

Temporal variation of the phytoplankton community at short sampling intervals in the Mundaú reservoir, Northeastern Brazil

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RESUMO – (Variação temporal da comunidade fitoplanctônica em curtos intervalos amostrais no reservatório de Mundaú, Nordeste brasileiro). O objetivo deste estudo foi detectar a influência dos fatores abióticos sobre a comunidade fitoplanctônica em um reservatório de abastecimento, em curtos intervalos amostrais. As amostras foram coletadas na subsuperfície (0,1 m) e fundo das regiões pelágica (8 m) e litorânea (2 m), durante dois períodos sazonais, estações seca e chuvosa. As variáveis abióticas analisadas foram: temperatura da água, oxigênio dissolvido, condutividade elétrica, sólidos totais dissolvidos, turbidez, pH, nitrogênio total, nitrito, nitrato, fósforo total, fósforo total dissolvido e ortofosfato. A biomassa fitoplanctônica foi determinada a partir de valores de biovolume. A influência das variáveis abióticas na dinâmica das espécies fitoplanctônicas foi determinada através da Análise de Correspondência Canônica. A biomassa algal variou de $1,17 \times 10^4$ a $9,21 \times 10^4 \mu\text{g.L}^{-1}$, sendo que as cianobactérias apresentaram valores de biomassa entre $1,07 \times 10^4$ e $8,21 \times 10^4 \mu\text{g.L}^{-1}$. A mais alta disponibilidade de fósforo, limitação de nitrogênio, pH alcalino e estabilidade térmica favoreceram florações de cianobactérias, especialmente durante o período seco. As diferenças entre os horários e as estações amostrais na distribuição da comunidade fitoplanctônica foram determinadas pelos valores de temperatura, pH, fósforo total e turbidez. As associações fitoplanctônicas que mais se destacaram foram do grupo funcional Sn, formado por *Cylindrospermopsis raciborskii*, que predominou no sistema em ambos períodos sazonais. Concluiu-se que o fitoplâncton apresentou uma forte influência das variáveis abióticas especialmente no estabelecimento de padrões sazonais de distribuição.

Palavras-chave: *Cylindrospermopsis raciborskii*, eutrofização, nutrientes, reservatório de abastecimento

ABSTRACT – (Temporal variation of the phytoplankton community at short sampling intervals in the Mundaú reservoir, Northeastern Brazil). The aim of this study was to determine how abiotic factors drive the phytoplankton community in a water supply reservoir within short sampling intervals. Samples were collected at the subsurface (0.1 m) and bottom of limnetic (8 m) and littoral (2 m) zones in both the dry and rainy seasons. The following abiotic variables were analyzed: water temperature, dissolved oxygen, electrical conductivity, total dissolved solids, turbidity, pH, total nitrogen, nitrite, nitrate, total phosphorus, total dissolved phosphorus and orthophosphate. Phytoplankton biomass was determined from biovolume values. The role abiotic variables play in the dynamics of phytoplankton species was determined by means of Canonical Correspondence Analysis. Algae biomass ranged from 1.17×10^4 to $9.21 \times 10^4 \mu\text{g.L}^{-1}$; cyanobacteria had biomass values ranging from 1.07×10^4 to $8.21 \times 10^4 \mu\text{g.L}^{-1}$. High availability of phosphorous, nitrogen limitation, alkaline pH and thermal stability all favored cyanobacteria blooms, particularly during the dry season. Temperature, pH, total phosphorous and turbidity were key factors in characterizing the phytoplankton community between sampling times and stations. Of the species studied, *Cylindrospermopsis raciborskii* populations were dominant in the phytoplankton in both the dry and rainy seasons. We conclude that the phytoplankton was strongly influenced by abiotic variables, particularly in relation to seasonal distribution patterns.

Key words: *Cylindrospermopsis raciborskii*, eutrophication, nutrients, water supply reservoir

Introduction

Reservoirs are continental environments generally viewed as a transition between lotic and lentic systems, as they are manmade lakes used to fulfill specific needs

(Straskraba & Tundisi 2000). These artificial ecosystems exhibit space/time variability affecting the formation of several ecological niches. The ability or potential algae have to comply with habitat heterogeneity is a result of their behavior and reproduction characteristics. Thus,

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phytoplankton is important in predicting environmental events and is a much-needed input in interpreting the functioning of reservoirs.

The small shift in daytime length in tropical environments does not impede seasonal changes in phytoplankton communities. Fluctuations in biomass and phytoplankton composition are mainly related to hydrological changes (Huszar & Reynolds 1997). Short-term studies are important to the understanding of processes occurring on short time scales, such as atelomixis, deoxygenating and denitrification, which contribute toward changes in the dynamics and structure of phytoplankton communities.

In Brazil, studies on phytoplankton in short sampling intervals (24 hours) have been carried out in systems of the southeastern region (Ramirez & Bicudo 2002; 2005; Lopes *et al.* 2005) and northern region (Huszar & Reynolds 1997; Melo & Huszar 2000), which exhibit distinct climate characteristics from the northeastern region. In Brazilian lakes and reservoirs studied in 24 hour sampling intervals, temperature plays an important role in the structure and dynamics of the phytoplankton community, explaining the space and time variability of algae throughout a daily cycle.

The northeastern region of Brazil is mainly characterized by its semi-arid climate, where water shortages reflect the temporary aspect of its hydrographic basins and the low precipitation, typically below 1.000 mm.y⁻¹ (Strahler 1986). The construction of reservoirs is a solution to problems associated to water needs, assuring availability in the dry season. However, influencing factors such as long water residence time in the reservoirs, high temperatures and evapotranspiration, along with an ever increasing dumping of domestic and industrial sewage from urban centers, have inflicted environmental problems such as eutrophication on reservoirs located in northeastern Brazil. In the region and particularly in the state of Pernambuco, 90% of all reservoirs are eutrophic (Bouvy *et al.* 2000) and algae blooms occur frequently in a number of aquatic systems. The most common cyanobacteria blooms are from *Cylindrospermopsis raciborskii* (Woloszynska) Seenayya & Subba Raju (Bouvy *et al.* 1999; 2000; 2001), *Microcystis aeruginosa* (Kützing) Kützing (Chellappa & Costa 2003) and *Anabaena spiroides* Klebahn (Molica *et al.* 2005).

