Vertical and temporal dynamics of cyanobacteria in the Carpina potable water reservoir in northeastern Brazil

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(With 3 figures)

Abstract

This study analysed vertical and temporal variations of cyanobacteria in a potable water supply in northeastern Brazil. Samples were collected from four reservoir depths in the four months; September and December 2007; and March and June 2008. The water samples for the determination of nutrients and cyanobacteria were collected using a horizontal van Dorn bottle. The samples were preserved in 4% formaldehyde for taxonomic analysis using an optical microscope, and water aliquots were preserved in acetic Lugol solution for determination of density using an inverted microscope. High water temperatures, alkaline pH, low transparency, high phosphorous content and limited nitrogen content were found throughout the study. Dissolved oxygen stratification occurred throughout the study period whereas temperature stratification occurred in all sampling months, with the exception of June. No significant vertical differences were recorded for turbidity or total and dissolved forms of nutrients. There were high levels of biomass arising from *Planktothrix agardhii*, *Cylindrospermopsis raciborskii*, *Geitlerinema amphibium* and *Pseudanabaena catenata*. The study demonstrates that, in a tropical eutrophic environment with high temperatures throughout the water column, perennial multi-species cyanobacterial blooms, formed by species capable of regulating their position in the water column (those that have gas vesicles for buoyancy), are dominant in the photic and aphotic strata.

Keywords: perennial cyanobacterial blooms, population dynamics, tropical ecosystem, water supply system.

Dinâmica vertical e temporal de cianobactérias no reservatório de Carpina de abastecimento de água no nordeste do Brasil

Resumo

O presente estudo analisou as variações vertical e temporal de cianobactérias em um reservatório de abastecimento de água no nordeste do Brasil. As amostras foram coletadas em quatro profundidades no reservatório, durante quatro meses (setembro e dezembro de 2007, março e junho de 2008). As amostras de água para a determinação de nutrientes e de cianobactérias foram coletadas por meio de garrafa horizontal de Van Dorn. As amostras foram preservadas em formol 4% para posterior análise taxonômica utilizando um microscópio óptico, e alíquotas de água foram preservadas em solução de Lugol acético para determinação da densidade através de um microscópio invertido. Altas temperaturas da água, pH alcalino, baixa transparência, alto teor de fósforo e limitação de nitrogênio foram encontrados ao longo do estudo. Durante todo o estudo, foi verificada estratificação do oxigênio dissolvido enquanto que estratificação térmica só não foi observada em junho. Diferenças verticais não foram registradas para a turbidez e formas totais e dissolvidas de nutrientes. Ocorreram altas biomassas de *Planktothrix agardhii*, *Cylindrospermopsis raciborskii*, *Geitlerinema amphibium* e *Pseudanabaena catenata*. O presente estudo demonstra que, em um ambiente eutrófico tropical com temperaturas elevadas em toda a coluna d'água, florações perenes multiespécies de cianobactérias formadas por espécies capazes de regular a sua posição na coluna de água (aqueles que possuem vacúolos de gás para flutuação) são dominantes nas camadas fótica e afótica.

Palavras-chave: blooms perenes de cianobactérias, dinâmica populacional, ecossistemas tropicais, sistema de abastecimento público.

1. Introduction

A number of studies have sought to explain the worldwide success of cyanobacteria in fresh water ecosystems with different environmental characteristics. These organisms are often associated with eutrophic conditions, CO_2 availability and high temperatures (Shapiro, 1990), low luminosity (Niklisch and Kohl, 1989), alkaline pH (Reynolds and Walsby, 1975), high concentrations of nutrients, especially phosphorus (Watson et al., 1997), and a low N:P ratio (Smith, 1983), and buoyancy regulation (Walsby et al., 1997). However, the specific composition, dominance and vertical distribution of species depends on the synergistic effects of climatic and hydrological variables, as well as the particular characteristics of each species regarding survival strategy.

An important feature of blooming cyanobacteria is the ability of some species to regulate buoyancy by using gas vacuoles (Hasler and Poulícková, 2003). The position of the layer formed by gas-vesiculate cyanobacteria may be determined by the irradiance throughout the course of the day (van Liere and Walsby, 1982). As cyanobacteria can accumulate at certain depths, the populations are often observed as blooms in a stratified layer of the water column (Reynolds et al., 1987; Halstvedt et al., 2007).

