

Phytoplankton responses to an extreme drought season: A case study at two reservoirs from a semiarid region, Northeastern Brazil

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ABSTRACT

The temporal phytoplankton biomass variation at two Neotropical reservoirs during an extreme drought season were analyzed. Here we sought to evaluate the main abiotic factors involved in dynamics of phytoplankton during this drought period. The main difference between the reservoirs was the intensive fish and shrimp farming in one of the reservoirs. For quantitative analysis, sampling with bottles were carried out at an average depth of 0.5 m. Water temperature, pH and electrical conductivity parameters were measured *in situ* and water samples were collected for dissolved inorganic nitrogen and soluble reactive phosphorus analyses. Aquaculture was probably one among the causes for the reservoirs were so different in the physical and chemical variables, as shown by the principal components' analysis. The results showed specific groups dominance in both reservoirs. In the Cachoeira II reservoir, an invasive dinoflagellate, *Ceratium furcoides*, was present in all analyzed months, while, in the Saco I reservoir, cyanobacteria group represented more than 50% of phytoplankton biomass, mainly *Microcystis aeruginosa* and *Dolichospermum* sp. In two reservoirs precipitation, soluble reactive phosphorus and electrical conductivity were positively related with phytoplankton. Phytoplankton biomass was considerably larger in the Cachoeira II reservoir, due to the greater size and biovolume of the dominant dinoflagellate. These findings suggest that species dominance in extreme drought events may be favored.

INTRODUCTION

Brazilian reservoirs were constructed at the beginning of the 1900s, to serve as water supplies, to generate energy and as a source of income through the introduction of commercially-valuable organisms (Nogueira *et al.*, 1999). Due to long drought periods, in Northeast Brazil, most reservoirs are destined to the domestic supply (Maia, 1988). These ecosystems may present a temporal heterogeneity in physical and chemical variables, mainly

in tropical regions, due to climatic aspects and rainfall seasonality that change throughout the year (Morais *et al.*, 2017). These variations directly reflect the communities that inhabit these lentic waters, mainly in phytoplankton (Soares *et al.*, 2008).

Phytoplankton community plays an important role in providing energy in the aquatic food web and oxygen producing (Melack, 1979). Phytoplankton blooms are common in marine and freshwater habitats, however, when excessive are harmful to ecosystems (Heisler *et al.*, 2008). Occurrences of harmful algal blooms (HAB) in reservoirs, caused by several genera of Cyanobacteria (CyanoHABs; *e.g.* *Microcystis* Lemmermann, *Dolichospermum* Bory de Saint-Vincent & Flandrin, *Cylindrospermopsis* G. Seenayya & N. Subba Raju) have been observed worldwide (Sant'Anna *et al.*, 2011; Wells *et al.*, 2015). According to Moura *et al.* (2018) characteristics of semiarid climate (*e.g.* high temperatures and irregular precipitations) of the Northeast Brazil has favored CyanoHABs.

In addition to CyanoHABs, an invasive dinoflagellate has drawn attention to its dominant character in Brazilian freshwater ecosystems (Cavalcante *et al.*, 2016). *Ceratium furcoides* (Levander) Langhans was first reported in Brazil around the 2000s, and have since been reported in rivers and reservoirs in almost all regions (Oliveira and Oliveira, 2018). Although not toxic, *C. furcoides* can compromise local biodiversity, due to competing species absence, and reduce levels of dissolved oxygen during bloom decay (due to the oxygen

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consumption by decomposing bacteria), which can be lethal to other aquatic organisms (Smayda, 1997).

In tropical reservoirs, oscillations in water temperature are not so high as those observed in temperate regions (Alexe *et al.*, 2017). In addition, the current state of global warming and the increase in effluent production (rich in nitrogen and phosphorus compounds), occurrences of blooms may become more common in these regions (Jacoby *et al.*, 2000; Dolman *et al.*, 2012; Paerl and Otten, 2013; Niedźwiecki *et al.*, 2017). Although several reports show the strong relationships among phosphorus concentrations with cyanoHABs and dinoflagellates, other physical, biological and chemical factors may modulate algal species' responses to nutrient loadings (Glibert *et al.*, 2005). In an extreme drought seasons, where increase in nutrient accumulation and water temperatures can be found, phytoplankton structure may behave differently causing a robust species dominance (Costa *et al.*, 2016).

Understanding the dynamics of phytoplankton in adverse situations is of great relevance in order to avoid the occurrence further tragedies such as the 'Caruaru Syndrome, Brazil' of 1996 caused by cyanobacteria (Azevedo *et al.*, 2002). After this tragedy, Brazil became the first country to adopt specific legislation that includes the analysis of cyanobacteria in the monitoring of water supply. Phytoplankton autecology studies in reservoirs contribute to the knowledge of this important aquatic community and to the health and safety of individuals using these water bodies (Harke *et al.*, 2016).