There are studies demonstrating that, under eutrophic conditions, phytoplankton biomass is controlled by abiotic factors (the bottom-up effect); small variations in nutrient levels within short sampling intervals result in a rapid change in the structure of the algae community. However, there is a lack of studies using short sampling intervals and associating environmental conditions of

aquatic systems in northeastern Brazil with the phytoplankton community. Thus, the aim of the present study was to detect the influence of abiotic variables on temporal distributions (daily and between the dry and rainy seasons) of a phytoplankton community in a eutrophic drinking water supply system (the Mundaú Reservoir) in northeastern Brazil during short periods.

Material and methods

The Mundaú reservoir lies within the coordinates 08°56'47''S and 36°29'33''W at an altitude of 716 m. Maximum reservoir depths are 10 and 9 meters in the rainy and dry seasons, respectively. The accumulation capacity of this reservoir is 1.968.000 m³ and the water retention time coincides with the duration of the dry season.

The occurrence of macrophytes is not important, but isolated banks of *Nymphaea* spp have been observed. The terrestrial vegetation around the reservoir is made up of species featured in the *caatinga* (xeric scrubland and thorn forest). This reservoir is intended for the public water supply, but currently receives part of the urban drainage from the city of Garanhuns, Pernambuco (SHR 2000).

Samples were collected in two seasonal periods: dry (January 2005) and rainy (June 2005) over 20 hour sampling periods during daylight (8 am, 12 pm and 4 pm) and dark (8 pm, 12 am and 4 am) hours. Samples were collected from the subsurface in pelagic (E₁) and littoral (E₂) zones using a van Dorn bottle. Samplings were performed at 8 m and 2 m, respectively.

Abiotic variables were determined *in situ* and included water temperature and dissolved oxygen using an oximeter (Schott Glaswerke Mainz, handylab OX1); electrical conductivity and total dissolved solids (TSD) by means of a conductivimeter (Schott Glaswerke Mainz, handylab LF1); turbidity using a turbidimeter (Hanna Instruments, HI 93703), and pH using a potentiometer (Digimed, DMPH-2). Water transparency was determined using a 25 cm diameter Secchi disc. The determination of the photic zone was performed following the procedure described in Margalef (1983).

Samples were collected at two depths in each of the sampling seasons using a Van Dorn bottle for subsequent laboratory analyses of dissolved and total nutrients. The water was conditioned in 300 mL polyethylene flasks and kept refrigerated until the analysis. Samples were filtered through 47 mm AP20 glass multi-pore filters for the determination of dissolved nutrients. Non-filtered aliquots were used for the determination of total nutrients. Analysis to determine concentrations of total nitrogen (µg.TN.L⁻¹), nitrite

($\mu\text{g.N-NO}_2\text{-L}^{-1}$) and nitrate ($\mu\text{g.N-NO}_3\text{-L}^{-1}$) followed procedures described in Valderrama (1981), Mackereth *et al.* (1978) and Golterman *et al.* (1971), respectively. Total phosphorus ($\mu\text{g.TP.L}^{-1}$) and total dissolved phosphorus ($\mu\text{g.TDP.L}^{-1}$) were determined following Valderrama (1981). Orthophosphate ($\mu\text{g.P-PO}_4\text{-L}^{-1}$) was determined following Strickland & Parsons (1965). The content of particulate phosphorus ($\mu\text{g.PP.L}^{-1}$) and dissolved organic phosphorus ($\mu\text{g.DOP.L}^{-1}$) were determined from the difference between TP and TDP, and PTD and P- PO_4 , respectively.

Samples for taxonomic analysis were preserved in 4% formaldehyde. Identification was performed down to species level using an optical microscope (Zeiss/Axioskop) or to the highest possible taxonomic resolution using relevant literature (Komárek & Foot 1983; Sant'Anna 1984; Round *et al.* 1990; Komárek & Anagnostidis 1999; Komárek & Anagnostidis 2005).

Water aliquots of 100 mL were collected daily from the reservoir and preserved in acetic Lugol's solution for the determination of cell density (cell.L^{-1}) following the Utermöhl method (Hasle 1978). Densities were converted into biovolumes following the procedure in Edler (1979).

Analysis of variance (ANOVA) was calculated using the BioEstat 3.0 statistical package (Ayres *et al.* 2003) and employed to determine the degree of temporal variation (time of the day and seasonal period) and spatial variation (depth and sampling station). The significance level was set at 5%. Canonical Correspondence Analysis using the PC-ORD software version 4.14 for Windows (McCune & Mefford 1999) was employed for the evaluation of the temporal gradient and to determine what abiotic variables were influencing the dynamics of phytoplankton species.

Results

In the dry period, the Mundaú reservoir exhibited lower oxygenated water, higher pH in the subsurface and lower turbidity when compared to the rainy season, which had well-oxygenated water, pH ranging from near neutral to lower values and high turbidity, especially near the sediment in the pelagic zone (Tab. 1, 2).

No vertical differences were observed ($p > 0.05$) in the dry season regarding temperature, dissolved oxygen, electrical conductivity, total dissolved solids, turbidity and pH. A difference in turbidity ($F = 15.850$, $p < 0.01$) was observed between the light and dark hours; higher turbidity was found in the dark hours, except in E_2 at a depth of 2 m (Tab. 1). Electrical conductivity and total dissolved solids had lower variation coefficients (0.38% and 0.31%), with no vertical or temporal

variability during light and dark hours.

The most significant vertical differences in the rainy season were observed in E_1 , where temperature ($F = 15.180$, $p < 0.01$), dissolved oxygen ($F = 89.497$, $p < 0.001$), electrical conductivity ($F = 31.235$, $p < 0.001$), total dissolved solids ($F = 36.577$, $p < 0.001$) and pH ($F = 32.216$, $p < 0.001$) had higher values at the subsurface. No differences were observed between light and dark hours in the rainy season, with the exception of the concentrations of dissolved oxygen at the subsurface of the pelagic zone ($F = 28.880$, $p < 0.01$), which were higher during dark hours.

The analysis of nutrients from the dry season (Tab. 1) as a function of depth revealed differences in the concentrations of total nitrogen ($F = 10.026$, $p < 0.01$) and total dissolved phosphorus ($F = 19.267$, $p < 0.001$) at both stations as well as orthophosphate and total phosphorus, with higher values at the bottom ($p < 0.01$), particularly in E_1 . Vertical differences for NO_3 and NO_2 were registered only during daylight hours, with the smaller values occurring at the subsurface, except for the NO_2 concentrations in E_2 . These two nitrogen rich forms also displayed horizontal variation between light and dark hours

NO_3 levels were higher in E_1 , whereas NO_2 levels were higher in E_2 . NO_3 concentrations were higher during dark hours at the subsurface and during light hours at the bottom. NO_2 levels between light/dark hours exhibited a similar pattern in E_1 , but an opposite pattern in E_2 .