Studies carried out in a wide variety of habitats have recorded frequent occurrence of cyanobacteria populations and large biomasses formed by these organisms (van Rijn and Shilo, 1986; Romo and Miracle, 1993; Dokulil and Mayer, 1996; Dokulil and Teubner, 2000; Reynolds and Petersen, 2000; Mischke and Nixdorf, 2003; Stüken et al., 2006; Figueredo and Giani, 2009). However, few studies have focused on the vertical variation in cyanobacteria (Konopka, 1982; Hasler and Poulícková, 2003; Padisák et al., 2003; Jann-Para et al., 2004; Halstvedt et al., 2007).

Northeastern Brazil has areas marked by a well-defined dry season, often featuring prolonged drought, and a rainy season. These seasons are influenced by climatic events that, in turn, affect biological communities in reservoirs, especially the phytoplankton community.

Since the intoxication and death of 76 dialysis patients in the city of Caruaru, Pernambuco State, in 1996, large biomasses of different populations of cyanobacteria have often been recorded in northeastern Brazil (Azevedo, 1996; Bouvy et al., 2000; Costa et al., 2006, Moura et al., 2007; Chellappa et al., 2008; Dantas et al., 2008). The studies cited have demonstrated the occurrence of blooms, formed mainly by *Cylindrospermopsis raciborskii* (Woloszynska) Seenaya & Subba Raju, *Microcystis aeruginosa* (Kützing) Kützing or *Planktothrix agardhii* (Gomont) Anagnostidis & Komárek.

The northeastern Brazil reservoirs offer favourable conditions for the occurrence of cyanobacterial populations, which form different communities with accentuated vertical variation in specific biomass. Thus, the aim of the study was to determine the species composition and measure the biomass of cyanobacterial populations throughout the vertical and temporal gradient, correlating the populations with the environmental conditions in the different water column strata during the dry and rainy seasons in a eutrophic potable water reservoir in northeastern Brazil.

2. Material and Methods

The research was carried out at the Carpina reservoir in the district of the same name (8° 1' 27" S and 36° 8' 27" W), Pernambuco State, northeastern Brazil (Figure 1). Located in the lower course of the Capibaribe River, it receives organic waste as well as that from agricultural activities conducted upstream, involving temporary subsistence farming and perennial sugar-cane cultivation. This ecosystem is important for irrigation, drinking water supply and fishing throughout the basin. It has a high accumulation capacity ($2.7 \times 10^5 m^3$) and comprises 6,600 km^2 of the hydrographic basin. Based on rainfall data, the area is characterised climatologically by a dry season and a rainy season. According to the records of mean rainfall, the rainy season is between March and August, the lowest rainfall being in August and the highest in June, whereas the dry season extends from September to February. It has been demonstrated that the reservoir is eutrophic (Moura et al., 2007). Data on accumulated weekly rainfall from September 2007 to June 2008 and mean weekly and monthly air temperatures, were obtained from the Meteorology Institute (INPE, 2010).

The sampling station was established in the central region of the reservoir (07° 53' 42.1'' S and 35° 20' 27.2'' W), which has an average depth of 13.0 m. Samples were collected from a single sampling station in four dates: September 25, 2007; December 5, 2007; March 3, 2008; and June 6, 2008, at four predefined sampling depths, determined by the light penetration gradient – two in the photic zone (subsurface and 0.5 m) and two below the photic zone (2.0 m and 7.0 m).

Water samples were collected from four different depths using a horizontal van Dorn bottle. Abiotic variables were determined in situ: water temperature and dissolved oxygen using an oximeter (Schott Glaswerke Mainz, Handylab OX1); turbidity using a turbidimeter (Hanna Instruments, HI 93703); and pH using a potentiometer (Digimed, DMPH-2). Water transparency was determined using a Secchi disc. The photic zone was determined by the procedure described by Cole (1983). Determinations of the concentration of nitrite ($\mu g.N\text{-}NO_2.L^{-1}$) and nitrate ($\mu g.N\text{-}NO_3.L^{-1}$) were based on Mackereth et al. (1978) and Golterman et al. (1978), respectively. The determination of total phosphorus ($\mu g.TP.L^{-1}$) was based on Valderrama (1981), whereas that of total dissolved phosphorus ($\mu g.TDP.L^{-1}$) and orthophosphate ($\mu g.P\text{-}PO_4.L^{-1}$) followed Strickland and Parsons (1965).

