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Phytoplankton abundance, dominance and coexistence in an eutrophic reservoir in the state of Pernambuco, Northeast Brazil

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ABSTRACT

The present study reports the phytoplankton abundance, dominance and co-existence relationships in the eutrophic Carpina reservoir, Pernambuco, Brazil. Sampling was carried out at six different depths bimonthly at a single reservoir spanning two climatic periods: dry season (January, September, and November 2006) and rainy season (March, May, and July 2006). Density, abundance, dominance, specific diversity and equitability of the community were determined, along with chlorophyll *a*, and physical and chemical variables of the environment. Eight species were considered abundant, and their densities corresponded to more than 90% of the total phytoplankton community quantified. Cyanobacteria represented more than 80% of this density. *Cylindrospermopsis raciborskii* was the only dominant taxon in the dry season, and was co-dominant in the rainy season. *C. raciborskii*, *Planktothrix agardhii* and *Geitlerinema amphibium* had the greatest densities and lowest vertical variation coefficients. The statistical analysis indicated relationships with vertical and seasonal variations in the phytoplankton community and the following variables: total dissolved solids, water temperature, electrical conductivity and pH. The changes in the environmental variables were discrete and regulated by the establishment of precipitation however, they were able to promote vertical and seasonal instability in the structure of the phytoplankton community.

Key words: Carpina reservoir, *Cylindrospermopsis raciborskii*, Cyanobacteria, limnological characteristics, phytoplankton structure, vertical distribution.

INTRODUCTION

Most reservoirs are formed by the damming of rivers and are considered hybrid systems between rivers and lakes (Thornton et al. 1990). The importance of these artificial aquatic systems is huge, especially in the northeastern Brazil, which is largely dominated by a semi-arid climate, with long periods of drought (Chellapa and Costa 2003). The purposes of reservoirs include providing water for the public, flood control, the production of electricity, irrigation, navigation, the farming of aquatic organisms and recreation.

Problems regarding artificial eutrophication in reservoirs are common and are caused by anthropogenic actions, which lead to innumerous changes in the structure and dynamics of the phytoplankton community. This community is one of the main groups of primary producers and promptly responds to nutrient changes in reservoir aquatic ecosystems. According to Margalef (1983), the composition of the phytoplankton community and the relationship among its species reflect the scope of such changes in an environment better than any technological tool. Environmental changes frequently stimulates results in high densities of phytoplankton, known as algal blooms, which could compromise wa-

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ter quality and have serious consequences to the health of humans and animals (Bouvy et al. 2003). A classic example of these effects occurred in the city of Caruaru (PE, Brazil) in 1996, with the death of dozens of patients in a dialysis clinic following the contact with water contaminated by toxins released by blooms of Cyanobacteria (Jochimsen et al. 1998).

Knowledge on the structure and dynamics of the phytoplankton community is extremely important to understand the effects of eutrofication, which are fundamental to the comprehension of the behavior and characterization of the community (Crossetti and Bicudo 2005). Despite the increase in phytoplankton research, the scarcity of studies on vertical and seasonal variations in eutrophic ecosystems (especially in northeastern Brazil) lends importance to the present investigation.

There have been a large number of studies on eutrophic ecosystems in Brazil in the last ten years, mainly addressing Cyanobacteria ecology. The dominance and coexistence of species of Cyanobacteria in Marechal Dutra reservoir (Rio Grande do Norte, Brazil) were determined throughout a long dry period with low water transparency, the presence of inorganic nutrients, anoxia of the hypolimnion and high degree of electrical conductivity (Chellapa and Costa 2003). The favorable climatic conditions to the development of phytoplankton and the increasing eutrophication of bodies of water lead to the emergence of blooms of specific invading groups, such as Cyanobacteria (Crossetti and Bicudo 2005). In the state of Pernambuco (Brazil), saxitoxins and anatoxin-*a* were detected in samples collected from the Tapacurá reservoir during blooms caused by *Anabaena spiroides* Klebahn, *Pseudanabaena* sp. *Cylindrospermopsis raciborskii* (Woloszynska) Seenaya and Subba Raju, and *Microcystis aeruginosa* (Kützing) Kützing from March to May 2002 (Molica et al. 2005).

The Carpina reservoir in the state of Pernambuco, which is the subject of the present study, was initially constructed for flood control purposes and currently provides water for the surrounding towns, as well as being an important fishing source for the river communities of the region. The Carpina reservoir has eutrophic characteristics once it receives organic and agricultural wastes. From April 2001 to March 2002, the structure of the phytoplankton community of the reservoir had its surface and bottom (not the entire water column) compared, and dense blooms of *Planktothrix agardhii* (Gomont) Anagnostidis and Komárek were observed (Moura et al. 2007). However, no significant differences were found. The aim of the present study was to carry out a survey of the Carpina reservoir in the northeastern Brazil with regard to the phytoplankton community, addressing seasonal and vertical variations in composition and density, as well as relating these characteristics to limnological and climatic variables.

MATERIALS AND METHODS

The Carpina reservoir (7°51′ and 7°57′S, 35°19′ and 35°27′W) is located in the coastal plantation zone of the state of Pernambuco (Brazil), and is part of the Capibaribe River basin. The reservoir has an accumulation capacity of approximately 270,000,000 m^3. The climate of the region is characterized as warm, humid, pseudotropical according to Köppen classification. There are two distinct seasons: a rainy season from March to August and a dry season from September to February (Moura et al. 2007).

Sampling was carried out at a single point in the reservoir located in the limnetic zone near the dam and spillway (07°53′51″S, 35°20′13″W) at six depths that were defined based on the indirect calculation of the vertical light attenuation coefficient (Poole and Atkins 1929): a) surface (100% available light); b) 1.0 m; c) 2.0 m; d) 4.0 m; (to 1% available light); e) 8.0 m; and f) 10.0 m. Sampling was carried out between January and November 2006, spanning three months of the dry season (DS – January, September and November) and three months of the rainy season (RS – March, May and July). The monthly data were treated as repetitions of the climatic seasons and presented as the mean of each period.

In the studied period, the region was climatically characterized by daily and hourly (09:00 am and 3:00 pm) values of the following parameters: air temperature, which ranged from 28.1 to 29.6°C in the dry season, and 25.8 to 30.5°C in the rainy season; wind direction and speed, which was instable in the dry season, oscillating between southeasterly and easterly and ranging from 2.5 to 3.5 m/s; wind oscillating between southerly and northeasterly and ranging from 1.6 to 3.5 m/s in the rainy season. Daily exposure to sunlight ranged from 8.2 to 9.5 hours in the dry season, and from 6.8 to 10.1 hours in the rainy season. Monthly precipitation ranged from 12.3 to 84.0 mm in the dry season, and from 158.2 to 338.0 mm in the rainy season (INMET – National Meteorology Institute).