There was an increase in nitrogen-composed products, total nitrogen, nitrate and nitrite (Tab. 2) in the rainy season as well as a reduction in dissolved-phosphate elements, total dissolved phosphorus, orthophosphate and dissolved organic phosphorus (Tab. 2). Vertical differences were significant only in E_1 , with total nitrogen levels, nitrate, nitrite and total phosphorus significantly higher ($p < 0.01$) near the sediment. Horizontal differences between light/dark hours were more evident for total nitrogen and orthophosphate concentrations. These two nutrients had higher values at the subsurface in the dark hours. Total nitrogen was higher concentrations in E_2 , whereas orthophosphate was higher in E_1 .

Biotic variables – Phytoplankton flora was represented by 66 infrageneric taxa and six generic taxa. The highest species richness was observed for Chlorophyta, corresponding to 54.17% of the infrageneric taxa identified, followed by Cyanophyta (19.44%), Bacillariophyta (15.28%), Euglenophyta (8.33%), Dinophyta (1.39%) and Cryptophyta (1.39%) (Tab. 3).

Phytoplankton biomass ranged from 1.17×10^4 to $9.21 \times 10^4 \mu\text{g.L}^{-1}$ (Fig. 1). The community was made up of Bacillariophyta, Chlorophyta, Cryptophyta,

Table 1. Physical and chemical variables of the Mundaú reservoir, Northeastern Brazil at the sampling stations E₁ e E₂ during the dry season. (-) dates without sampling.

	E ₁								E ₂							
	0.1 m				8 m				0.1 m				2 m			
	Light		Dark		Light		Dark		Light		Dark		Light		Dark	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Secchi (m)	0.3	0.0	-	-	-	-	-	-	0.4	0.0	-	-	-	-	-	-
T °C	27.5	0.8	27.3	0.4	25.4	0.5	25.3	0.2	28.3	0.6	27.5	0.8	27.2	1.3	26.9	0.4
Dissolved oxygen (mg.L ⁻¹)	0.8	0.4	1.2	1.1	0.2	0.2	0.4	0.2	0.8	0.0	1.8	1.1	0.7	0.1	1.2	1.0
Electric conductivity (uS.cm ⁻¹)	396.3	0.6	398.3	1.5	393.7	3.5	394.7	3.5	396.0	1.7	398.0	1.0	392.0	2.0	390.3	2.3
TDS (mg.L ⁻¹)	349.3	0.6	350.7	1.2	346.3	2.1	347.0	3.0	349.0	1.7	351.3	0.6	345.7	1.5	343.7	2.1
Turbidity (NTU)	32.9	1.4	35.9	2.2	21.2	5.0	26.3	5.1	32.9	1.4	36.6	1.2	32.5	4.6	29.9	3.9
pH	8.3	0.1	8.3	0.2	7.2	0.1	7.2	0.1	8.4	0.1	8.2	0.1	7.9	0.4	7.6	0.3
TN (µg.L ⁻¹)	57.4	11.4	61.9	5.4	102.7	22.3	81.6	13.4	61.9	22.7	59.9	8.9	70.5	30.2	80.1	20.4
NO ₃ (µg.L ⁻¹)	165.7	35.9	214.1	43.1	331.5	149.4	214.1	72.8	131.2	97.9	172.6	83.7	179.5	83.7	179.5	97.9
NO ₂ (µg.L ⁻¹)	8.2	0.5	13.8	3.6	42.6	48.7	8.2	2.4	39.2	39.6	20.4	16.0	8.5	0.9	23.2	26.4
TP (µg.L ⁻¹)	106.5	5.2	104.8	10.5	147.2	17.3	130.0	19.8	95.6	14.6	110.0	10.5	117.4	17.2	105.4	2.0
TDP (µg.L ⁻¹)	54.9	7.8	49.8	9.7	73.1	7.8	73.6	7.3	49.2	8.6	56.5	4.5	60.6	5.6	60.6	3.1
PO ₄ (µg.L ⁻¹)	75.2	2.7	70.6	9.6	76.7	7.0	92.0	8.0	67.5	5.3	75.2	5.3	69.0	4.6	69.0	20.1
PP (µg.L ⁻¹)	51.6	13.0	55.0	7.2	74.1	9.6	56.4	25.6	46.4	12.0	53.5	9.4	56.8	21.3	44.7	3.7
DOP (µg.L ⁻¹)	54.9	7.8	26.7	8.6	48.1	6.5	43.6	7.0	27.2	9.4	32.0	5.6	38.1	7.1	38.1	7.6
N:P	1.2	0.3	1.3	0.2	1.5	0.3	1.4	0.1	1.4	0.3	1.2	0.3	1.4	0.8	1.7	0.5

Table 2. Physical and chemical variables of the Mundaú Reservoir, Northeastern Brazil at the sampling stations E₁ e E₂ during the rainy season. (-) dates without sampling.