Samples were preserved in 4% formaldehyde for taxonomic analysis. Identification was performed with an optical microscope (Zeiss/Axioskop) and based on specific literature for cyanobacteria. Water aliquots were preserved in acetic Lugol's solution for the determination of cell density ($cell.mL^{-1}$), based on Utermöhl (1958). Densities were converted into bio-volumes following the procedure in Hillebrand et al. (1999) and converted into

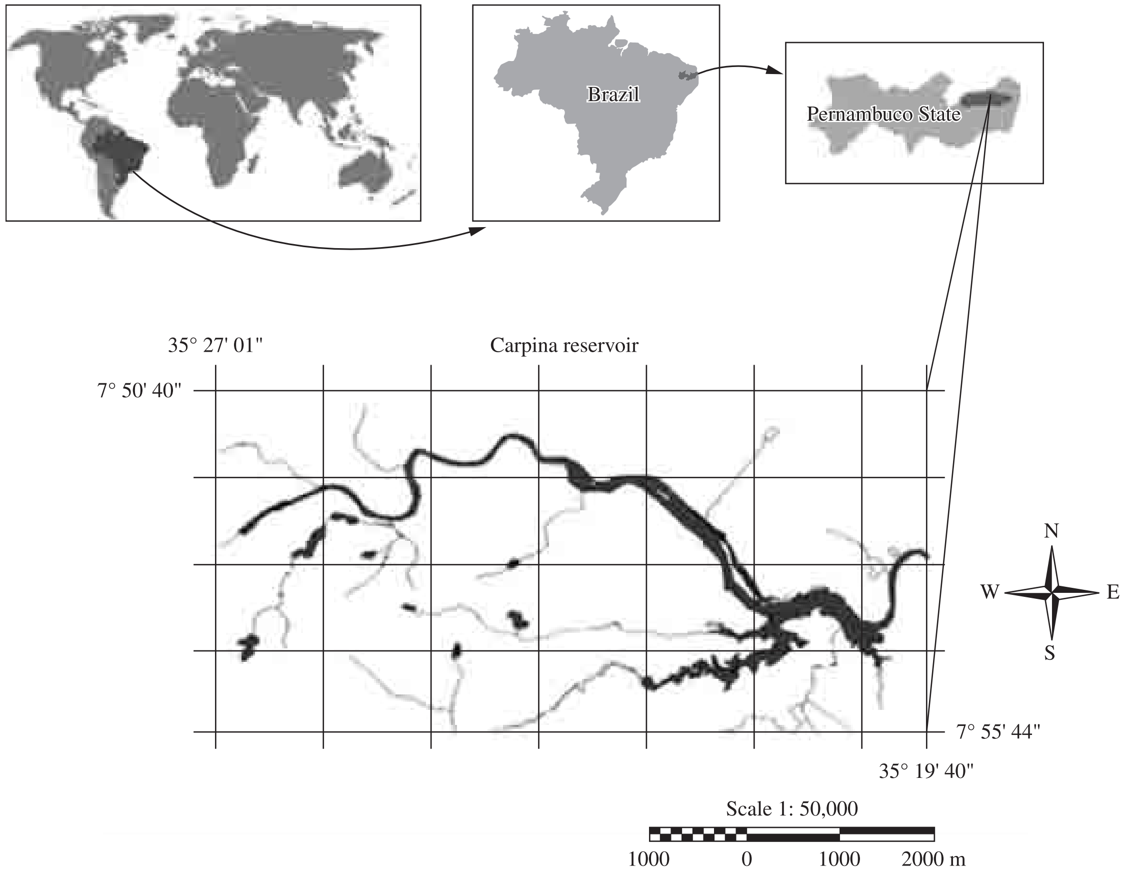

Figure 1. Map showing location of Carpina reservoir in Pernambuco State, northeastern Brazil.

biomass, assuming a gravity of 1 $mg.mm^3$ (Wetzel and Likens, 2000). Heterocytes and akinetes per trichome in *C. raciborskii* were sampled and recorded, expressed in percentages. Species abundance was determined by the method described by Lobo and Leighton (1986), which defines abundant species as those with biomass values above the mean values for the community.

