PT (>2.35.10^6 cel/mL); ARG (>1.42.10^{6}cel/mL); IT (>3.97.10^{3}cel/mL) and BQ (>1.27.10^6 cel/mL). The microcystin concentration was at least 3.1 μ.L-1 (BQ), and a maximum of 3.4 μ.L-1 (PT), being higher in ARG, GAR and PT.

4. Discussion

Semi-arid regions are characterized by prolonged drought and a short period of rainfall, which, together with multiple uses, leads to a reduction in water volume and an increase in water residence time, particularly in reservoirs, due to the need to maintain a minimum flow to guarantee uses in periods of extreme scarcity. Studies have shown that low water levels in aquatic ecosystems

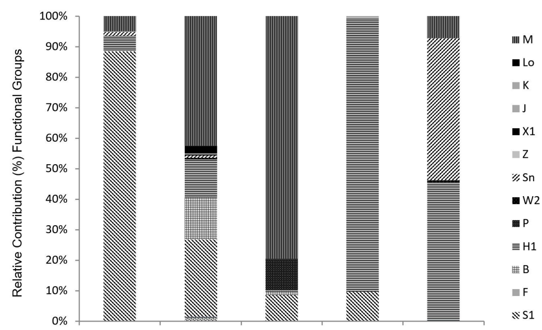

Figure 6. Relative contribution (%) of the main functional groups in each reservoir in July and August 2015. ARG = Armando Ribeiro Gonçalves; BQ = Boqueirão; GAR = Gargalheiras; IT = Itans; PT = Passagem das Traíras.

of these regions are often associated with high levels of nutrients and organic matter, evolving to increase algal biomass and consequently turbidity (Naselli-Flores, 2003; Bouvy et al., 2003; Costa et al., 2006a, 2009). Thus, the reduction of the amount of rainfall and the use of water influence the availability of light in the system (Xiao et al., 2011), which in turn, as a cascade effect, modifies its trophic state, interfering strongly in the dynamics of phytoplankton (Barbosa et al., 2012). This is because, light availability, nutrients and system mixing regime are determinant for phytoplankton growth and distribution (Reynolds, 2006). On the other hand, the reduction of water level in reservoirs, for example, favors the increase of water residence time, leading to the dominance of strategically and potentially toxic cyanobacteria (Romo et al., 2013), which culminates in the aggravation of eutrophication and consequent loss of water quality (Padisak and Reynolds, 1998). The definition of this scenario in regions subject to the periodic rain scarcity regime, as in the case of the semi-arid region, is of extreme importance for the understanding of the biotic and abiotic processes regulating uhe system, which are essential for predicting cyanobacterial bloom events in water supplies and establishment of prevention and mitigation mechanisms.

Since 2012 the state of Rio Grande do Norte (Brazil) faces one of the most severe droughts ever recorded, severely affecting the local population. The volumes of the reservoirs are drastically reduced, and some have collapse, probably due to the natural and periodic oscillation of regional climate phenomena intensified by El Niño.

The water transparency and volume of the reservoirs (> 90% reduction) reported in this study are much lower than those reported by other studies in the same region during less severe periods of water scarcity (> 10 <60% reduction). High levels of total phosphorus and biomass of potentially toxic cyanobacteria were also found. In this condition of drastic reduction of water volume and high turbidity, our results evidenced the permanence and high eutrophic state and the dominance of cyanobacteria in the five reservoirs studied, reinforcing the results obtained in other studies carried out in the same reservoirs (Fonseca et al., 2015; Vieira et al., 2015; Panosso et al., 2007; Eskinazi Sant'Anna et al., 2013; Costa et al., 2009). In the same way, this same scenario is configured in studies carried out in other reservoirs located in the same basin (Freitas et al., 2011; Bezerra, 2011; Medeiros et al., 2015). These results show a strong relationship between the limnetic conditions generated by extreme drought and the loss of water quality and phytoplankton composition. The potential of this relationship is clearly evidenced by the increase in the total biovolume of the phytoplankton, which was at least 89% and a maximum of 543% in relation to the values found by other studies carried out in the same reservoirs even under extreme dry conditions. Likewise, the increase in density of cyanobacteria was extremely significant with a minimum of 63% and a maximum of 471% (Table 1). In relation to total phosphorus (PT) levels, the five reservoirs analyzed presented extremely high concentrations. In ARG we detected values lower than those found by Vieira et al. (2015), when it presented volume reduction of only 12%, and higher than the value observed by Costa et al. (2009), when the reservoir was 100% full.