Three samples for the quantitative analysis were collected using a wide-mouth recipient at the surface, and a Van Dorn bottle at different depths was used for the qualitative and quantitative analyses of the phytoplankton community and chlorophyll *a*. The samples for the quantitative analysis were preserved in a solution of acetic Lugol.

The following physicochemical limnological variables were determined: water transparency (Secchi disk – Z_{ds}); euphotic zone, based on Cole (1975) ($Z_{euf} = Z_{ds} \times 3.0$); water temperature (°C); dissolved oxygen ($mg.L^{-1}$), using a field oxymeter (Handylab OX1); turbidity (NTU), using a turbidimeter (model HI93703); pH, electrical conductivity ($\mu S.cm^{-1}$) and total dissolved solids ($mg.L^{-1}$), using a field YSI device (model 556).

The phytoplankton community was identified with the aid of specialized literature for each group of alga using a binocular microscope (Zeiss, Axiovert). The quantitative analysis (organisms per liter) was based on the method described by Utermöhl (1958) using an inverted microscope (Zeiss, Axiovert), following the calculation method described by Villafaiñe and Reid (1995). Organism counts were carried out on a grid with three repetitions for each depth sampled; the values are presented as the mean of the repetitions. Density values were transformed into scientific notation ($\times 10^4$).

Chlorophyll *a* analysis was based on the method described by Chorus and Bartram (1999) using heated 90% alcohol. Chlorophyll *a* was used for the determination of the trophic state index – TSI (Chl-*a*), along with the transparency values obtained from the Secchi disc, following the method described by Carlson (1977) and modified for tropical environments by Toledo Jr. (1983).

For the analysis of the abiotic variables, mean ($\overline{X}$), standard deviation (σ) and coefficient of variance (CV) values were determined. Abundance and dominance were determined from the density data, following the criteria proposed by Lobo and Leighton (1986). Abundant species were those with values above the mean value of the community, and dominant species were those with values surpassing 50% of the total density. Species diversity and evenness indices ($bit.cel.^{-1}$) were calculated based on the methodology proposed by Pielou (1977) using the "Diversity" statistical program. The scaling of the data was performed using principal component analysis (PCA) with the aid of the NTSYS statistical package (version 2.1). The data were then selected for the subsequent correlations of the sample units, environmental variables and abundance species, using canonical correspondence analysis (CCA) with the aid of the PC-Word program. Significance among the data was assessed using the Monte Carlo permutation test ($p<0.05$) with the aid of the PC-Word program.

RESULTS

ABIOTIC VARIABLES

The highest mean air temperature, wind speed and exposure to sunlight values occurred in the first month of the rainy season. Precipitation was typical for the region. The depth of the Secchi disc (0.30 to 0.70 m in the dry season and 0.40 to 0.85 m in the rainy season) and the eutrophic zone (Z_{euf}) (0.90 to 2.10 m in the dry season and 1.20 to 2.55 m in the rainy season) exhibited little variation between seasons, with slightly higher values in the rainy season. The vertical light attenuation coefficient ranged from 2.40 to 5.60 m in the dry season, and from 2.0 to 4.25 m in the rainy season, with a total absence of light beginning at the depth of 6.0 m.

The water column exhibited an average pattern of low stratification throughout the entire study ($\sigma = 0.3$; $CV = 1.0$) and slightly higher values in the rainy season. Water temperature ($\overline{x} = 27.5$ in the dry season; $\overline{x} = 28.1$ in the rainy season), dissolved oxygen ($\overline{x} = 4.38$ in the dry season; $\overline{x} = 5.18$ in the rainy season), electrical conductivity ($\overline{x} = 1914$ in the dry season; $\overline{x} = 2060$ in the rainy season), total dissolved solids ($\overline{x} = 1246$ in the dry season; $\overline{x} = 1699$ in the rainy season) and turbidity ($\overline{x} = 23.1$ in the dry season; $\overline{x} = 22.0$ in the rainy season) values were higher in the rainy season, whereas pH ($\overline{x} = 8.6$ in the dry season; and $\overline{x} = 8.5$ in the rainy season) was slightly higher in the dry season (Fig. 1).