	E ₁								E ₂							
	0.1 m				8 m				0.1 m				2 m			
	Light		Dark		Light		Dark		Light		Dark		Light		Dark	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Secchi (m)	0.3	0.0	-	-	-	-	-	-	0.3	0.0	-	-	-	-	-	-
T °C	23.6	0.2	23.3	0.2	22.9	0.4	22.7	0.2	23.8	0.3	23.2	0.2	23.5	0.2	23.0	0.2
Dissolved oxygen (mg.L ⁻¹)	6.3	0.4	7.7	0.1	1.2	0.9	1.8	1.6	6.4	0.3	6.3	1.2	6.1	0.8	5.9	1.1
Electric conductivity (uS.cm ⁻¹)	755.3	110.9	690.3	24.2	526.0	26.9	537.3	26.3	664.0	3.5	681.3	20.6	667.0	2.0	685.0	22.1
TDS (mg.L ⁻¹)	678.7	90.7	626.0	22.3	476.7	24.5	485.7	23.3	602.3	3.8	617.7	18.6	605.3	1.2	621.7	20.0
Turbidity (NTU)	53.5	8.2	55.2	7.3	433.7	163.3	362.3	70.5	39.1	10.5	41.2	11.6	50.0	7.5	34.5	15.2
pH	7.3	0.2	7.3	0.1	6.8	0.1	6.9	0.2	7.1	0.0	7.1	0.2	7.2	0.4	7.2	0.3
TN (µg.L ⁻¹)	88.4	11.9	162.6	46.0	242.4	22.0	201.6	8.4	136.7	22.0	183.1	37.5	210.9	83.5	168.8	81.6
NO ₃ (µg.L ⁻¹)	234.4	44.2	259.8	20.6	769.7	57.8	621.2	15.5	283.3	63.2	279.4	20.6	277.4	23.7	304.8	25.5
NO ₂ (µg.L ⁻¹)	52.8	13.5	71.3	3.3	199.4	25.7	195.7	27.7	62.6	22.9	70.2	9.5	67.7	23.3	73.4	12.6
TP (µg.L ⁻¹)	73.3	7.8	82.8	4.0	298.3	38.1	311.7	59.6	88.0	13.9	87.6	12.3	84.5	12.8	88.0	11.8
TDP (µg.L ⁻¹)	28.2	14.5	29.8	19.6	21.0	2.5	24.2	15.1	17.1	2.7	27.4	4.8	17.9	3.1	20.6	7.0
PO ₄ (µg.L ⁻¹)	24.9	3.6	61.5	37.0	39.1	10.7	29.6	31.0	14.3	3.4	41.4	30.6	26.0	12.5	35.5	12.3
PP (µg.L ⁻¹)	45.1	22.4	53.0	15.9	277.2	40.2	287.5	59.7	70.9	15.4	60.2	7.9	66.7	13.4	67.4	8.7
DOP (µg.L ⁻¹)	20.1	13.4	9.7	8.6	8.3	5.9	14.6	6.2	12.4	1.9	13.9	5.3	9.4	7.1	9.1	6.7
N:P	2.7	0.4	4.4	1.4	1.8	0.4	1.5	0.2	3.5	0.6	4.7	1.2	5.5	1.7	4.3	2.1

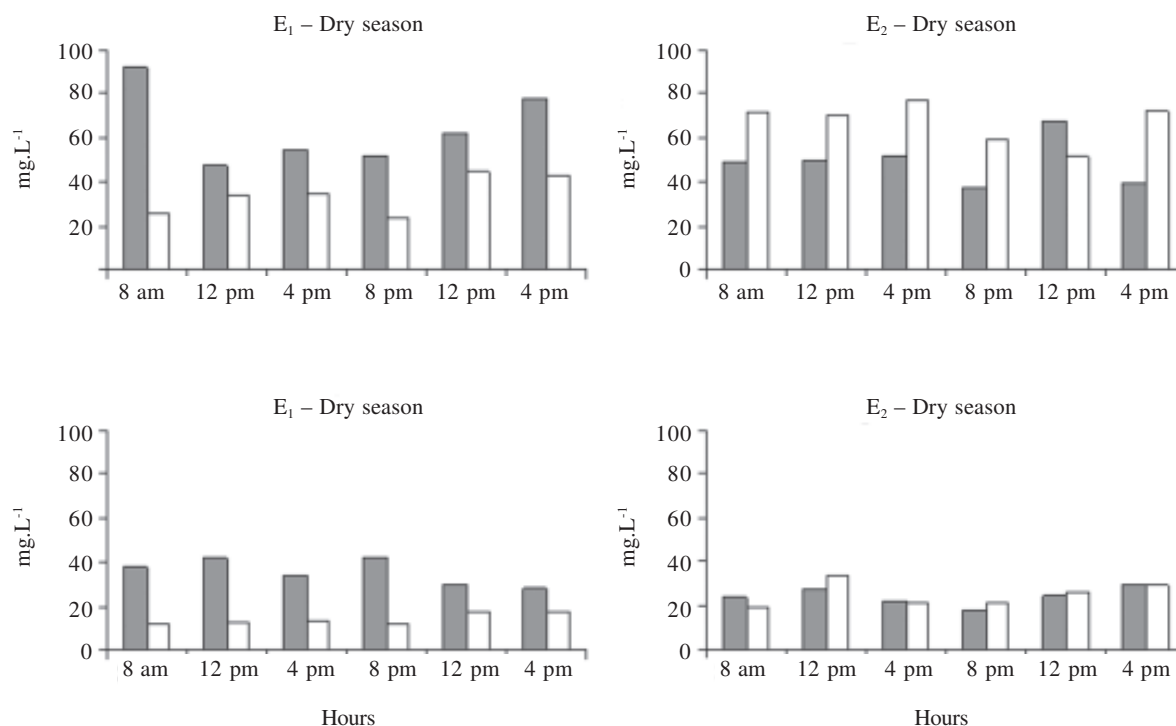


Figure 1. Spatial and temporal variations of phytoplanktonic biomass in the Mundaú reservoir, Northeastern Brazil.

Cyanophyta, Dinophyta and Euglenophyta. Cyanophyta – the dominant group (Tab. 3), with more than 80% of total biomass – was the only group displaying significant differences in depth, particularly in E₁. Biomass values were significantly higher at the subsurface ($F = 18.255$, $p < 0.01$). There were differences in total biomass between seasons, with less biomass in the rainy season (Fig. 1). In the dry season, the increase of phytoplankton biomass occurred beginning at 12 am, reaching its highest values at the first daylight, especially in E₁ (Fig. 1). Higher biomass in the rainy season was registered in E₁ during daylight hours until 8 pm, with a reduction beginning at 12 am to 4 am (Fig. 1).

Cylindrospermopsis raciborskii (Woloszinska) Seenayya et Subba-Raju, *Geitlerinema amphibium* (Agardh ex Gomont) Anagnostidis, *Cyclotella meneghiniana* Kützing and *Synedra rumpens* Kützing displayed higher biomasses in the dry season, whereas *Microcystis aeruginosa* (Kützing) Kützing, *M. flos-aquae* (Wittrock) Kirchner, *Chlorella vulgaris* Chodat and *Cryptomonas ovata* Ehrenberg displayed higher biomasses in the rainy season (Tab. 3).

C. raciborskii was the dominant species throughout the study (Tab. 3). In the dry season, this species had statistical differences as a function of depth at both sampling sites ($F_{E1} = 18.945$ and $F_{E2} = 8.291$; $p < 0.05$ and $p < 0.01$, respectively), with higher biomass at the subsurface in E₁ and near the sediment in E₂. This species had higher biomass values in the dark hours in E₁ and in

the daylight hours in E₂. In the rainy season, differences were only detected in E₁ and *C. raciborskii* had a higher biomass at the subsurface, with an opposite light-dark pattern than that observed in the dry season.