Analysis of variance (ANOVA) was used, with the level of significance being set at 5%. Spearman's correlation (*rs*) was performed on cyanobacteria species in relation to abiotic variables. Statistical analysis was performed using the 2004 Statistica program (StatSoft, Inc., Tulsa, OK, USA). Canonical correspondence analysis (CCA) was used to assess associations between cyanobacteria and environmental variables. The abiotic variables were log transformed (x) and progressively reduced using the "forward selection" routine on the Canoco 4.5 program. Significance ($p < 0.05$) was tested using the Monte Carlo test, with 999 unrestricted permutations.

3. Results

Throughout the months studied, air temperature exhibited a variation of approximately 3 °C. The accumulated precipitation in the 30 days prior to each collection was 73 mm for September 2007, 20 mm for December 2007, 19 mm for March 2008 and 148 mm for June 2008.

Table 1 displays the vertical profiles of abiotic parameters. No significant vertical differences were found in turbidity ($F = 0.029$) or pH (0.014) ($p > 0.05$). Dissolved oxygen stratification occurred throughout the study period ($F = 5.762$, $p < 0.05$). No anoxia occurred at any sampling depth, whereas temperature stratification occurred in all sampling months, with the exception of June 2008. No vertical variations were found in total and dissolved forms of nutrients, total phosphorus ($F = 0.020$), total dissolved phosphorus ($F = 0.002$), orthophosphate ($F = 0.004$), nitrate ($F = 0.936$) and nitrite ($F = 0.041$) ($p > 0.05$).

Despite the small climatic variation among the study months, significant monthly differences occurred in water temperature ($F = 10.61$), turbidity ($F = 272.46$), pH ($F = 77.25$), total phosphorus ($F = 177.89$), total dissolved phosphorus ($F = 4299.77$), orthophosphate ($F = 1223.19$) and nitrite ($F = 158.79$) ($p < 0.05$). No significant differences were found for dissolved oxygen or nitrate ($F = 1.62$ and $F = 1.15$, respectively) ($p > 0.05$). In June 2008, there was no thermal stratification, turbidity presented its lowest values, and nutrient concentrations reached their highest values.

Table 1. Values for water temperature, dissolved oxygen, turbidity, pH, nitrite, nitrate, total nitrogen, total dissolved phosphorus, orthophosphate and total phosphorus, Secchi disc, photic zone, light attenuation coefficient (K) (m) values in September 2007, December 2007, March 2008 and June 2008 in the Carpina reservoir, northeastern Brazil.

Variables	Depths	Months			
		September	December	March	June
Water temperature (°C)	0.0 m	27.10	29.00	30.0	27.90
	0.5 m	27.00	28.80	29.2	27.90
	2.0 m	26.70	28.20	28.90	27.70
	7.0 m	26.40	27.60	27.80	27.60
Dissolved Oxygen ($mg.L^{-1}$)	0.0 m	8.50	5.90	11.50	6.00
	0.5 m	7.74	5.70	9.98	5.70
	2.0 m	7.05	3.00	5.65	4.40
	7.0 m	2.26	1.30	3.85	3.60
Turbidity (UNT)	0.0 m	505.00	57.00	60.00	43.92
	0.5 m	546.00	76.00	67.00	63.00
	2.0 m	619.00	97.00	83.00	61.00
	7.0 m	506.00	60.00	61.00	45.25
pH	0.0 m	8.04	8.82	8.40	8.31
	0.5 m	8.03	8.79	8.43	8.32
	2.0 m	8.03	8.73	8.41	8.38
	7.0 m	8.17	8.62	8.32	8.32
Nitrite ($\mu g.L^{-1}$)	0.0 m	3.21	6.42	5.20	871.29
	0.5 m	4.28	7.49	-	917.00
	2.0 m	4.28	14.98	10.4	817.02
	7.0 m	1.07	249.26	7.8	979.85
Nitrate ($\mu g.L^{-1}$)	0.0 m	39.98	13.33	12.61	195.27
	0.5 m	53.30	13.33	4.20	214.17
	2.0 m	6.66	33.32	5.60	201.57
	7.0 m	6.66	946.15	5.60	222.98
Total dissolved phosphorus ($\mu g.L^{-1}$)	0.0 m	41.28	27.52	109.55	-
	0.5 m	48.78	20.01	107.63	-
	2.0 m	51.28	38.77	134.54	-
	7.0 m	57.54	28.77	113.40	-
Orthophosphate ($\mu g.L^{-1}$)	0.0 m	43.85	43.85	152.32	-
	0.5 m	76.73	29.23	157.23	-
	2.0 m	73.08	54.81	167.06	-
	7.0 m	51.15	3.65	132.66	-
Total phosphorus ($\mu g.L^{-1}$)	0.0 m	116.46	111.28	223.66	1266.69
	0.5 m	115.17	121.64	231.84	1520.03
	2.0 m	106.11	116.46	240.02	1312.76
	7.0 m	108.70	104.81	215.47	1687.01
Secchi disc and Photic zone (m)		0.50 (1.35)	0.30 (0.81)	0.35 (0.95)	0.45 (1.22)
Light attenuation coefficient (K) (m)		3.40	5.77	4.86	3.78