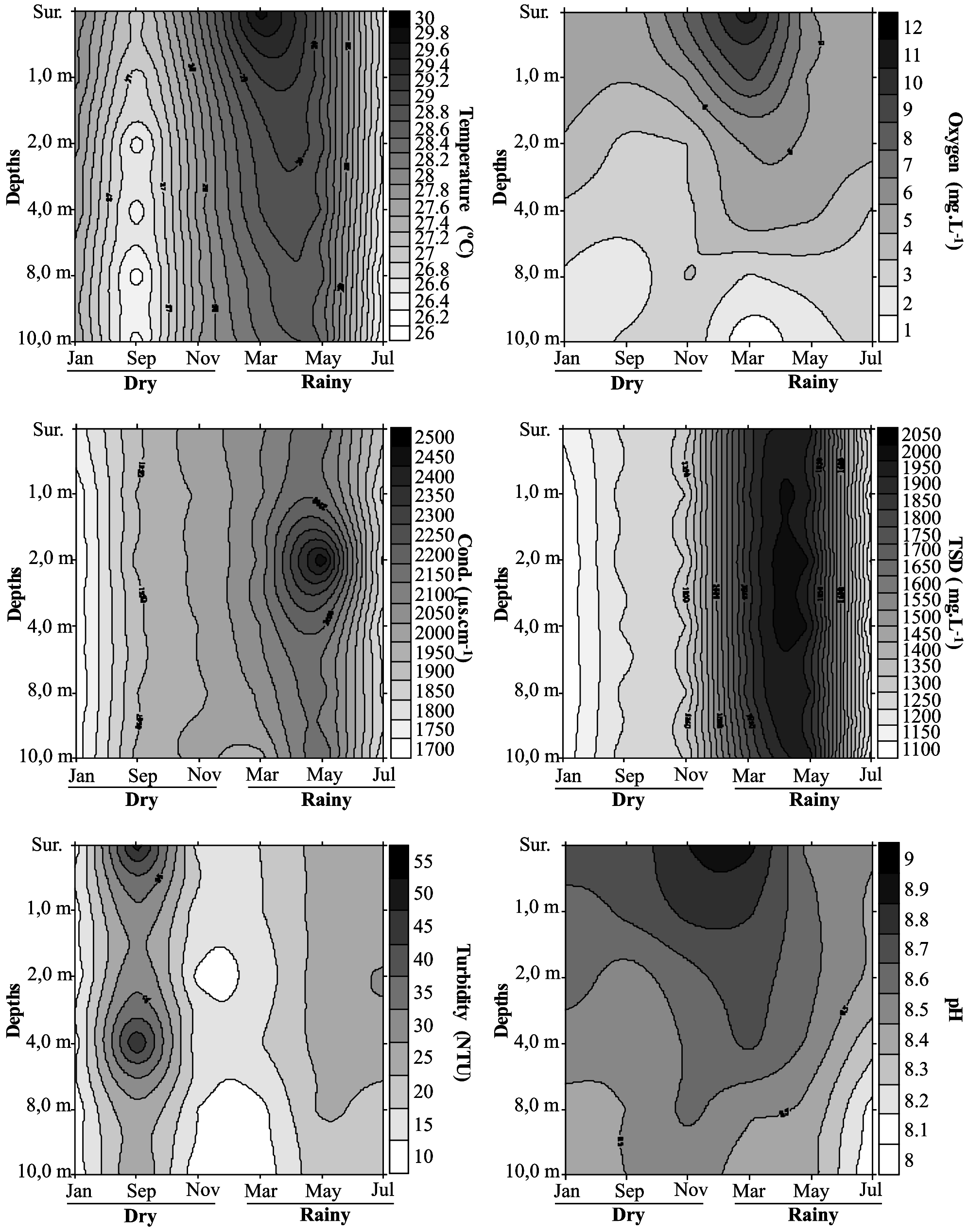

Fig. 1 – Mean seasonal and vertical variation in temperature, dissolved oxygen, electrical conductivity, total dissolved solids, turbidity and pH in the Carpina reservoir (PE, Brazil) from January to November 2006 (DS: dry season; RS: rainy season).

BIOTIC VARIABLES

Sixty-one taxa distributed among five divisions were inventoried: 27 Chlorophyta (44%), 20 Cyanobacteria (33%), four Euglenophyta (7%), eight Bacillariophyta (13%), and two Dinophyta (3%) (Table I). Chlorophyta had the greatest contribution to taxon richness in both seasons, with a greater number of species in the rainy season, whereas there was a decrease in species of Cyanobacteria in the dry season. The remaining groups exhibited little variation between seasons. Species diversity was discreetly greater in the rainy season. However, there were values ranging from 1.0 to 2.0 bit.cel.$^{-1}$ throughout the study, indicating low diversity in the phytoplankton community. Evenness was ≤ 0.5, thereby indicating a predominance of one or more species.

TABLE I

Species list of the phytoplankton community in the Carpina reservoir (PE, Brazil) from January to November 2006.

SPECIES LIST
CYANOBACTERIA
CYANOPHYCEAE
CHROOCOCCALES
CHROOCOCACEAE
Chroococcus limneticus Lemmermann
Chroococcus minutus (Kützing) Nägeli
Chroococcus minimus (Keissler) Lemmermann
Chroococcus turgidus (Kützing) Nägeli
MERISMOPEDIACEAE
Aphanocapsa sp.
Merismopedia punctata Meyen
Merismopedia minima Beck
MICROCYSTACEAE
Microcystis aeruginosa (Kützing) Kützing
Microcystis flos-aquae (Wittrock) Kirchner
Microcystis robusta (Clark) Nygaard
Microcystis wesenbergii (Komárek) Komárek
SYNECHOCOCCACEAE
Synechocystis sp.
NOSTOCALES
NOSTOCACEAE
Anabaena constricta (Szafer) Geitler
Anabaena circinalis Rabenhorst
Cylindrospermopsis raciborskii (Woloszynska) Seenaya & Subba Raju
Raphidiopsis mediterranea Skuja
OSCILLATORIALES
OSCILLATORIACEAE
Oscillatoria princeps Vaucher ex Gomont
PHORMIDIACEAE
Planktothrix agardhii (Gomont) Anagnostidis & Komárek
PSEUDANABAENACEAE
Geitlerinema amphibium (C. Agardh) Anagnostidis
Pseudanabaena catenata Lauterbom
BACILLARIOPHYTA
COSCINODISCOPHYCEAE
THALASSIOSIROPHYCIDAE
THALASSIOSIRALES
STEPHANODISCACEAE
Cyclotella meneghiniana Kützing
Coscinodiscus sp.
COSCINODISCOPHYCIDAE
AULACOSEIRALES
AULACOSEIRACEAE
Aulacoseira granulata (Ehrenberg) Simonsen
FRAGILARIOPHYCEAE
FRAGILARIOPHYCIDAE
FRAGILARIALES
FRAGILARIACEAE
Synedra rumpens Kützing
Ulnaria ulna (Nitzsch) P. Compère
BACILLARIOPHYCEAE
BACILLARIOPHYCIDEAE
NAVICULALES
PINNULARIACEAE
Pinnularia sp.
NAVICULINEAE
PLEUROSIGMATACEAE
Gyrosigma sp.
BACILLARIALES
BACILLARIACEAE
Nitzschia sp.
CHLOROPHYTA
CHLOROPHYCEAE
CHLOROCOCCALES
GOLENKINIACEAE
Golenkinia radiata Chodat
SCENEDESMACEAE
Crucigenia fenestrata (Schmidle) Schmidle
Crucigenia tetrapedia (Kirchner) W. West & G.S. West
Crucigenia quadrata Morren
Scenedesmus acuminatus (Lagerheim) Chodat
Scenedesmus quadricauda (Turpin) Brébisson
Tetrastrum triangulare (Chodat) Komárek
Tetradesmus wisconsinensis G.M. Smith
COELASTRACEAE
Actinastrum gracillimum Smith
Actinastrum hantzschii Lagerheim
Coelastrum microporum Nägeli
Coelastrum astroideum De Notaris
BOTRYOCOCCACEAE
Dictyosphaerium pulchellum H.C. Wood
CHLORELLACEAE
Ankistrodesmus gracilis (Reinsch) Korshikov
Chlorella vulgaris Beijerinck
Monoraphidium arcuatum (Korshikov) Hindák
Monoraphidium contortum (Thuret) Komàrková-Legnerová
Monoraphidium griffithii (Berkeley) Komárková-Legnerová
Kirchneriella obesa (G.S. West) Schmidle
Kirchneriella lunaris (Kirchner) K. Möbius
Kirchneriella lunaris var. *irregularis* G.M Smith
SPHAEROPLEALES
NEOCHLORIDACEAE
Schroederia sp.
Tetraedron minimum (A. Braun) Hansgirg
TETRASPORALES
PALMELLACEAE
Sphaerocystis sp.
Planktosphaeria gelatinosa G.M. Smith
ZYGNEMATALES
CLOSTERIACEAE
Closterium sp.
VOLVOCALES
CHLAMINOMONADACEAE
Chlamydomonas sp.
DINOPHYTA
DINOPHYCEAE
PERIDINIALES
GYMNODINIACEAE
Gymnodinium sp.
PERIDINIACEAE
Peridinium sp.
EUGLENOPHYTA
EUGLENOPHYCEAE
EUGLENALES
EUGLENACEAE
Euglena sp.
Phacus curvicauda Svirenko
Trachelomonas volvocina Ehrenberg
Trachelomonas sp.