The reservoirs of this study, Cachoeira II and Saco I reservoirs, have capacities of 21,031,000 m³ and 36,000,000 m³ of water respectively. However, due to a

long period of drought before and during this study, these reservoirs were at low levels. According to the Brazilian Department of Constructions Against Droughts – *Departamento Nacional de Obras Contra as Secas* (DNOCS) – these reservoirs, since January 2017, were at less than 1% of their maximum capacity. With this volume, the average depth of the Cachoeira II reservoir was 2.0 m, while the Saco I reservoir was 0.7 m. Both reservoirs are intended for drinking water supply. The main factor differentiating these reservoirs, was an aquaculture station implemented in Saco I reservoir, as an attempt to promote income for the local community. When the reservoir was full, intensive fish and shrimp farming were carried out.

In order to increase the knowledge about HAB and biodiversity in reservoirs from the semiarid Brazil, the present study aimed determine the main abiotic factors which control phytoplankton in two reservoirs in Northeastern Brazil during an extreme drought season.

METHODS

Study sites

The present study was carried out in two important sources of drinking water supply and income, to fish and shrimp farmers in the semiarid region, from February 2017 to September 2017. Samples containing phytoplankton were collected in Saco I (038°17'35"W, 07°56'53"S) and Cachoeira II (038°19'52"W, 07°58'12"S) reservoirs, both located at the semiarid region of Pernambuco state, Northeastern Brazil (Fig. 1).

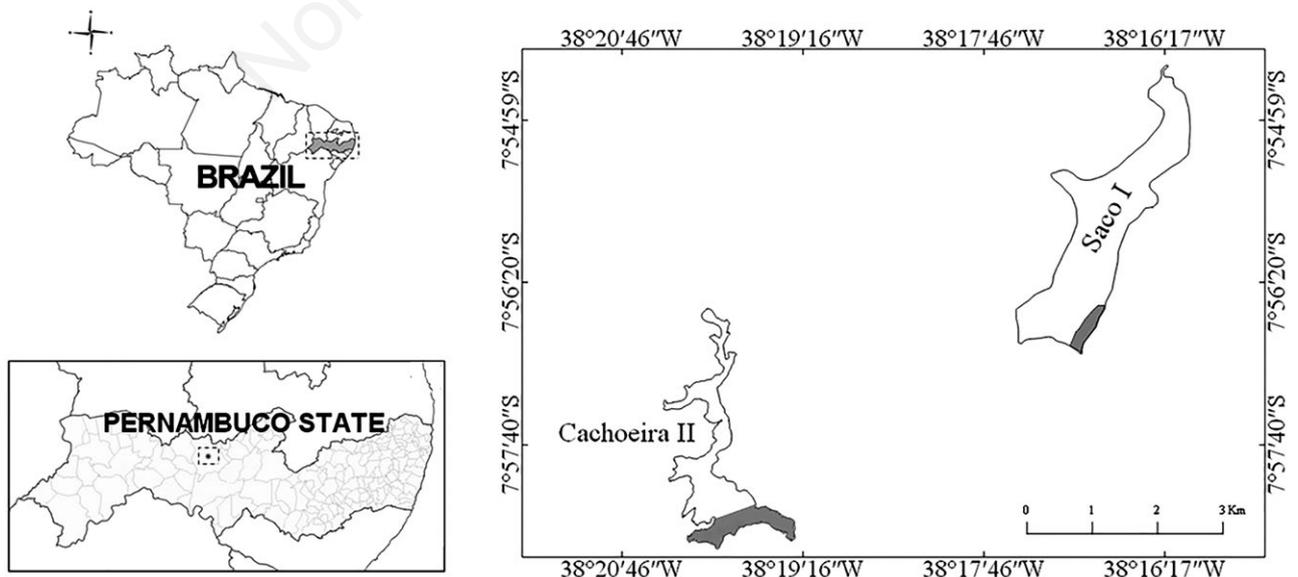


Fig. 1. Study area located in Pernambuco state, Northeastern Brazil. The reservoirs area during the study is represented by the gray color.

Data collection took place during daytime, always around 10:00 a.m., in three points, remote from the vegetation. Due to a long drought period, both reservoirs dried up and had restricted access, in October 2017 which prevented new data collection for the study.

For qualitative analysis horizontal hauls were performed using a plankton net (20 μm) at an average depth of 0.5 m. In quantitative analyses vertical sampling with bottles were carried out at the same depth. During the sampling days, when visiting the second reservoir, all necessary care was taken in order to avoid cross-contamination between the reservoirs studied. In addition, 70% alcohol was used to ensure no contamination occurred during sample disposal.