Fourteen cyanobacteria were identified, belonging to three orders: Chroococcales, Oscillatoriales and Nostocales. Despite the low biomasses of *Chroococcus* sp. and *Aphanizomenon* sp., these species occurred throughout the study, whereas *C. minutus*, *Oscillatoria* sp., *Pseudanabaena* sp. and *Merismopedia punctata* Meyen only occurred in June 2008. *C. raciborskii* and *P. agardhii* were abundant throughout the study at all depths, and *Oscillatoria* sp. was abundant in June at depths below the photic zone (2.0 and 7.0 m) (Table 2). A large number of *C. raciborskii* trichomes had heterocytes (41.97%) and few had akinetes (0.45%).

Table 2 and Figure 2 display the vertical and temporal distribution of the biomass of each species. The biomass in June was approximately 50% lower than that in the other months studied. Vertical variations were found in species biomasses (Table 2). However, there were no significant vertical differences in the biomass of *C. raciborskii* ($F = 0.06$), *P. agardhii* ($F = 0.05$), *Pseudanabaena catenata* ($F = 0.014$), *G. amphibium* ($F = 0.43$) or *Oscillatoria* sp. ($F = 0.61$) ($p > 0.05$). Although the vertical differences did not achieve statistical significance, these species did not demonstrate a similar distribution pattern among depths throughout the study. Temporal differences were found in the biomass of the abundant species *C. raciborskii* ($F = 14.99$), *G. amphibium* ($F = 8.16$), *Oscillatoria* sp. ($F = 3.59$), *P. agardhii* ($F = 4.68$) and *P. catenata* ($F = 27.23$) ($p < 0.05$).

The results of the Canonical Correspondence Analysis are displayed in Table 3 and Figure 3. There were relationships among the environmental variables and the biological information and events did not take place randomly. The Eigenvalues of Axes one and two explain 42.0% of the biological data variance. The correlation of the species with the environmental conditions on both axes was high.

The CCA Axis one clearly separated June 2008 from the other months. Sampling units in June/08 were positively related to the axis, with total phosphorus correlated to this axis. The appearance of *Oscillatoria* sp. in June was positively correlated with the increase in nutrient concentrations ($rs = 0.49$, $p < 0.05$). In the others months, blooms were formed by *P. agardhii*, *C. raciborskii*, *P. catenata* and *G. amphibium.*

Axis two revealed that the sampling units in September 2007 were separated from those of December 2007 and March 2008. Turbidity was positively associated with Axis two, with the highest values in September 2007. Temperature was negatively associated to this axis and only grouped the sampling units in December 2007 and March 2008.

4. Discussion

Aquatic ecosystems exhibit spatial and temporal variability promoted by high levels of uncertainty in relation to phytoplankton communities. The dominance of a particular species within a phytoplankton community is related to a set of biotic and abiotic factors.

The environmental conditions of the Carpina reservoir are favourable to cyanobacteria and are determinants of the dynamics of this community. The highest water temperatures and greatest stratification occurred in March 2008, along with the greatest density of cyanobacteria. In June 2008, there was a considerable increase in nutrients, especially total phosphorus content, as well as accentuated de-stratification. This month also had the lowest density of cyanobacteria, an increase in richness (four species only occurred in this month), and the establishment of *Oscillatoria* sp. with greater biomasses below the photic zone. The occurrence and abundance of *Oscillatoria* sp. supports the observation made by Reynolds (1996) regarding the ideal environmental conditions for the development of species of the S association, which is formed by *Oscillatoria*-like genera.