Mean chlorophyll *a* values ranged from 29.4 to 58.3 mg.m^{-3} in the dry season, and from 38.6 to 54.1 mg.m^{-3} in the rainy season. The amplitude of the coefficient of variation for chlorophyll *a* throughout the water column was twice as large in the dry period compared to the rainy season (CV = 26.6% in the dry season, and 11.8% in the rainy season) (Fig. 2). The TSI (Chl-*a*) ranged from 63.7 to 70.5 in the dry season, and 66.4 to 69.7 in the rainy season (Fig. 2). Among depths, the coefficient of variance for the TSI (Chl-*a*) was 3.9% in the dry season and 1.8% in the rainy season. The classification of the TSI by the Secchi disc also revealed hypereutropic values, ranging from 65 to 77.3 in the dry season, and 62 to 73.2 in the rainy season.

Mean phytoplankton density ranged from 1410 × 10^4 org.L^{-1} (surface) to 1135 × 10^4 org.L^{-1} (8 m) in the dry season, and from 1798 × 10^4 org.L^{-1} (surface) to 1000 × 10^4 org.L^{-1} (10.0 m) in the rainy season. All groups had higher density values in the rainy period, with Cyanobacteria making the greatest contribution [1440 × 10^4 org.L^{-1} (surface) to 889 × 10^4 org.L^{-1} (10.0 m)], followed by Chlorophyta [154 × 10^4 org.L^{-1} (surface) to 60 × 10^4 org.L^{-1} (10.0 m)], Bacillariophyta [84 × 10^4 org.L^{-1} (surface) to 43 × 10^4 org.L^{-1} (10.0 m)], Euglenophyta [118 × 10^4 org.L^{-1} (surface) to 7 × 10^4 org.L^{-1} (10.0 m)] and Dinophyta [1.2 × 10^4 org.L^{-1} (surface) to 0.3 × 10^4 org.L^{-1} (2.0 and 8.0 m)] (Fig. 3).

Cyanobacteria was dominant throughout the study, accounting for an average of 93% of total density in the dry season, and 84% in the rainy season, with an average variation among depths of 1063 × 10^4 (4.0 m) org.L^{-1} to 1331 × 10^4 org.L^{-1} (surface) in the dry season, and from 889 × 10^4 org.L^{-1} (10.0 m) to 1440 × 10^4 org.L^{-1} (surface) in the rainy season (Fig. 3). The analysis of the vertical pattern revealed that the phytoplankton groups exhibited distinct distribution patterns. In the dry season, homogenous distribution was observed for Cyanobacteria and Chlorophyta (CV = 8% and CV = 16%, respectively). Bacillariophyta was concentrated at intermediate depths (1.0 and 2.0 m) and at the deepest depth (10.0 m, CV = 56%), whereas Euglenophyta occurred primarily at shallow depths (CV = 80%). Dinophyta contributed little to the community in the dry season, with larger populations between 2.0 and 4.0 m. In the rainy season, all groups of alga generally exhibited greater concentrations of individuals in the surface strata (surface and 1.0 m).

The greater contribution of Cyanobacteria to total density occurred mainly due to blooms of *Cylindrospermopsis raciborskii*, which ranged from 854 × 10^4 org.L^{-1} (surface) to 548 × 10^4 org.L^{-1} (10.0 m) in the rainy season, and from 977 × 10^4 org.L^{-1} (surface) to 757 × 10^4 org.L^{-1} (4.0 m) in the dry season, with an approximately 17% difference between seasons. Greater densities of *C. raciborskii* occurred at the surface in both seasons. However, the coefficients of variation among the depths were low (9% in the dry season, and 14% in the rainy season), indicating equilibrium in their distribution.

Eleven of the taxa had the greatest contributions to abundance. The Cyanobacteria *C. raciborskii*, *Planktothrix agardhii*, *Geitlerinema amphibium* (C. Agardh) Anagnostidis and *Pseudanabaena catenata* Lauterborn, as well as the Chlorophyta *Monoraphidium arcuatum* (Korshikov) Hindák and *Monoraphidium griffithii* (Berkeley) Komárková-Legnerová, were common in both seasons. *Anabaena constricta* (Szafer) Geitler, *Cyclotella meneghiniana* Kützing, *Synedra rumpens* Kützing, *Nitzschia* sp. and *Euglena* sp. were abundant only in the rainy season. Abundant species accounted for 90.6% of the total density in the dry season, and 92.8% in the rainy season. *C. raciborskii*, *P. agardhii* and *G. amphibium* had the greatest densities and lowest coefficients of variation between depths throughout the study.

C. raciborskii was the only dominant species in the dry season, accounting for 69% of the total density. The greatest densities were also attributed to *C. raciborskii* in the rainy season, which accounted for 49.6% of the total phytoplankton community. However, this value did not constitute dominance.