The results show an increase in total phosphorus concentrations based on previous studies. Brazilian legislation regulates the limit of 30 $\mu g.L^{-1}$ of phosphorus for water intended for human consumption (Brasil, 2005), evidencing the extrapolation of this limit in all reservoirs studied. Values above the recommended limit are also found in other studies of the Brazilian semi-arid region (Huszar et al., 2000; Bouvy et al., 2000). The dominance of cyanobacteria is directly linked to high concentrations of nutrients, mainly phosphorus (Padisák and Reynolds, 1998).

The five reservoirs investigated in this study did not present contamination by heavy metals in the water, but the sediment was contaminated by Chromium and Niquel. The concentration of Bario detected in the water of the reservoirs is within the limits permitted by Brazilian legislation. In the sediment, the limits permitted by Brazilian legislation (Brasil, 2004) for Cromo metal, the acceptable level 2 limit is up to 90 $mg.Kg^{-1}$, which was exceeded in all dams, with the exception of ARG which showed 88.4 $mg.Kg^{-1}$. Niquel has a recommended level 2 limit of 35.9 $mg.Kg^{-1}$ that was also exceeded in all reservoirs. Local studies show high concentrations of heavy metals in several water bodies in the state of Rio Grande do Norte (Sindern et al., 2007), as well as levels of some of these metals found in soil intended for fruit production activities in the Piancó-Piranhas-Açu basin (Morais et al., 2015). Eskinazi-Sant'Anna et al. (2006) found levels of lead, Niquel, Zinco, Manganes, Cadmio and Iron iron above the value allowed by Brazilian legislation in the water of these same reservoirs. The authors warn of the hazards of these metals in water used for human consumption, since these elements are absorbed by the body and can be associated with structures such as proteins and nucleic acids, changing their functionalities. Contamination of water by heavy metals is increasingly an environmental concern because of a lack of degradability, leading to bioaccumulation and magnification in the aquatic biota. The chemical action of metals associated with other disturbances in the system can also cause mortality of organisms at different levels of the aquatic chain.

The drastic reduction of water volume has potentiated the proliferation of cyanobacteria within the phytoplankton community. ARG maintained blooms of *Planktothrix agradhii* and *Cylindrospermopsis raciborskii*, already reported by Costa et al. (2009) and Fonseca et al. (2015). Blooms of *Sphaerocavum brasiliense* and *Planktothrix isothrix* in BQ and GAR were not found by Costa et al. (2009) and Fonseca et al. (2015), but Medeiros et al. (2015) showed blooms of these species in other semiarid reservoirs in the same period of intense drought. During drought periods the diversity of cyanobacterial species is relatively low, but the cell density is extremely high. Arfi (2005) discusses about this relationship and shows that algal biomass is increased when the reservoir level is low and this algal density is benefited by nutrient resuspension and thermal circulation. According to him, larger algal biomass occurs when reservoir levels are low. Rain raises the level of aquatic systems, reducing light availability and algal biomass, generating changes in the composition of different algal associations in tropical systems (Chellappa et al., 2008; Dantas et al., 2008).

The total biomass of phytoplankton is higher in all reservoirs compared to values found by Costa et al. (2009) and Vieira et al. (2015), with the exception of PT. ARG shows an increase ratio of 442%, while in BQ it is 540%; GAR of 530% and IT about 90% (Table 1). The density of cyanobacteria detected in this study was very high in relation to the values found by Costa et al. (2009) and Fonseca et al. (2015), whose density was less than 500.000 cel.ml^{-1}. The values exceeded acceptable levels for drinking water of 20,000 cel.ml^{-1}, in accordance with Brazilian legislation (Brasil, 2011). The registered microcystin levels exceeded the value of 1.0 µg.L^{-1}, the maximum limit established for domestic water supplies, in accordance with Brazilian legislation. Concentrations up to 1 µg.L^{-1} of microcystin were recently observed by Fonseca et al. (2015) in ARG, PT, IT and GAR in July 2011 when these reservoirs had the smallest reduction in volume compared to our results. It is important to mention that other toxins such as saxitoxins and cylindrospermopsins may also be present in water, increasing the risk to human health and aquatic biota.