S. rumpens was subdominant in the dry season, with biomasses higher than 5% of total biomass average in both sampling periods and seasons. *C. meneghiniana* contributed with 5% of the total biomass in E₁, particularly near the sediment. However, *S. rumpens* displayed significant horizontal differences, with the biomass enhanced in E₂ ($F = 24.959$, $p < 0.001$). *C. raciborskii* was dominant in the rainy season, followed by *M. aeruginosa*, particularly at the subsurface in both seasons. Other taxa, such as *M. flos-aquae*, *C. ovata* and *S. rumpens*, were also important, with biomasses higher than 5% of total biomass average at least at one of the depths or sampling stations. *M. flos-aquae* and *C. ovata* were more abundant at the subsurface, with *C. ovata* having a more significant biomass in E₂. Among subdominant species, only *C. ovata* and *M. flos-aquae* exhibited a light-dark pattern. *C. ovata* had higher biomass during daylight hours, particularly at the subsurface. *M. flos-aquae* had higher biomass during dark hours, except in E₁ during the dry season.

The results from the Canonical Correspondence Analysis are displayed in Tab. 4 and 5 as well as Fig. 2 and 3. The Monte Carlo test proved significant ($p < 0.01$). There were relationships between environmental variables and biological information.

Table 3. Phytoplanktonic species and average biomass ($\mu\text{g.L}^{-1}$) observed in the Mundaú reservoir, Northeastern Brazil. (-) dates without sampling.

Species	E ₁ Dry season		E ₂ Dry season				E ₁ Rainy season				E ₂ Rainy season					
	0.1 m		8 m		0.1 m		2 m		0.1 m		8 m		0.1 m		2 m	
	Light	Dark	Light	Dark	Light	Dark	Light	Dark	Light	Dark	Light	Dark	Light	Dark	Light	Dark
BACILLARIOPHYTA																
<i>Aulacoseira granulata</i> (Ehrenberg) Simonsen	-	37	-	-	-	71	-	-	-	-	-	-	-	-	-	-
<i>A. granulata</i> var. <i>angustissima</i> Müller	38	39	-	29	56	-	19	-	-	38	-	-	-	-	-	18
<i>Cyclotella meneghiniana</i> Kützing	1886	1608	1304	1506	1435	1674	2094	1388	347	303	131	128	354	362	105	282
<i>Diploneis ovalis</i> (Hilse) Clève	-	23	-	23	-	-	91	-	-	-	-	-	-	-	-	-
<i>Eunotia major</i> (Wm Smith) Rabenhorst	-	-	-	-	-	-	-	-	249	19	20	-	-	-	-	-
<i>E. monodon</i> Ehrenberg	-	75	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Gomphonema augur</i> Ehrenberg	-	-	-	-	-	-	-	16	-	-	32	-	-	-	-	-
<i>Navicula cuspidata</i> Kützing	-	-	-	-	-	-	-	-	19	-	32	-	-	-	-	22
<i>Nitzschia palea</i> (Kützing) W. Smith	-	113	152	222	284	148	226	190	74	-	76	-	-	-	-	145
<i>Pleurosigma</i> sp.	-	-	-	-	-	-	-	-	74	-	-	-	-	-	-	-
<i>Synedra rumpens</i> Kützing	2680	2669	2433	2452	4357	4756	5266	4222	134	349	513	204	141	217	205	222
CHLOROPHYTA																
<i>Actinastrum hantzschii</i> Lagerheim	-	-	1	-	5	-	-	-	-	6	6	-	5	11	-	3
<i>Ankistrodesmus gracilis</i> (Reinsch) Korsikov	-	1	-	1	-	-	-	-	4	-	-	-	-	-	-	-
<i>Botryococcus protuberans</i> W. West & G.S. West	428	147	587	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Chlorella vulgaris</i> Chodat	63	69	41	58	677	502	342	185	406	492	474	400	457	261	289	256
<i>Closteriopsis acicularis</i> (G.M. Smith) Belch & Swale	-	2	-	-	11	-	7	-	-	-	-	-	-	-	-	-
<i>Closterium parvulum</i> Nägeli	201	152	168	176	195	147	228	141	75	50	-	75	72	-	48	100
<i>Coelastrum microporum</i> Nägeli	87	-	15	15	-	-	-	30	29	29	-	-	-	-	-	-
<i>C. pseudomicroporum</i> Korsikov	167	100	149	133	-	22	114	92	89	111	44	67	128	107	22	66
<i>Crucigenia quadrata</i> Morren	67	58	10	35	6	6	77	42	51	51	56	12	18	-	-	7
<i>Dictyosphaerium ehrenbergianum</i> Nägeli	-	-	-	-	18	36	5	9	-	-	-	-	4	9	4	-
<i>D. pulchellum</i> Wood	13	28	24	17	30	15	41	40	15	10	20	18	12	7	11	6
<i>Golenkinia radiata</i> Chodat	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Kirchneriella lunaris</i> (Kirchn.) Möebius	2	1	-	1	11	11	4	1	6	9	1	1	4	2	5	3
<i>K. obesa</i> (W. West) Schmidle	15	14	6	9	13	21	8	11	6	7	2	2	9	9	4	7
<i>Monoraphidium arcuatum</i> (Korsikov) Hindák	11	6	6	14	43	50	29	10	21	71	28	35	49	39	52	56
<i>M. circinale</i> (Nygaard) Nygaard	3	4	4	4	1	1	2	3	-	-	-	-	-	-	-	-
<i>M. contortum</i> (Thuret) Komárkova-Legnerová	34	23	71	62	24	27	58	67	19	26	6	7	14	18	21	19
<i>M. griffithi</i> (Berkele) Komárkova-Legnerová	7	4	3	6	2	6	15	14	24	18	7	15	13	7	10	10
<i>M. pusillum</i> (Printz) Komárkova-Legnerová	14	14	25	26	12	23	27	31	10	11	5	3	10	3	6	9

continua

Tabela 3 (continuação)