PRINCIPAL COMPONENT ANALYSIS AND CANONICAL CORRESPONDENCE ANALYSIS

Principal component analysis (PCA) explained 83.9% in Factors 1 and 2, with a grouping of the species *A. constricta* (Aco), *P. agardhii* (Pag) and *M. griffithii* (Mgr) on the positive side of Axis 1 and a negative association (negative side of Axis 1), with a relationship between *C. raciborskii* (Cra) and water temperature

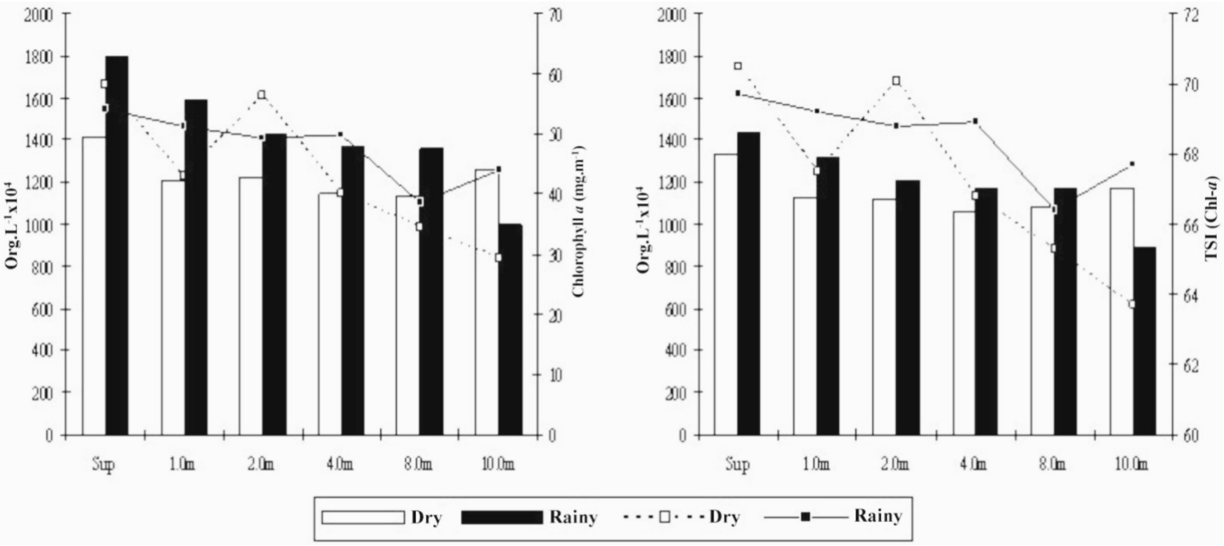

Fig. 2 – A) Variation in total phytoplankton density (columns) and Chlorophyll a (lines) between the analyzed depths. B) Variation in Cyanobacteria density (columns) and TSI (Chl-*a*) (lines) between depths analyzed in the Carpina reservoir (PE, Brazil) from January to November 2006.

(T °C). Also on the negative side of Axis 1, there was an association between conductivity (Cond) and total dissolved solids (TDS). On Axis 2, there was a positive association between dissolved oxygen (Oxy) and chlorophyll *a* (Chl-*a*) (Fig. 4 and Table II).

The Monte Carlo test revealed that the correlation of the data from the canonical correspondence analysis was only significant ($p<0.05$) for Axis 1, indicating a relationship between some of the environmental and biological variables (Table III). From an analysis of the canonical coefficients, total dissolved solids proved to be the variable of greatest importance in the scaling of the data. However, the "inter-set" correlations also revealed a strong influence of water temperature, electrical conductivity and pH over the species *C. raciborskii* and *G. amphibium* (Table IV and Fig. 5).

DISCUSSION

The monitoring of water quality using a biological approach is a relatively recent practice. These studies involving phytoplankton organisms in reservoirs represent a significant advance in the determination of water quality in these aquatic systems. The knowledge on the phytoplankton dynamics is relevant because temporal and spatial fluctuations in its composition and biomass may be efficient indicators of natural or antropic alterations in the aquatic ecosystems (Lira et al. 2009).

The phytoplankton community exhibited some variation in composition and richness between the dry and rainy seasons. However, these changes involved species classified as occasional in the ecosystem, accounting for less than 0.5% of the organisms quantified in each season. Changes were observed in species diversity and evenness, but such changes were not sufficient to alter the indicators of low diversity and non-homogeneous distribution of individuals among the species. In eutrophic reservoirs, it is common to report low values for these indices, as environmental conditions in a situation of trophy tend to favor a small number of species that have large densities and alternate in the dominance of the community (Huszar et al. 1998, Figueiredo and Giani 2001, Chellapa and Costa 2003).

All the taxonomic groups in the Carpina reservoir had higher numbers of organisms in the rainy season, with greater contributions from Cyanobacteria and Chlorophyta. These changes were more evident in the first sampling in the period – a time of transition between seasons. According to others studies, this transition period causes greater instability in the phytoplankton community once the environmental characteristics of the new climatic season are not yet well defined, and the phytoplankton response occurs under the influence of the previous season (Figueiredo and Giani 2001, Dos Santos and Calijuri 1998). Thus, the higher water tem-