Environmental parameters

Water temperature ($^{\circ}\text{C}$), pH and electrical conductivity ($\mu\text{S cm}^{-1}$ at 25°C) parameters were measured *in situ* with a multi-parameter probe (HI 9829 model, Hanna Instruments Lda., Amorim, Portugal). Water samples were collected from the subsurface of the reservoirs. Dissolved inorganic nitrogen ($\text{DIN}=\text{NO}_3\text{-N}+\text{NO}_2\text{-N}+\text{NH}_4\text{-N}$; mg L^{-1}) levels were measured with a spectrometry with wavelength ranging from 530 to 630nm, using a colorimetric test, following manufacturer's recommendations. Soluble reactive phosphorus (SRP; mg L^{-1}) analysis was performed following the ascorbic acid method (APHA, 1998). Precipitation data were obtained from Serra Talhada-A350 meteorological station (OMM: 81912 at ca. 7 km from reservoir), available at the National Institute of Meteorology website (INMET, 2018).

Phytoplankton density and community structure

Samples for quantitative phytoplankton analysis were taken from both reservoirs and were immediately fixed with formaldehyde (4%). Taxonomic classification was made according to Bicudo and Menezes (2006) following keys and specific bibliography of each algal group, including González (1996), Cybis *et al.* (2006) and Popovský and Pfiester (1990). Phytoplankton quantitative analyses were conducted in triplicate (using different samples), with an optical microscope binocular (BA300 model, Motic[®], Xiamen, China), and a Sedgwick-Rafter (ind mL^{-1}), species were counted at 400 or 1000x of magnification. Colonies, single cells, filaments and cenobites were considered as a single individual. Phytoplankton biovolume ($\text{mm}^3 \text{L}^{-1}$) was estimated following the method described by (Sun and Liu, 2003). Population proportion was calculated using the average of phytoplankton counted in three different chambers. Taxa were grouped into similar groups: Chlorophyceae, Cyanobacteria, Bacillariophyceae, Dinophyceae and Euglenophyceae.

Statistical analysis

Structural diversity was calculated using statistical methods recommended by Heywood (2004) for taxonomic studies. Simpson's index was used to measure richness, while the phytoplankton species diversity (Shannon index) and evenness values were obtained using the PAST statistical software (Hammer *et al.*, 2001). Principal component analysis (PCA) was performed to determine differences in the environmental variables (electrical conductivity, pH, DIN, SRP and Temperature) between the two reservoirs, using correlation to produce a cross product matrix. Canonical correspondence analysis (CCA) was performed to identify the influence of the environmental variables on phytoplankton biovolume. The significance of the CCA model was determined using the Monte Carlo permutation test. For CCA the monthly average of the environmental variables were used, while in PCA the values of each sampling station were used. All statistical analyses were performed at 5% significance level. PCA and CCA were performed on RStudio[®] software (RStudio Inc, USA).

RESULTS

Environmental parameters

Precipitation data showed that 2017 was an atypical year in relation to the historical average (last 30 years) for this region. The monthly precipitations during the months studied were below the historical average, except for June and July 2017 (125.0 and 50.2 mm respectively). The lowest precipitation sampled were recorded in August and September (2.4 mm in each month).

The reservoirs of this study were very different in relation to the majority of the environmental variables (Tab. 1). PCA ordination ($F=51.76$; $P=0.001$) for 5 abiotic variables explained 71.40% of data variability in the first two axes (Fig. 2); the precipitation data were not plotted. Electrical conductivity ($r=0.63$), pH ($r=0.52$) and DIN ($r=0.51$) were the principal variables in the composition of axis 1 (46.54%), while temperature ($r=0.78$) and SRP ($r=-0.56$) were the most important variables for the axis 2 (24.86%). PCA's diagram presented a clear limnological distinction between these reservoirs, especially regarding to electrical conductivity.

Phytoplankton occurrence and abundance

During the study, 16 taxa of 5 different groups were found. Eight Cyanobacteria: *Chroococcus dispersus* (Keissler) Lemmermann, *Aphanocapsa elachista* West & G. S. West, *Dolichospermum* sp., *Merismopedia* sp., *Microcystis aeruginosa* (Kützing) Kützing, *Pseudanabaena limnetica* (Lemmermann) Komárek,

Synechococcus sp., five Chlorophyceae: *Chlorella* sp., *Cosmarium bioculatum* Brébisson ex Ralfs *Dictyosphaerium* sp., *Pediastrum duplex* Meyen, *Pediastrum simplex* Meyen, *Staurastrum leptocladum* Nordstedt, *Trochiscia* sp., and only one of the class Bacillariophyceae: *Aulacoseira granulata* (Ehrenberg) Simonsen, Euglenophyceae: *Trachelomonas volvocina*

(Ehrenberg) Ehrenberg and Dinophyceae: *Ceratium furcoides* (Levander) Langhans.