Species	E ₁ Dry season				E ₂ Dry season				E ₁ Rainy season				E ₂ Rainy season				
	0.1 m		8 m		0.1 m		2 m		0.1 m		8 m		0.1 m		2 m		
	Light	Dark	Light	Dark	Light	Dark	Light	Dark	Light	Dark	Light	Dark	Light	Dark	Light	Dark	
<i>Oocystis lacustris</i> Chodat	-	-	-	-	1	3	5	-	-	-	-	57	10	-	-	-	-
<i>Pediastrum tetras</i> (Ehrenberg) A. Braun	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Scenedesmus acuminatus</i> (Langeheim) Chodat	15	-	4	-	-	7	-	8	15	8	8	30	22	-	-	-	15
<i>S. acuminatus</i> var. <i>bernardii</i> (G. M. Smith) Dedussenko	-	-	-	-	-	-	3	-	3	8	-	3	5	3	-	-	3
<i>S. acutus</i> Meyen	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8
<i>S. arcuatus</i> Lemmermann	1	3	-	-	-	-	-	7	6	3	-	-	-	-	-	-	-
<i>S. bernardii</i> G. M. Smith	-	-	5	-	-	-	-	9	9	-	-	-	-	9	9	-	-
<i>S. bicaudatus</i> (Hansgirg) Chodat	-	-	5	3	-	-	4	9	-	-	-	-	-	-	-	-	2
<i>S. eornis</i> (Ehrenberg) Chodat	-	2	2	2	-	-	3	-	-	-	-	2	-	3	-	-	-
<i>S. quadricauda</i> (Turpin) Brébisson	7	7	16	4	13	48	14	21	18	31	14	9	43	17	17	9	9
<i>S. quadricauda</i> var. <i>parvus</i> G. M. Smith	48	26	33	28	18	22	11	38	4	11	2	2	2	-	6	4	4
<i>Scenedesmus</i> sp.	-	-	-	-	-	-	-	4	-	18	-	-	-	4	-	-	-
<i>Tetraedron caudatum</i> (Corda) Hansgirg	-	-	-	1	-	-	-	4	-	-	-	-	-	-	-	-	-
<i>T. gracile</i> (Reinsch) Hansgirg	38	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>T. incus</i> (Teiling) G. M. Smith	10	12	14	17	24	3	7	10	-	3	-	-	-	-	-	-	-
<i>T. mediocris</i> Hindák	-	2	-	-	-	-	2	2	-	-	-	-	-	-	-	-	-
<i>T. minimum</i> (A. Braun) Hansgirg	16	35	65	51	24	20	65	35	28	24	4	8	4	16	8	-	-
<i>T. triangulare</i> (Chodat) Komárek	35	39	25	26	27	12	25	23	15	12	6	3	12	6	18	6	6
<i>T. victoriae</i> Wolosynska	-	-	-	-	-	-	-	-	-	73	-	-	-	-	-	-	-
<i>Tetrastrum elegans</i> Playfair	6	3	55	35	18	6	26	16	13	19	6	31	-	6	6	13	13
CYANOPHYTA																	
<i>Chroococcus limneticus</i> Lemmermann	-	-	-	-	73	42	37	3	26	21	16	16	15	16	26	32	32
<i>C. minutus</i> Kützing	28	33	21	30	10	12	18	17	11	10	9	11	20	6	10	4	4
<i>C. turgidus</i> Kützing	33	62	21	24	104	106	64	22	51	85	85	61	313	153	184	80	80
<i>Cylindrospermopsis raciborskii</i> (Wolz.) Seenayya et Subba-Raju	53238	55465	23438	29849	41018	38808	59439	49189	31242	25563	9310	11868	18380	19014	18382	19626	19626
<i>Geitlerinema amphibium</i> (Agardh ex Gomont) Anagnostidis	550	642	1350	939	323	361	805	874	578	541	394	333	409	386	438	574	574
<i>Merismopedia minima</i> Beck	17	13	41	38	5	2	13	19	7	6	10	1	4	2	1	3	3
<i>M. punctata</i> Meyen	263	250	251	242	84	182	240	281	112	104	297	379	79	38	80	91	91
<i>Microcystis aeruginosa</i> (Kützing) Kützing	1661	795	831	741	129	221	775	1553	1257	1571	398	788	1422	1309	2104	1031	1031
<i>M. flos-aquae</i> (Wittrock) Kirchner	848	125	187	61	-	242	612	550	848	1937	241	363	232	838	843	729	729
<i>M. panniformis</i> Komárek et al.	-	-	-	-	-	-	-	39	-	-	-	-	-	-	-	-	-
<i>M. wesenbergii</i> (Komárek) Komárek	-	-	-	-	-	-	-	-	-	190	98	-	182	95	91	-	-
<i>Pseudanabaena catenata</i> Lauterborn	268	149	8	8	15	7	85	19	53	68	-	-	29	15	67	31	31
<i>Raphidiopsis mediterranea</i> Skuja	1606	1042	103	286	459	406	1113	1384	1014	928	186	334	754	487	714	813	813
<i>Spirulina</i> sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

continua

Tabela 3 (continuação)

Species	E ₁ Dry season				E ₂ Dry season				E ₁ Rainy season				E ₂ Rainy season				
	0.1 m		8 m		0.1 m		2 m		0.1 m		8 m		0.1 m		2 m		
	Light	Dark	Light	Dark	Light	Dark	Light	Dark	Light	Dark	Light	Dark	Light	Dark	Light	Dark	
DINOPHYTA																	
<i>Gymnodinium</i> sp.	-	23	-	-	-	130	-	89	44	-	-	-	-	-	-	-	130
EUGLENOPHYTA																	
<i>Euglena oxyuris</i> Schwarda	-	-	-	48	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Euglena</i> sp.	-	-	33	-	-	-	-	-	-	32	32	-	-	31	-	31	32
<i>Lepocinclis ovum</i> (Ehrenberg) Lemmermann	-	-	-	-	-	-	172	175	-	-	-	-	-	-	-	-	-
<i>Phacus</i> sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	132
<i>Trachelomonas oblonga</i> Lemmermann	173	-	-	-	-	-	-	-	118	-	346	-	-	221	-	-	115
<i>T. volvocina</i> Ehrenberg	14	-	15	28	14	-	-	-	-	14	-	-	29	42	27	14	14
CRYPTOPHYTA																	
<i>Cryptomonas ovata</i> Ehrenberg	193	43	-	21	597	206	391	132	729	472	41	293	947	419	834	724	724
Total biomass	64786	63956	31522	37269	50265	48232	72669	61100	37719	33684	12633	15554	24447	23902	24667	25432	25432

Table 4. Statistical synthesis of the CCA first two axes performed in the Mundaú reservoir Northeastern Brazil.