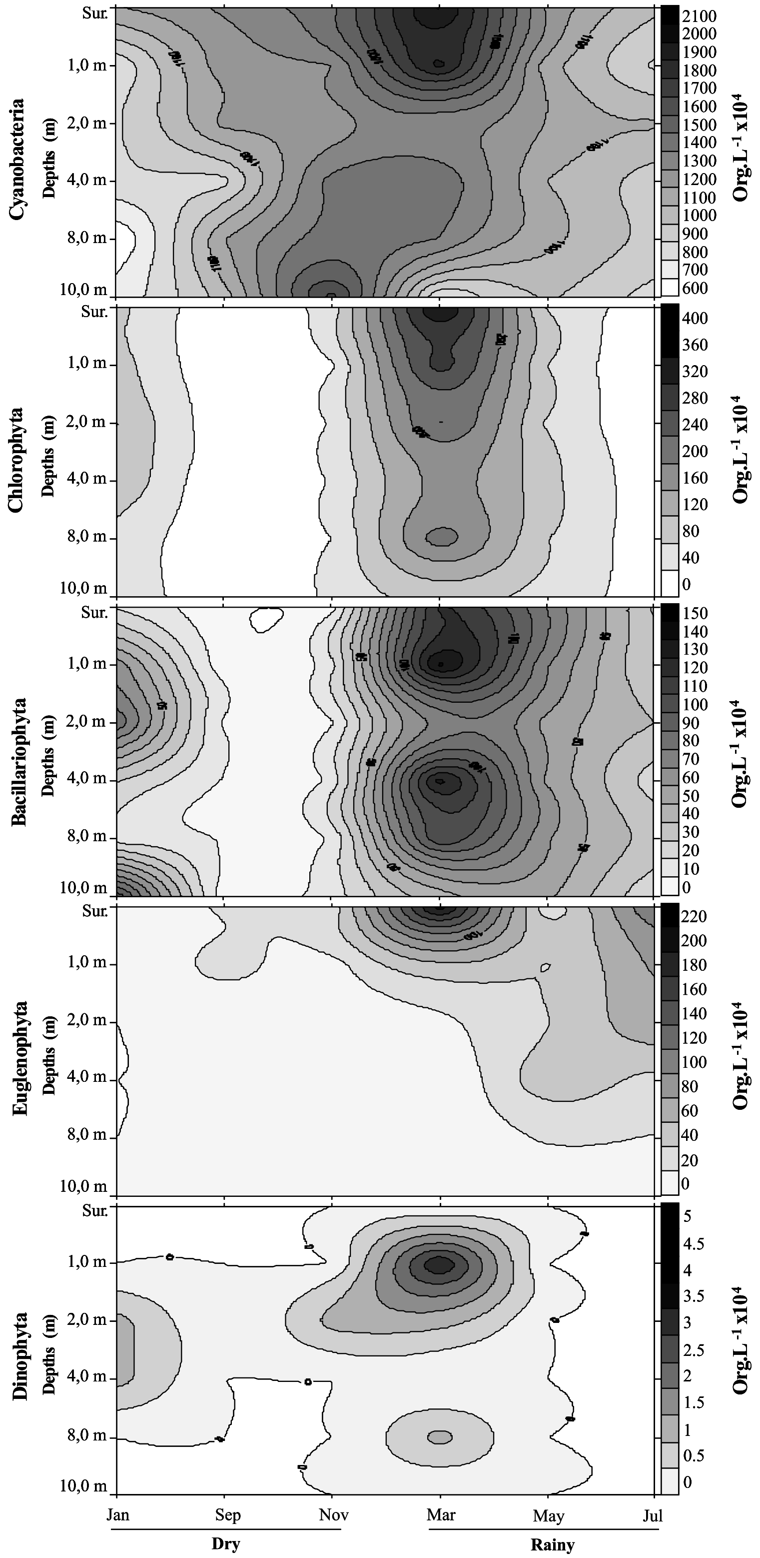

Fig. 3 – Density of phytoplankton groups ($\times 10^4$ org.L^{-1}) between depths analyzed in the Carpina reservoir (PE, Brazil) from January to November 2006.

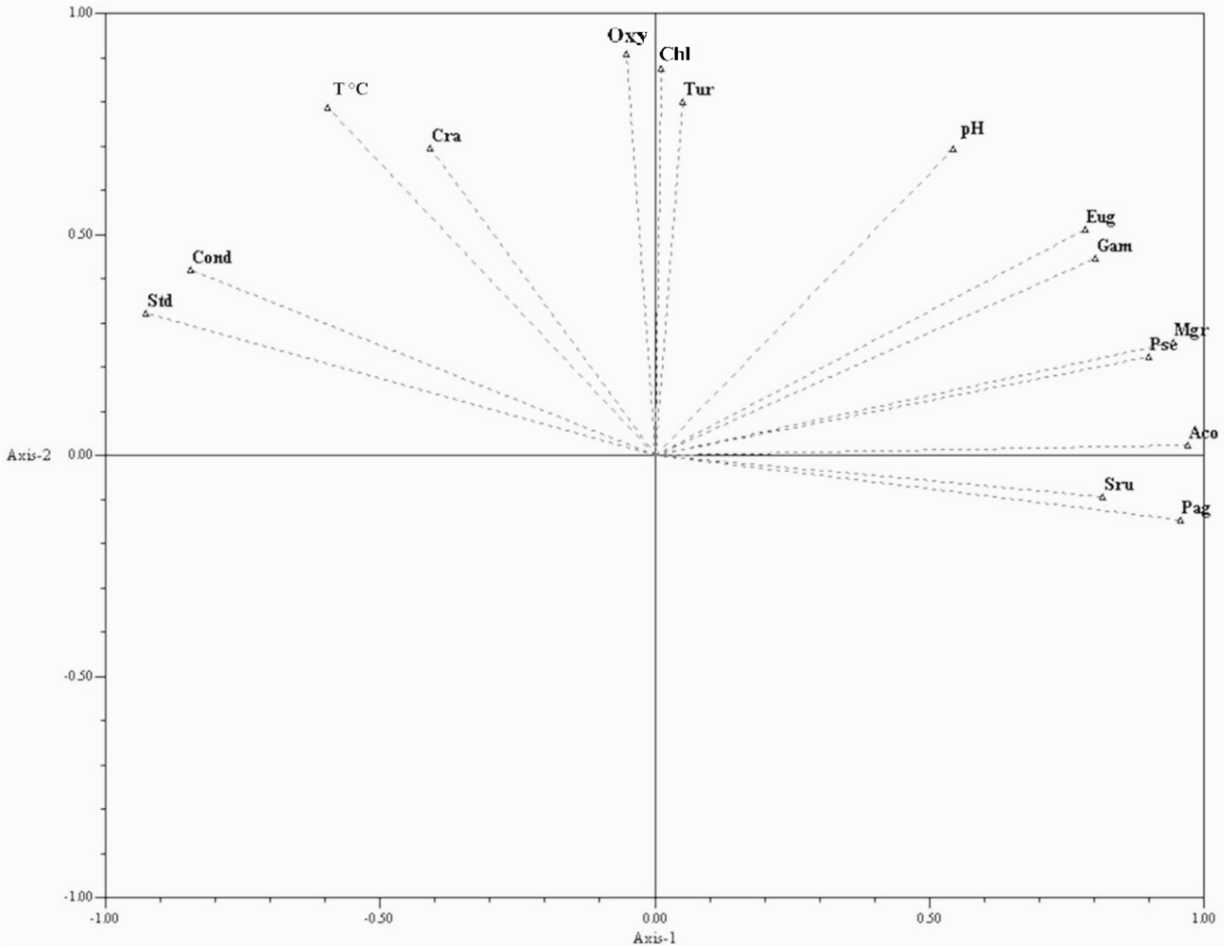

Fig. 4 – PCA of the most representative environmental and biological variables in the Carpina reservoir (PE, Brazil) from January to November 2006. Abbreviations: Aco (*Anabaena constricta*), Cra (*Cylindrospermopsis raciborskii*), Gam (*Geitlerinema amphibium*), Pag (*Planktothrix agardhii*), Pse (*Pseudanabaena* sp.), Sru (*Synedra rumpens*), Mgr (*Monoraphidium griffithii*), Eug (*Euglena* sp.), Chl-*a* (Chlorophyll *a*), T °C (water temperature), Oxy (dissolved oxygen), Cond (electrical conductivity), TDS (total dissolved solids), Tur (turbidity) and pH.

perature was the variable with the greatest influence during the transition period in the Carpina reservoir.