Dolichospermum sp. was reported only in the Saco I reservoir, present from February to August 2017. *M. aeruginosa* were reported in all months of this study for the Saco I reservoir. In addition, *M. aeruginosa* was also present in the Cachoeira II reservoir in April, June, July

Tab. 1. Monthly variation (mean±standard deviation) of environmental parameters during February to September 2017.

Parameter		February	March	April	May	June	July	August	September
Cond ($\mu\text{S cm}^{-1}$)*	C	601±22	518±34	318±89	328±26	320±52	307±45	299±21	302±75
	S	11,490±200	28,190±150	21,470±350	26,270±200	14,880±195	16,000±300	19,300±90	24,330±110
pH	C	8.03±0.10	8.35±0.12	7.81±0.09	7.57±0.25	8.58±0.13	7.82±0.05	7.9±0.11	8.61±0.30
	S	8.34±0.20	8.45±0.28	8.81±0.10	8.65±0.13	8.97±0.18	9.59±0.35	8.54±0.40	9.49±0.12
Temp ($^{\circ}\text{C}$)	C	27.40±1.5	28.33±1.2	26.78±0.9	26.01±1.7	24.21±1.1	22.03±0.9	23.31±1.3	23.28±2.0
	S	27.46±2.4	28.82±1.8	26.76±1.4	26.85±2.2	22.34±1.2	21.44±3.8	23.44±2.8	23.64±2.2
DIN (mg L^{-1})	C	2.62±0.11	1.24±0.40	1.69±0.34	1.47±0.55	0.85±0.24	0.82±0.11	0.46±0.03	0.83±0.24
	S	3.51±0.33	0.58±0.05	0.36±0.13	1.62±0.16	1.07±0.09	1.55±0.38	1.23±0.35	2.05±0.42
SRP (mg L^{-1})	C	0.85±0.09	0.51±0.01	0.52±0.4	0.72±0.6	1.10±0.08	0.66±0.5	1.22±0.04	1.02±0.2
	S	0.90±0.07	0.36±0.09	1.08±0.3	0.73±0.1	1.07±0.2	0.42±0.5	1.57±0.2	1.35±0.08
RAIN (mm)		17.3	23.1	33.4	19.5	125.0	50.2	2.4	2.4

Cond, electrical conductivity; Temp, water temperature; DIN, dissolved inorganic nitrogen; SRP, soluble reactive phosphate; RAIN, monthly precipitation; C, Cachoeira II reservoir; S, Saco I reservoir; *electrical conductivity at 25°C .

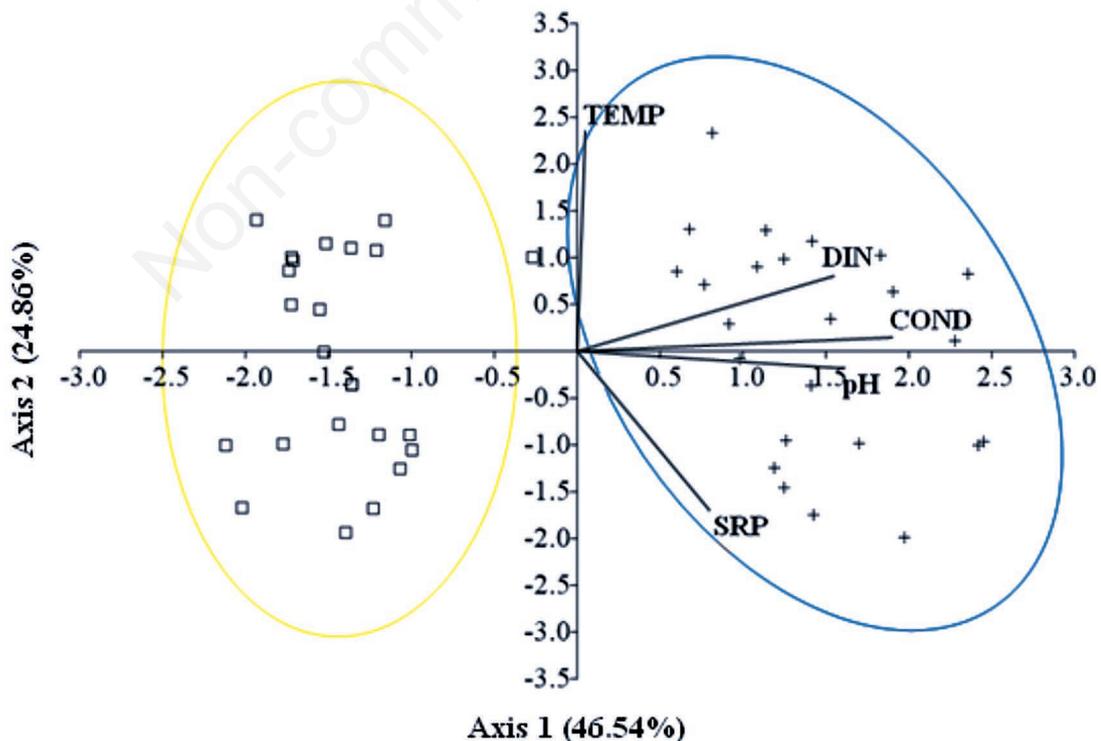


Fig. 2. Principal components analysis (PCA) ordination diagram for environmental variables of each sampling stations of Cachoeira II (yellow ellipsoid) and Saco I (blue ellipsoid) reservoirs.