In the eutrophic Carpina reservoir, which has high water temperatures (above 26 °C), the increase in nutrients in the water column and de-stratification may be understood as the product of mixture and input of allochtonous nutrients caused by rain. The synergism between these factors led to events of reorganization of the community and consequent reduction in the biomass of abundant species.

The multi-species biomass dominance that occurred in the reservoir was generally formed by *P. agardhii*, *C. raciborskii*, *G. amphibium* and *P. catenata*. The *P. agardhii* and *P. catenata* biomasses exhibited little variation throughout the study, whereas the *C. raciborskii* biomass was greater during the period of thermal stratification. The group formed by *P. agardhii*, *P. catenata* and *C. raciborskii* was influenced by turbidity and the amount of available nutrients, especially dissolved forms. Reynolds et al. (2002) classify these species as S1, as they inhabit mixed, turbid waters and are tolerant to light deficiency. The large amounts of *C. raciborskii* biomass (S_N) certainly occurred due to the fact that this organism does not require high degrees of luminosity (such as S1 species) as well as the fact that this species develops well in environments with high temperatures.

Despite the occurrence of toxic blooms of *M. aeruginosa* reported for northeastern Brazil (Azevedo, 1996; Chellappa et al., 2000; Costa et al., 2006), the current environmental conditions in the Carpina reservoir favour the occurrence of multi-species blooms formed by the association of filamentous non-heterocytic cyanobacteria and *C. raciborskii*, which is similar to findings described in other studies on eutrophic or hypertrophic reservoirs in tropical, subtropical and temperate regions. In Albufera Lake in Valencia, Spain, Romo and Miracle (1994) found that filamentous cyanobacteria account for 80 to 90% of the total biomass. The authors also found an increase in *C. raciborskii*, *P. subtilis* and *Planktolyngbya contorta* (Lemmermann) Anagnostidis & Komárek during periods in which there was an increase in the N:P ratio, followed by quiescence of the water. Mischke (2003) found two types of cyanobacteria associations – one formed by *P. agardhii* and *A. gracile* and another formed by *Limnothrix amphigranulata*,

Table 2. Biomass values ($mg.L^{-1}$) for each species at each depth in September 2007, December 2007, March 2009 and June 2008 in the Carpina reservoir, northeastern Brazil; abundant species in bold type.

Species	September				December				March				June			
	0.0 m	**0.5 m**	**2.0 m**	**7.0 m**	**0.0 m**	**0.5 m**	**2.0 m**	**7.0 m**	**0.0 m**	**0.5 m**	**2.0 m**	**7.0 m**	**0.0 m**	**0.5 m**	**2.0 m**	**7.0 m**
Chroococcales																
Aphanocapsa elachista W. West & G.S. West	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0042	0.0000	0.0056	0.0112	0.0112
Chroococcus minimus (Keissler) Lemmermann	0.0000	0.0000	0.0000	0.0000	0.0014	0.0000	0.0000	0.0000	0.0000	0.0095	0.0071	0.0047	0.0000	0.0013	0.0000	0.0062
Chroococcus minutus (Kützing) Nägeli	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0078	0.0148	0.0383	0.0078
Chroococcus sp.	0.0000	0.0073	0.0073	0.0073	0.0000	0.0073	0.0073	0.0073	0.0000	0.0000	0.0107	0.0000	0.0000	0.0050	0.0146	0.0050
Merismopedia punctata Meyen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0073	0.0145
Microcystis aeruginosa (Kützing) Kützing	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2343	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nostocales																
Anabaena circinalis Rabenhorst	0.0000	0.0000	0.0000	0.0000	0.2540	0.0000	0.3262	0.2228	0.0000	0.0000	0.0000	0.0000	0.0761	0.0000	0.0000	0.0000
Aphanizomenon gracile Lemmermann	0.0200	0.1000	0.0599	0.0200	0.0000	0.0763	0.0971	0.0200	0.0728	0.1200	0.0191	0.0200	0.0000	0.0266	0.0400	0.0400
Cylindrospermopsis raciborskii (Woloszynska) Seenaya & Subba Raju	**1.2925**	**1.6336**	**1.1969**	**1.7835**	**2.5013**	**2.1647**	**2.2938**	**2.3936**	**3.3985**	**2.1715**	**2.0959**	**1.9550**	**0.4006**	**0.8751**	**1.0782**	**0.7871**
Oscillatoriales																
Geitlerinema amphibium (C. Agardh) Anagnostidis	**0.1505**	0.0903	0.2257	0.0752	**0.6931**	**0.6101**	**0.4457**	0.2680	**0.5765**	**0.7210**	**1.4668**	**0.9932**	**0.3311**	**0.3110**	**0.6320**	**0.4715**
Oscillatoria sp.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0558	**0.2792**	**0.4467**
Planktothrix agardhii (Gomont) Anagnostidis & Komárek	**1.6644**	**2.8532**	**2.4728**	**2.1875**	**2.3016**	**1.9454**	**2.2441**	**2.7943**	**3.3774**	**1.6817**	**2.2554**	**1.5930**	**0.5389**	**1.1413**	**1.4900**	**1.2047**
Pseudanabaena catenata Lauterborn	**0.6685**	**0.8940**	**1.0184**	**0.9173**	0.2760	0.3056	0.1986	0.1220	0.9854	**0.8014**	**0.9853**	**0.7054**	0.0156	**0.3576**	**0.3705**	**0.3290**
Pseudanabaena sp.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0090	0.0209	0.0120
Total biomass	3.7959	5.5711	4.9737	4.9835	6.0260	5.1021	5.6055	5.8207	8.4106	5.4955	6.8226	5.2666	1.3623	2.7763	3.9108	3.2909