Although there were higher values for a large part of the environmental parameters in the rainy season, the differences in comparison to the dry season were not particularly expressive. However, the statistical analyses reveal that the changes were sufficient to associate total dissolved solids, water temperature, electrical conductivity and pH to the growth of the phytoplankton community with the onset of the rains. The occurrence of seasonal models for many physiochemical parameters is common in tropical reservoirs, which are basically defined by the strong influence of rainfall (Huszar et al. 2000, Figueiredo and Giani 2001, Domitrovic 2003, Borges et al. 2008).

Although the rainy season led to a greater increase in the phytoplankton community of the Carpina reservoir, it also resulted in an expressive reduction in the density of *C. raciborskii*, which was previously dominant in the system. According to Bouvy et al. (2003) and Reynolds (1997), *C. raciborskii* has a low degree of affinity to increases in rainfall, which favors the coexistence of other species. Tucci and Sant'Anna (2003) agree with this opinion and attribute the morphology of *C. raciborskii* – which has fine, elongated trichomes – to the favoring of coexistent species during rainy periods,

TABLE II

Correlation factors (%) of principal component analysis (PCA) between abundance species and environmental variables in the Carpina reservoir (PE, Brazil) from January to November 2006.

Abbreviations	Abundance species and environmental variables	Factor 1	Factor 2
%		20,23	14,35
Aço	*Anabaena constricta*	0,959	0,125
Cra	*Cylindrospermopsis raciborskii*	–0,484	0,669
Gam	*Geitlerinema amphibium*	0,552	0,665
Pag	*Planktothrix agardhii*	0,968	–0,519
Pse	*Pseudanabaena catenata*	0,865	0,317
Sru	*Synedra rumpens*	0,828	–0,296
Mgr	*Monoraphidium griffithii*	0,908	0,355
Eug	*Euglena* sp.	0,719	0,599
Chl	Chlorophyll *a*	–0,860	0,886
T°C	Water temperature	–0,668	0,719
Oxy	Dissolved oxygen	–0,131	0,884
Cond	Electric conductivity	–0,874	0,316
Std	Total dissolved solids	–0,954	0,227
Tur	Turbidity	–0,216	0,782
Ph	pH	0,494	0,745

TABLE III

Summary of CCA results for the most representative environmental and biological variables in the Carpina reservoir (PE, Brazil) from January to November 2006.

	Axis 1	Axis 2
Eigenvalue	0.054	0.005
% of variance explained	79.9	7.3
Cumulative % explained	79.9	87.2
Pearson Correlation (species – environment)	0.998	0.938
Monte Carlo Test (p)		
Eigenvalue	0.010	0.070
Correlation species – environment	0.010	0.080

and for such it does not provide enough shade to impede an increase in the population of other species. However, it should be stressed that the majority of species that coexist in blooms of Cyanobacteria also form part of this group and are capable of living in adverse conditions and grow competitively when conditions are favorable (Hašler and Paulíčková 2003, Komárková and Tavera 2003, Bouvy et al. 2006). Although Cyanobacteria was dominant throughout the study and there was an increase in density with the onset of the rains, its representativity within the community decreased by approximately 9.5%, which was due to the increase in the populations of opportunistic species from other phytoplankton groups (*S. rumpens* and *Euglena* sp.), as well as the reduction in the *C. raciborskii* population.

In the eutrophic Gargalheiras reservoir in the state of Rio Grande do Norte (northeastern Brazil), some species of Cyanobacteria that establish dominance in the dry season (including *C. raciborskii*) have been found to undergo a significant numerical reduction in the rainy

TABLE IV

Canonical coefficients and "inter-set" correlation coefficients for the most representative environmental and biological variables on Axes 1 and 2 of the CCA in the Carpina reservoir (PE, Brazil) from January to November 2006.

	Canonical coefficients		Inter-set correlations	
	Axis 1	Axis 2	Axis 1	Axis 2
Water temperature (T °C)	–0.114	–0.845	0.669	–0.585
Dissolved oxygen (Oxy)	0.403	–1.834	0.038	–0.815
Electric conductivity (Cond)	0.136	0.336	0.909	–0.069
Total dissolved solids (Std)	0.718	0.953	0.983	–0.082
Turbidity (Tur)	–0.127	0.502	0.030	–0.459
Ph	–0.446	1.182	–0.526	–0.609

season and take on the status of coexistence (Chellapa and Costa 2003). Conditions of greater stability of the water column, increased precipitation and dilution of nutrients have been indicated as the environmental factors that favor the reduction of Cyanobacteria species and the establishment of opportunistic taxa (Bouvy et al. 2003, Tucci and Sant'Anna 2003). The study of seasonal dynamics and toxicity of *C. raciborskii* in Lake Guiers (Senegal, West Africa) revealed that the ecological success attributed to this species is due to its large-scale tolerance to different climatic conditions (Berger et al. 2006).

In the present study, the stability of the water column, increased transparency and high water temperature in the rainy season provided conditions of competitive equality among the opportunistic species, leading to a reduction in the dominance of *C. raciborskii*.

A number of species found in the Carpina reservoir, such as *P. agardhii*, *A. constricta* and *P. catenata*, were also sensitive to the increased rainfall, but are opportunists and establish rapid growth in situations of increased light penetration. Species from the genus *Monoraphidium* and diatomaceae are generally characterized as opportunistic in conditions of luminosity and are tolerant to turbulent environments (Dos Santos and Calijuri 1998). In the present study, *M. griffithii* and *S. rumpens* exhibited an exceptional growth in the rainy season, when the conditions of light penetration and stability of the water column were better than in the dry season and therefore favorable to an increase in competitiveness.

Some studies report that the vertical distribution of phytoplankton species depends on a set of factors that involve the morphology and physiology of the taxa, as well as interactions between water mixture patterns and the availability of light and nutrients (Huszar et al. 2000, Bouvy et al. 2006, Borges et al. 2008). The concentration of the phytoplankton groups throughout the water column in the Carpina reservoir had different distribution patterns in the different seasons. In the dry season, the distribution of Cyanobacteria and Chlorophyta was homogenous, whereas the distribution of Bacillariophyta, Euglenophyta and Dinophyta was heterogeneous, with densities concentrated at few depths. In the rainy season, all groups exhibited a similar behavior, with greater concentrations at the surface and at a depth of 1.0 m.