and September 2017. *C. furcoides* was present in all months of this study in the Cachoeira II reservoir, and in the Saco I reservoir was reported starting June 2017. Chlorophyceae were alternately present in both reservoirs. However, this group is only clearly visualized in the density data (due to the size and biovolume reduced).

Large oscillations in phytoplankton biovolume were observed in both reservoirs. Phytoplankton biovolume was significantly higher for the Cachoeira II reservoir (Fig. 2). In this reservoir, the minimum and maximum biomass values were recorded in March ($0.78 \pm 0.05 \text{ mm}^3 \text{ L}^{-1}$) and September ($11.26 \pm 0.97 \text{ mm}^3 \text{ L}^{-1}$), respectively. While in the Saco I reservoir, the phytoplankton biovolume oscillated from 0.38 ± 0.02 to $2.38 \pm 0.20 \text{ mm}^3 \text{ L}^{-1}$. Observing the biovolume and biovolume relative, dominances of algal groups were observed in both reservoirs (Figs. 3 and 4). In the Cachoeira II reservoir a strong dominance of the *C. furcoides* was observed, while in the Saco I reservoir the Cyanobacteria (mainly *M. aeruginosa* and *Dolichospermum* sp.) were dominant. Shannon and Simpson indexes are reflections of the dominance of phytoplankton groups aforementioned. In the Cachoeira II reservoir, the Shannon and Simpsons indexes are 0 (zero), because only *C. furcoides* was found (Fig. 5).

Species-environment relationships

CCA for Cachoeira II was significant ($F=37.24$; $P=0.03$) and explained 78.97% of the total variation recorded in the first two axes (Fig. 6A); pH ($r=0.61$), precipitation ($r=-0.54$) and SRP ($r=0.44$) were the principal variables in the composition of axis 1 (44.35%), while electrical conductivity ($r=0.56$) and precipitation ($r=-0.54$) were the most important variables for axis 2 (35.62%). Even with low diversity in the Cachoeira II reservoir, a group formed by two cyanobacteria (*M. aeruginosa* and *Dictyosphaerium* sp.) was positively correlated with DIN and temperature. *C. furcoides* presented strong positive correlation with pH and electrical conductivity.

For the Saco I reservoir, CCA was also significant ($F=23.45$; $P=0.004$) and explained 76.02% of data variability in the first two axes (Fig. 6B); temperature ($r=0.68$), pH ($r=-0.51$) and DIN ($r=0.49$) were the most important variables in the composition of axis 1 (51.04%), while precipitation ($r=-0.63$) and SRP ($r=0.62$) were the most important variables for axis 2 (24.99%). Two groups formed by cyanobacteria were observed (Fig. 6B). *Dolichospermum* sp., *P. limnetica* and *Synechococcus* sp. (group 1) were positively correlated with temperature, DIN and electrical conductivity. This group was negatively correlated with pH and precipitation. Group 2 (formed by *C. dispersus* and *Merismopedia* sp.) was also positively correlated with DIN and SRP. *M. aeruginosa* was correlated with precipitation and pH.

DISCUSSION

This study describes the dynamics of phytoplankton in two reservoirs of great importance for the semiarid Brazil in an extreme drought period. Our results showed the last phytoplankton responses before both reservoirs were completely dry temporarily. The reservoirs were very distinct of each other in relations to the physical and chemical variables. Electrical conductivity levels of both reservoirs were very different, and this parameter can significantly influence phytoplankton composition (Qasim *et al.*, 1972; Nche-Fambo *et al.*, 2015; Van Meerssche and Pinckney, 2017; Huang *et al.*, 2018). According to Sellner *et al.* (1988) the increase of electrical conductivity can favor the cyanobacteria bloom, and this was clearly reported in the present study.