	Axis 1	Axis 2
Eigenvalue	0.062	0.015
Variance percentage explained	22.0	5.4
Variance percentage accumulated	22.0	27.4
Pearson correlation (species-environment)	0.934	0.844
Monte Carlo test		
Eingenvalues - <i>p</i>	0.01	0.03
Correlations species-environment	0.01	0.01

Eigenvalues of Axis 1 and 2 explain 27.4% of the biological data variance. The correlation of the species with environmental conditions was high on both axes.

CCA Axis 1 clearly split the seasons. The sampling units in the dry period were positively related to the axis, whereas those in the rainy period were negatively related. Taking into account the intra-set correlation, the variables positively associated to Axis 1 were temperature, pH, total dissolved phosphorus and orthophosphate, and a grouping of sampling units in the dry season was observed. These environmental variables had higher values in this season (Tab. 1 and 2). The chlorophyta *Closterium parvulum* Nägeli, *Monoraphidium contortum* (Thret) Komárkova-Legnerová and *Scenedesmus quadricauda* var. *parvus* G.M. Smith, cyanobacteria such as *Cylindrospermopsis raciborskii* and the diatoms *Aulacoseira granulata* (Ehrenberg) Simonsen, *Cyclotella meneghiniana* and *Synedra rumpens* all displayed higher biomasses in the dry season (Tab. 3).

Dissolved oxygen, electrical conductivity, total nitrogen and nitrite were negatively associated to Axis 1 and a grouping of sampling units in the rainy period was

Table 5. Canonic coefficients and intra-set correlation of the environmental variables for the axis 1 and 2 in the Mundaú reservoir Northeastern Brazil.

	Canonical coefficient		Correlation coefficient (intra-set)	
	Axis 1	Axis 2	Axis 1	Axis 2
Temperature	0.208	-1.396	0.884	-0.320
Dissolved oxygen	-0.071	-0.376	-0.810	-0.313
Electric conductivity	-0.339	0.601	-0.964	0.018
Turbidity	-0.154	-1.356	-0.490	-0.163
pH	0.050	1.172	0.626	-0.411
Total nitrogen	-0.087	0.731	-0.769	0.299
Nitrate	-0.086	-0.230	-0.490	0.344
Nitrite	0.108	0.008	-0.706	0.095
Total phosphorus	0.182	1.282	0.279	0.411
Total dissolved phosphorus	0.308	0.394	0.902	0.059
Orthophosphate	-0.051	-0.197	0.738	0.031

observed. These environmental variables had higher values in this period (Tab. 1 and 2). The Chlorophyta *Chlorela vulgaris*, *Monoraphidium arcuatum* (Korsikov) Hindák and *M. griffithii* (Berkel) Komárkova-Legnerová, the cyanobacteria *Chroococcus turgidus* Kützing, *Microcystis aeruginosa* and *M. flos-aquae*, and phytoflagellates such as *Cryptomonas ovata* and *Trachelomonas volvocina* Ehrenberg displayed higher biomasses in the rainy period (Tab. 3).

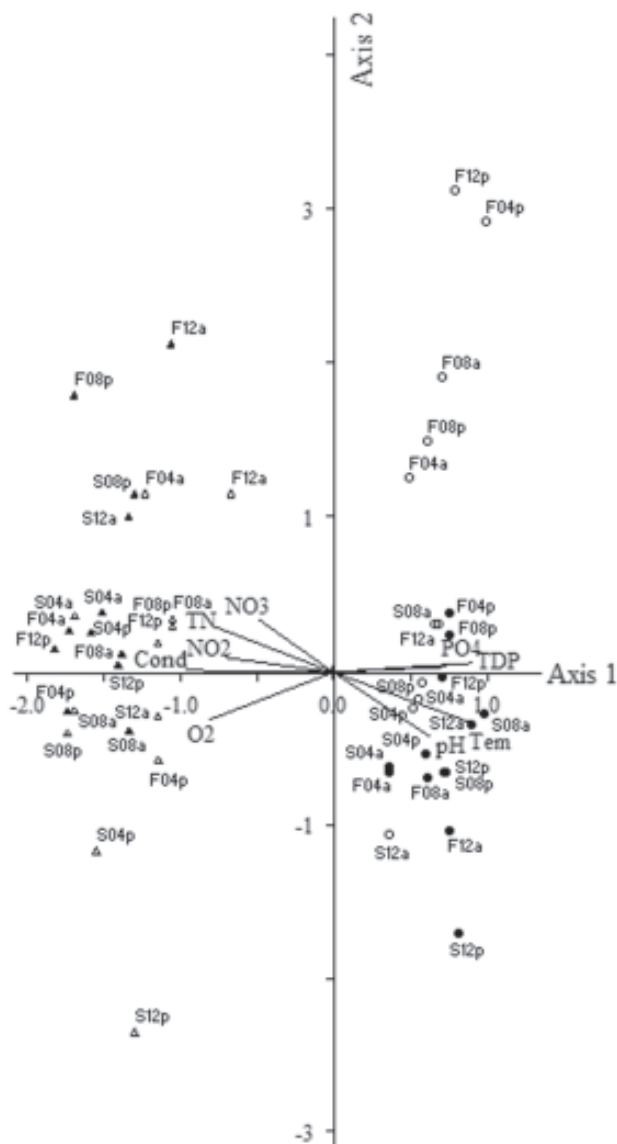


Figure 2. CCA ordination of the sampling unities, on the basis of the environmental variables of the Mundaú reservoir, Northeastern Brazil. The unities were identified according with the sampling station and the season period. ○ = E₁ Dry; ● = E₂ Dry; △ = E₁ Rainy; ▲ = E₂ Rainy. The unities identification respectively corresponds to the depths (S = Subsurface; B = Bottom) and daylight (8 am, 12 pm and 4 pm) and dark (8 pm, 12 am and 4 am) hours. Abbreviations: Cond = Electrical conductivity; NO₂ = Nitrite; NO₃ = Nitrate; O₂ = Dissolved oxygen; pH = pH; PO₄ = Orthophosphate; Tem = Temperature; TN = Total nitrogen; TDP = Total dissolved phosphorus; TP = Total phosphorus; Tur = Turbidity.