The Carpina reservoir did not exhibit expressive differences regarding phytoplankton composition (species richness). There were seasonal and vertical changes involving occasional species with low representativity in the community. The reservoir had a high degree of trophy and high densities of phytoplankton throughout the entire study, which was made up mostly by Cyanobacteria benefiting from the environmental conditions and their innate competitive advantages. Rainfall governed the differences in phytoplankton density found between species and affected the dominance of Cyanobacteria, especially the species *C. raciborskii*. Although relatively low, the reduction in the dominance of this group in the rainy season was sufficient for the establishment of opportunistic species, which achieved the status of coexistence. Although discreet, the changes in the environmental parameters between seasons and throughout the water column were important to reveal the instabil-

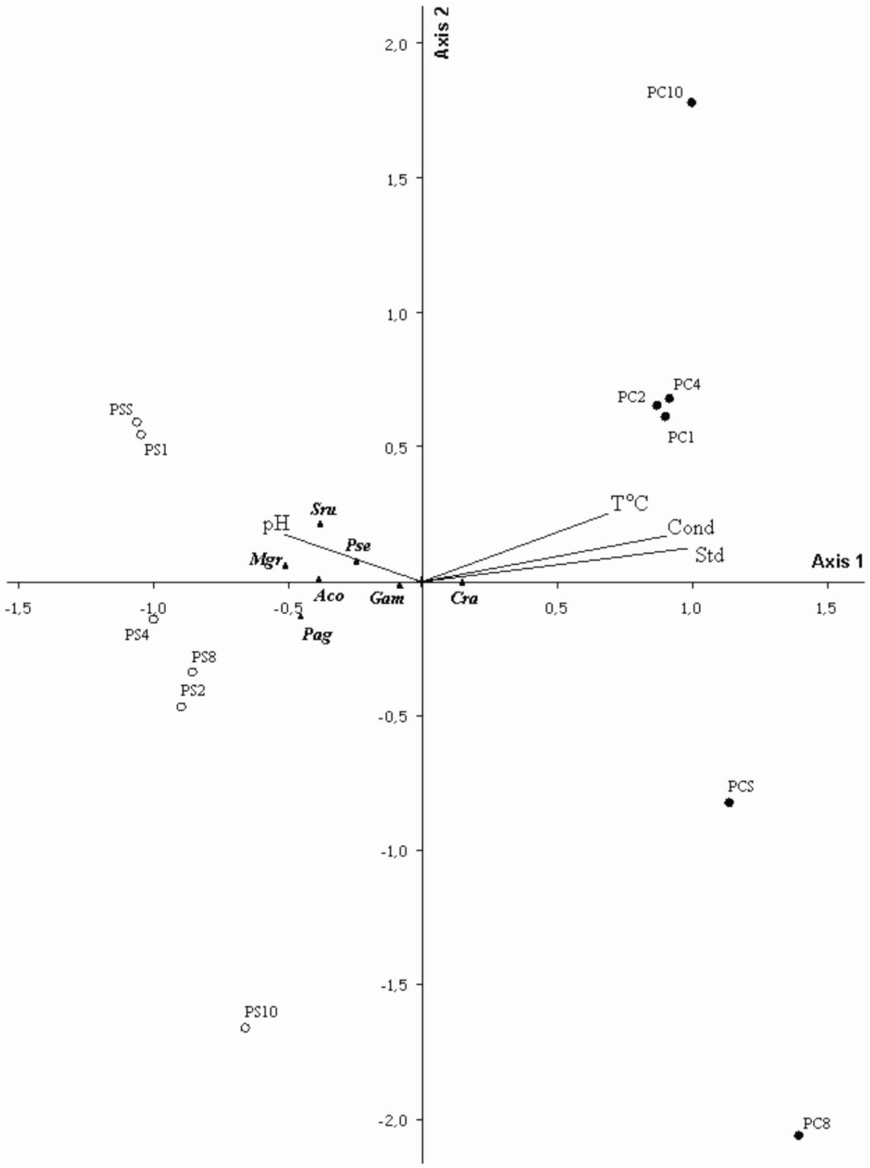

Fig. 5 – CCA scaling of the most representative environmental and biological variables in the Carpina reservoir (PE, Brazil) from January to November 2006. Abbreviations: Aco (*Anabaena constricta*); Cra (*Cylindrospermopsis raciborskii*); Pag (*Planktothrix agardhii*); Gam (*Geitlerinema amphibium*); Pse (*Pseudanabaena* sp.); Sru (*Synedra rumpens*); Mgr (*Monoraphidium griffithii*); T°C (water temperature), Oxy (dissolved oxygen), Cond (electrical conductivity), TDS (total dissolved solids), Tur (turbidity) and pH; DS (dry season); RS (rainy season); depths (S – surface; 1-1.0 m; 2-2.0 m; 4-4.0 m; 8-8.0 m; 10-10.0 m).

ity of the system and demonstrate that precipitation and water temperature are the main regulating factors of the phytoplankton community in tropical ecosystems.

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RESUMO

O presente estudo remete às relações de abundância, dominância e co-existência fitoplanctônica no reservatório eutrófico de Carpina, Pernambuco, Brasil. Foram realizadas amostragens bimensalmente, em seis profundidades, em um único ponto do reservatório, contemplando dois períodos sazonais: seco (janeiro, setembro e novembro/2006) e chuvoso (março, maio e julho/2006). A densidade, abundância, dominância, diversidade específica e equitabilidade foram determinadas, além da clorofila a e algumas variáveis físicas e químicas do ambiente. Oito táxons foram considerados abundantes e suas densidades corresponderam a mais de 90% do fitoplâncton total quantificado. As cianobactérias representaram mais de 80% desta densidade. *Cylindrospermopsis raciborskii* foi o único táxon dominante durante o período seco e co-dominante no chuvoso. *C. raciborskii*, *Planktothrix agardhii* e *Geitlerinema amphibium* destacaram-se com as maiores densidades e os menores coeficientes de variação vertical. As análises estatísticas indicaram relação entre as alterações verticais e sazonais da comunidade fitoplanctônica e seguintes variáveis: sólidos totais dissolvidos, temperatura da água, condutividade elétrica e pH. As alterações observadas para as variáveis ambientais foram discretas e reguladas pelo estabelecimento das precipitações, no entanto foram capazes de promover instabilidade vertical e sazonal na estrutura da comunidade fitoplanctônica.

Palavras-chave: reservatório de Carpina, *Cylindrospermopsis raciborskii*, cianobactérias, características limnológicas, estrutura fitoplanctônica, distribuição vertical.

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