Our results show that the extreme drought conditions, under which the reservoirs were inserted, influenced both phytoplankton composition and water quality, but not the increase in microcystin concentration. Tropical shallow lakes were studied in extreme events in Rio Grande do Norte (Castro et al., 2011), reinforcing the fact that cyanobacteria dominate, high trophic levels and high values of algal biomass in this type of environment. Other studies in the same region report the change in the phytoplankton dynamics and nutrients in the same environments of this study (Costa et al., 2009; Dantas et al., 2012; Vieira et al., 2015). The data obtained expose a fragility of these environments to anthropogenic activities, typical of semi-arid shallow lakes as reported by Fragoso Júnior et al. (2010) in studies of reservoirs in the Brazilian Northeast.

Cyanobacterial composition was common in the reservoirs. In PT, there was predominance of *C. Raciborskii* (group **Sn**), which are typical of warm and mixed environments. *Planktothrix agardhii* (group **S1**) predominated in Armando Ribeiro, as also reported by Vieira et al. (2015), and are also resistant to high turbidity environments (Padisák and Reynolds, 1998). Colonial species *S. brasiliense* and *Microcystis aeruginosa* present in almost all environments were favored by low volume, increased availability of phosphorus and low luminosity as found in Medeiros et al. (2015). Although *M. aeruginosa* did not appear in the same proportion of *S. brasiliense*, both represented GAR and present ecological similarities, since they belong to group **M** according to Reynolds et al. (2002). *Microcystis aeruginosa* is often reported in studies of Brazilian semi-arid reservoirs as one of the most common species in these environments (Dantas et al., 2008; Moura et al., 2011). *Aphanocapsa delicatissima* was expressively dominant composing bloom in Boqueirão, which because it is a species of shallow habitat and rich in nutrients as the environment in question, belongs to the group **K** (Reynolds et al., 2002). In GAR the highest bloom was of *Planktolyngbya spp*., a non-fixating species of atmospheric nitrogen (Dolman et al., 2012). According to the classification of the functional groups *Aphanocapsa* and *Microcystis* are taxa characteristic of waters enriched with nutrients, tolerant to high radiation and sensitive to discharges and low total light Reynolds et al. (2002). For Bicudo and Menezes (2006) these species together are characteristic of lakes and eutrophic environments.

The low volume dams and their direct relationship with the high density of cyanobacteria, as Arfi (2005) states, is directly related to the studied environments. The high values of cyanobacteria density were also linked with the high availability of nutrients and reported by Huszar et al. (2000) in eight tropical lakes located in different areas of Brazil, including reservoirs located in the semi-arid. The high turbidity of the reservoirs is one of the factors that constitute them as shallow tropical lakes and is correlated with the presence of species of the functional group **S1** typical of turbid and mixed environments.

According to the classification of Reynolds et al. (2002) and updated by Padisák et al. (2009), the groups that prevailed were **S1** representing mixed turbid environments in Armando Ribeiro Gonçalves, **M** from eutrophic to hypereutrophic environments, which characterize Gargalheiras, **H1** from eutrophic environments with stratification, shallow lakes and low nitrogen level, which is the case of Passagem of the Traíras and Itans. The **Sn** group of warm and mixed environments mainly characterized of Passagem of the Traíras, while the codon **B** of environments of small size to medium, mesotrophic and with species susceptible to stratification and **P** of shallow environments with 2m to 3m of depth high levels of trophic state, Which is the case of Gargalheiras. Vieira et al. (2015) also found functional groups **S1** and **H1** in ARG in July and August of 2011. Costa et al. (2009) showed that phytoplankton was represented basically by **M** in the rainy season and, like this work, S1 and Sn in drought, with alternation of species of association **H, H1, S1, K** and **Lo**. The main representatives of these groups in the reservoirs were potentially toxic species such as *Planktothrix agradhii* (**S1**), *Microcystis aeruginosa* (**M**), *Anabaena planktonica* and *Anabaena spp*. (**H1**), *Cylindrospermopsis raciborskii* (**Sn**) and other species.

In summary, our results suggest and reaffirm that the severe drought conditions in the semi-arid region, which drastically reduces the volume of water in the reservoirs, alter the light and phosphorus conditions of the system, which are determinant factors to increase the eutrophic condition and consequently the dominance of species of cyanobacteria. Our study shows that the extreme reduction of water volume has increased the cyanobacterial toxic blooms, which is permanently characterized in these reservoirs, in comparison with other studies carried out under conditions of lower water reduction. High concentrations of microcystins in water found in this study also reveals an impairment in the decrease of the water quality of reservoirs used for human consumption.

Acknowledgements

I would like to extend my sincerest thanks to Mr. Edson Santana for field assistance. And I am especially grateful to the Brazilian Coordination for the Improvement of Higher Education Personnel (CAPES) for financing this project and providing the basis for my master's research project.

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