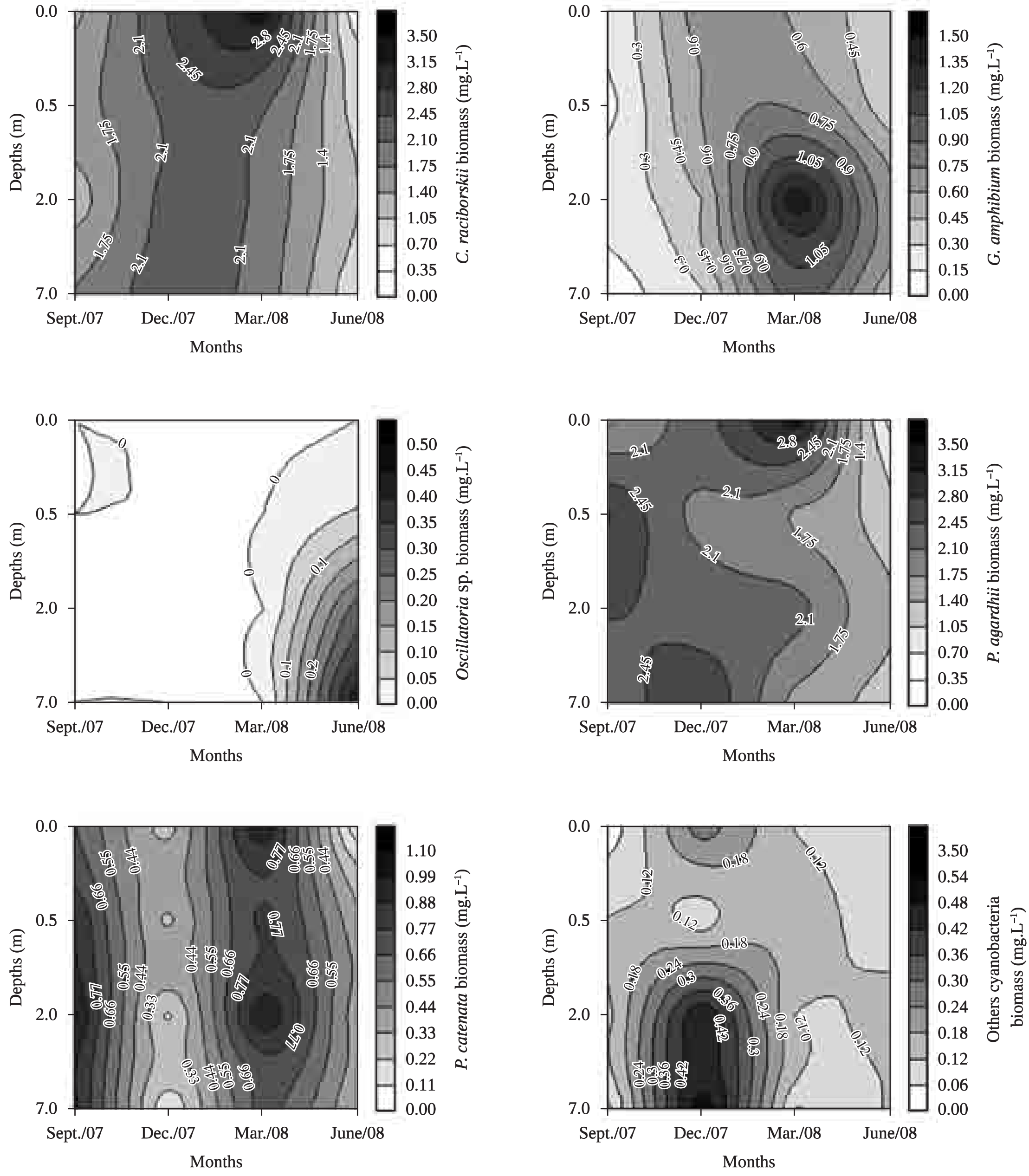

Figure 2. Vertical profiles and temporal variations in biomass of abundant cyanobacteria and other cyanobacteria (mg.L^{-1}) in the Carpina reservoir, northeastern Brazil.

L. planctonica and *Pseudanabaena* species – in the Langer See and Melangsee lakes in Brandenburg, Germany.

The results of the study reveal that vertical variations were less pronounced than seasonal variations in cyanobacterial populations in the Carpina reservoir, which is a tropical eutrophic environment with high temperatures throughout the water column. Perennial multi-species blooms of cyanobacteria were predominantly formed by species capable of regulating their position in the water column (those with gas vasicles for buoyancy). The species were abundant in both photic and aphotic strata that presented little variation in temperature. Greater intensity of rain led to over-saturation of nutrients, de-stratification of the water column, reduction in underwater light intensity, and was the greatest factor in the reorganization of the phytoplankton community. However, the rains did not significantly alter the dominance of the species of cyanobacteria.