Although it was not a measurable variable, possibly, the main factor that contributed to this distinction between the reservoirs was intensive aquaculture (fish and shrimp farming) carried out in the Saco I reservoir (Costa *et al.*, 2015; Santos *et al.*, 2016). Aquaculture effluents are generally rich in nitrogen and phosphorus (Islam, 2005), the accumulation of these nutrients over the years in Saco I reservoir, is probably the best explanation for the differences between the reservoirs in levels of DIN and SRP. The growth of the aquaculture and urbanization effluents disposal contributes to the eutrophication of the reservoirs in the world and these processes have not been followed by an improvement in wastewater treatment (Frankic and Hershener, 2003). According to Costa *et al.* (2006) and Sant'Anna *et al.* (2011) artificial eutrophication is considered the main factor responsible for water quality losses in the semiarid regions.

The low volume (about 1% of its total capacity) of the Cachoeira II and Saco I reservoirs could directly related to the water quality of this reservoir. Lacerda *et al.* (2018) showed the influence of the volume on the water quality

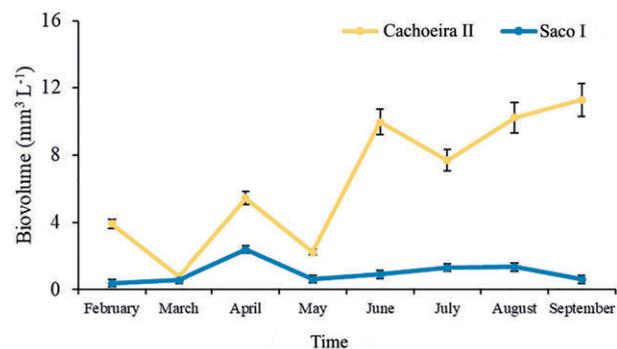


Fig. 3. Biovolume variations of phytoplankton during extreme drought season at the Cachoeira II (yellow lines) and Saco I (blue lines) reservoirs.

parameters of the Castanhão reservoir, the largest reservoir of the semiarid Brazil. According to these authors, while the volume of the reservoir decreased, total phosphorus and chlorophyll-*a* concentrations increased. In the present study, inorganic compounds accumulation was not observed due to the short sampling time, although the concentrations were already been very high.

According to Costa *et al.* (2016) a reduction of water level in shallow lakes may increase or decrease cyanobacterial blooms. This behavior was also reported in this study to the Cachoeira II reservoir, considering that occurrences of cyanobacteria were not recorded in all the study months. In the Saco I reservoir, the extreme drought season added to the effluents discharge, in previous years, strongly favored the CyanoHABs. Cyanobacteria are

intensively favored by eutrophication processes (Chellappa and Costa, 2003), high temperatures (Costa *et al.*, 2016) and low water transparency. Cyanobacteria preference for higher temperatures has been extensively demonstrated (Reynolds 1987; Bouvy *et al.*, 2000; Marinho and Huszar 2002; Reynolds, 2006; Paerl and Huisman, 2008), this relationship was clearly noted for some species in this study. In addition to temperature, CCA showed that DIN and pH had positive association with several species.

Harke *et al.* (2016) evidenced the fundamental role of nitrogen and phosphorus in the occurrence of *Microcystis* spp. blooms worldwide. According to Sant’Anna *et al.* (2011), *M. aeruginosa* and *Dolichospermum* spp. are the most widespread toxic cyanobacteria in Brazil, occurring in different parts of tropical and subtropical regions.

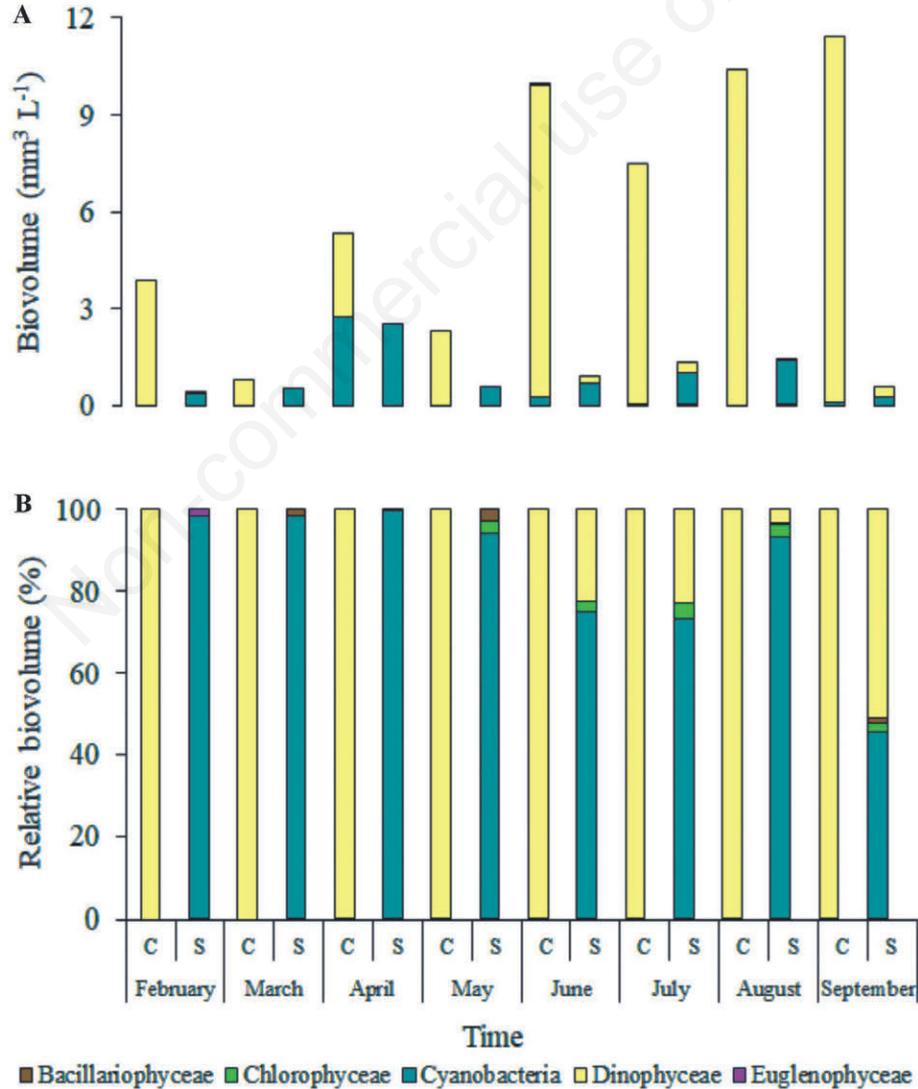


Fig. 4. Biovolume mean (A) and relative biovolume (A) of the phytoplankton groups during extreme drought season at two reservoirs from a semiarid region, Northeastern Brazil. C, Cachoeira II; S, Saco I.

Microcystis blooms have been continuously recorded in semiarid reservoirs (Bittencourt-Oliveira *et al.*, 2014; Lopes *et al.*, 2015; Lins *et al.*, 2016; Moura *et al.*, 2017) and, during this study, this taxon was responsible for one of the highest phytoplankton biomasses. *M. aeruginosa* was present during all months evaluated in Saco I reservoir. It is noteworthy the largest biovolumes occurred in both reservoirs in April 2017, where biovolumes reached 2433 and 2737 mm³ L⁻¹ in Saco I and Cachoeira II reservoirs, respectively. Severiano *et al.* (2018) found significant reductions of *M. aeruginosa* biomass with increasing zooplankton grazing. This may be a good tool to control populations of *M. aeruginosa* in tropical reservoirs.

In addition to cyanobacteria, the occurrence of invasive dinoflagellate, *Ceratium furcoides*, has also to be highlighted. *C. furcoides* was reported for the first time in 2007 in state of Minas Gerais, Brazil (Santos-Wisniewski *et al.*, 2007) and it was reported in semiarid region only in 2016 (Oliveira *et al.*, 2016). Since then, the species is in continuous expansion in the Brazilian freshwaters, mainly in lentic aquatic bodies, such as lakes and reservoirs (Oliveira and Oliveira, 2018). In this study, phytoplankton biomass in the Cachoeira II reservoir was significantly higher than that detected in the Saco I reservoir, due to the presence of the large cell of the *C. furcoides*.

High SRP content may have favored the *C. furcoides*

blooms, since it showed a high affinity for it in CCA for two reservoirs, thus corroborating Rocha (2016), who found positive relationships of high densities with total phosphorus. According to Cavalcante *et al.* (2016), *C. furcoides* is considered an excellent competitor among freshwater phytoplankton and the absence of natural predators (zooplankton) in Brazilian aquatic bodies,

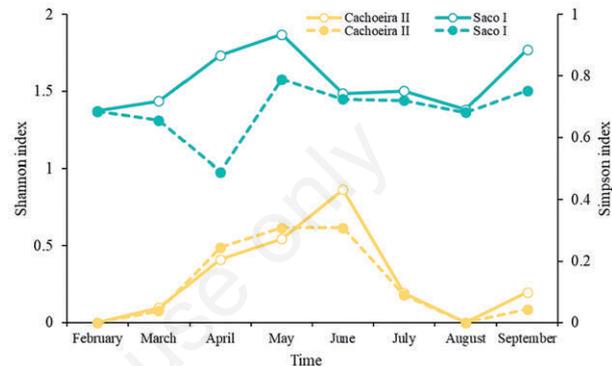


Fig. 5. Shannon (solid lines) and Simpson (dashed lines) index variations of phytoplankton during extreme drought season at two reservoirs from a semiarid region, Northeastern Brazil.