Table 3. Statistical summary and correlation coefficients for cyanobacteria species and abiotic variables on the first two CCA axes for the Carpina reservoir, Pernambuco, Brazil.

	Axis 1	**Axis 2**
Eigenvalues	0.053	0.026
Accumulated variance in biotic data (%)	28.1	42.0
Accumulated variance in species-environment relation (%)	57.4	85.8
Species-environment correlation	0.743	0.846
Monte Carlo test		
Significance of first canonical axis - *p*	0.048	
Significance of all canonical axes - *p*	0.003	

	Canonical coefficient		Intra-set correlation	
	Axis 1	Axis 2	Axis 1	Axis 2
Water temperature (T °C)	-0.12	-0.54	-0.16	-0.64
Turbidity (Turb)	-0.28	0.69	-0.37	0.82
Total phosphorus (TP)	0.69	0.15	0.93	0.17
Total dissolved phosphorus (TDP)	-0.55	-0.06	-0.73	-0.07

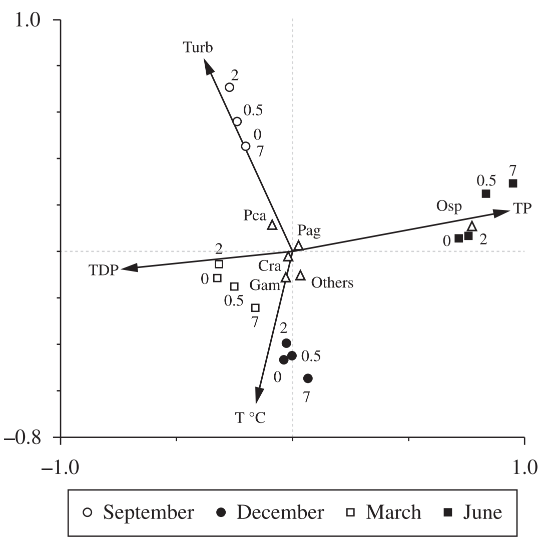

Figure 3. Biplot of CCA abiotic variables (T °C = water temperature, Turb = turbidity, TDP = total dissolved phosphorus and TP = total phosphorus) and dominant and abundant cyanobacteria in the Carpina reservoir. Cra = *Cylindrospermopsis raciborskii*, Gam = *Geitlerinema amphibium*, Osp = *Oscillatoria* sp., Pag = *Planktothrix agardhii*, Pca = *Pseudanabaena catenata*; Others = Others cyanobacteria. The numbers represent the depths.

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