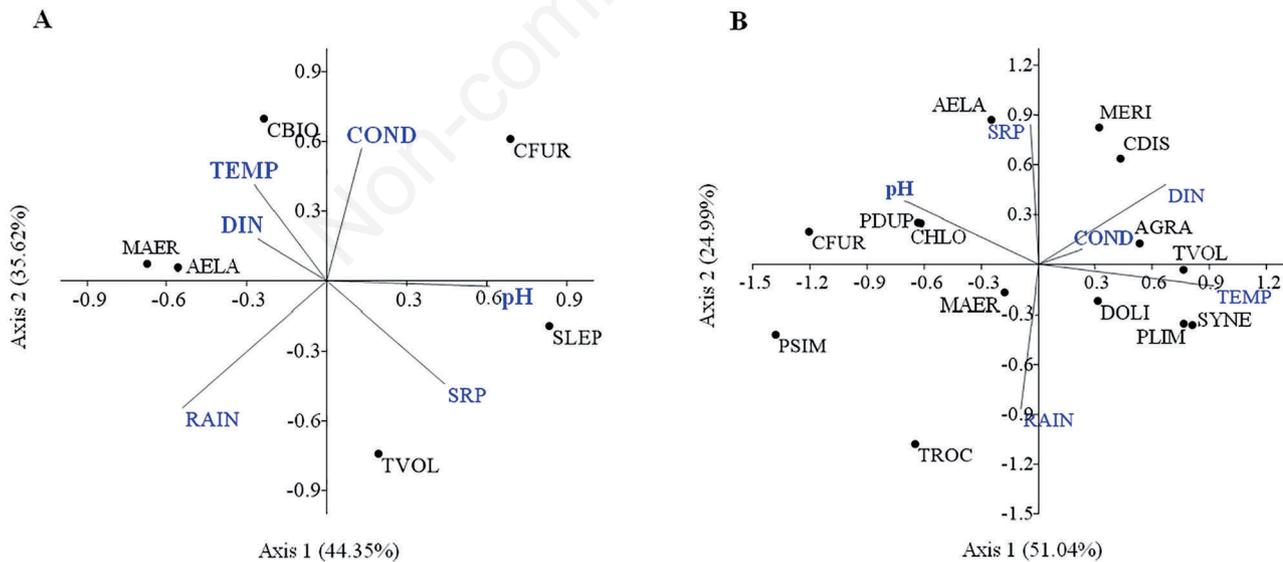


Fig. 6. Canonical correspondence analysis (CCA) biplot showing the relationship between environmental variables and monthly phytoplankton biovolume for Cachoeira II (A) and Saco I (B) reservoirs during drought at two reservoirs from a semiarid region, Northeastern Brazil. AELA, *Aphanocapsa elachista*; CDIS, *Chroococcus disperses*; DOLI, *Dolichospermum* sp.; MERI, *Merismopedia* sp.; MAER, *Microcystis aeruginosa*; PLIM, *Pseudanabaena limnetica*; SYNE, *Synechococcus* sp.; CHLO, *Chlorella* sp.; CBIO, *Cosmarium bioculatum*; DICT, *Dictyosphaerium* sp.; PDUP, *Pediastrum duplex*; PSIM, *Pediastrum simplex*; SLEP, *Staurastrum leptocladum*; TROC, *Trochiscia* sp.; CFUR, *Ceratium furcoides*; AGRA, *Aulacoseira granulate*; TVOL, *Trachelomonas volvocina*; TEMP, water temperature; COND, electrical conductivity; DIN, dissolved inorganic nitrogen; SRP, soluble reactive phosphate; RAIN, precipitation.

contribute to the invasion and appropriation of this species in Brazil. The results found by Gil *et al.* (2012), in tropical reservoir, Colombia, suggest a positive relationship between *C. furcoides* and ammonia concentrations. However, in Brazil, this species has shown better developed at high nitrite and nitrate concentrations (Nishimura *et al.*, 2015).

In this study, positively relationships of *C. furcoides* with inorganic compounds were not found. In addition, we report that this species can also develop in conditions of high electrical conductivities, since it was reported from June 2017 in the Saco I reservoir, when the electrical conductivity was approximately 15,000 $\mu\text{S cm}^{-1}$ at 25°C.

CONCLUSIONS

The extreme drought season may have favored the cyanobacterial blooms and the dominance of the invasive dinoflagellate, *C. furcoides*. Probably, in the Saco I reservoir, the nutrients accumulation from aquaculture was a differential that contributed to CyanoHABs. Phytoplankton biomass was considerably larger in the Cachoeira II reservoir, due to the greater size and biovolume of the dominant dinoflagellate. In the Saco I reservoir a higher number of toxic cyanobacteria was reported. Further studies need to be performed to evaluate the effect of aquaculture effluents on dynamics of phytoplankton, in dry and rainy season, to evaluate the effluent impacts in freshwater communities.

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