Spatial and temporal variations (between hours) were observed on Axis 2. Spatial differences between sampling stations were more pronounced in the dry season, whereas differences between the light and dark hours were more pronounced in the rainy period. The variables positively associated to Axis 2 were pH and total phosphorus, whereas turbidity and temperature were negatively associated to the axis. In the dry season, E₁ exhibited vertical differences and the CCA Axis 2 separated the sampling units from the subsurface and bottom, which were negatively and positively associated to the axis, respectively. Vertical differences were not observed in E₂ and all sampling units from this station were grouped in the CCA and negatively associated to Axis 2. In the dry period, the algae with higher biomasses in E₁ were mostly the cyanobacteria *Chroococcus minutus* Kützing, *C. raciborskii*, *Geitlerinema amphibium* and *Pseudanabaena catenata* Lauterborn. Of these, only *G. amphibium* had higher biomasses at the bottom. The algae in E₂ with higher biomasses were the Chlorophyta *C. vulgaris*, *M. arcuatum* and *Scenedesmus quadricauda* (Turpin) Brébisson, the cyanobacteria *Chroococcus limneticus* Lemmermann and *C. turgidus*, diatoms such as *S. rumpens*, and phytoflagellates such as *C. ovata* (Tab. 3).

CCA Axis 2 for the rainy season separated the sampling units from the light and dark hours, which were negatively and positively associated to the axis, respectively. The algae in this period with higher biomasses during daylight hours were the Chlorophyta *Dictyosphaerium pulchellum* Wood, *Scenedesmus quadricauda* and *Tetraedron triangulare* (Chodat) Komárek and phytoflagellates such as *Cryptomonas ovata*. Cyanobacteria such as *Microcystis flos-aquae* and the Chlorophyta *Coelastrum pseudomicroporum* Korsikov, *Monoraphidium arcuatum*, *M. contortum*, and *Tetrastrum elegans* Playfair had higher biomasses during dark hours (Tab. 3).

Discussion

Eutrophication is a frequent environmental problem in bodies of water throughout the world. Negative impacts include the excessive growth of certain groups of organisms, such as blue-green algae. Cyanobacteria are favored by a wide range of environmental factors. While they can occur in oligotrophic and mesotrophic systems (Hecky & Kling 1987; Huszar & Caraco 1998), these cyanobacteria are prevalent under eutrophic conditions, thriving in warm water temperatures (Shapiro 1990), low luminosity (Padisák & Reynolds 1998), alkaline pH (Reynolds & Walsby 1975) and high nutrient concentrations,

particularly phosphorus (Watson *et al.* 1997) and low N:P ratio (Smith 1983). Such conditions are found in the Mundaú reservoir and explain the development of substantial cyanobacteria biomass in this system.

Nostocales, Oscillatoriales and Chroococcales all occur in the Mundaú reservoir. Nostocales species

generally require a considerable luminosity and high temperatures. They are also more resistant to nutrient depletion, particularly nitrogen (Dokuil & Teubner 2000). Oscillatoriales are typical of high turbidity environments and low luminosity conditions (Reynolds 1997). Self-shadowing, due to the considerable development of



Figure 3. CCA ordination of the phytoplanktonic species found in the Mundaú reservoir, Northeastern Brazil. Abbreviations: Aha = *Actinastrum hantzschii*; Ang = *Ankistrodesmus gracilis*; Aug = *Aulacoseira granulata*; Aua = *A. granulata* var. *angustissima*; Bpr = *Botryococcus protuberans*; Cac = *Closteriopsis acicularis*; Chl = *Chroococcus limneticus*; Chm = *C. minutus*; Cht = *C. turgidus*; Cme = *Cyclotella meneghiniana*; Com = *Coelastrum microporum*; Cop = *C. pseudomicroporum*; Cov = *Cryptomonas ovata*; Cpa = *Closterium parvulum*; Cqu = *Crucigenia quadrata*; Cra = *Cylindrospermopsis raciborskii*; Cvu = *Chlorella vulgaris*; Deh = *Dictyosphaerium ehrenbergianum*; Dpu = *D. pulchellum*; Dov = *Diploneis ovalis*; Ema = *Eunotia major*; Emo = *E. monodon*; Eox = *Euglena oxyuris*; Esp = *Euglena* sp.; Gam = *Geitlerinema amphibium*; Gau = *Gomphonema augur*; Gra = *Golenkinia radiata*; Klu = *Kirchneriella lunaris*; Kob = *K. obesa*; Lov = *Lepocinclis ovum*; Mae = *Microcystis aeruginosa*; Mar = *Monoraphidium arcuatum*; Mci = *M. circinale*; Mco = *M. contortum*; Mep = *Merismopedia punctata*; Mfl = *Microcystis flos-aquae*; Mgr = *Monoraphidium griffithii*; Mmi = *Merismopedia minima*; Mop = *Monoraphidium pusillum*; Mpa = *Microcystis panniformis*; Mwe = *M. wesenbergii*; Ncu = *Navicula cuspidata*; Npa = *Nitzschia palea*; Ola = *Oocystis lacustris*; Pca = *Pseudanabaena catenata*; Phs = *Phacus* sp.; PIs = *Pleurosigma* sp.; Pte = *Pediastrum tetras*; Rme = *Raphidiopsis mediterranea*; Sab = *Scenedesmus acuminatus* var. *bernardii*; Sac = *S. acuminatus*; Sar = *S. arcuatus*; Sat = *S. acutus*; Sbe = *S. bernardii*; Sbi = *S. bicaudatus*; Sec = *S. ecornis*; Squ = *S. quadricauda*; Spa = *S. quadricauda* var. *parvus*; Sps = *Spirulina* sp.; Sru = *Synedra rumpens*; Ssp = *Scenedesmus* sp.; Tca = *Tetraedron caudatum*; Tel = *Tetrastrum elegans*; Tgr = *Tetraedron gracile*; Tin = *T. incus*; Tme = *T. mediocris*; Tmi = *T. minima*; Tob = *Trachelomonas oblonga*; Ttr = *Tetraedron triangulare*; Tvi = *T. victoriae*; Tvo = *Trachelomonas volvocina*.

heterocytes, results in a decreased availability of luminosity, thereby accelerating the succession process. The Nostocales nitrogen pool is then released for the Oscillatoriales by means of cell membrane disruption.

The above-mentioned conditions enable the occurrence of a considerable development of species that are able to fix nitrogen and tolerate low luminosity (Pádisák & Reynolds 1998; Dokuil & Teubner 2000). *Cylindrospermopsis raciborskii* has been reported as an opportunistic species (Istvánovics *et al.* 2000) able to maintain perennial populations, particularly in tropical systems (Briand *et al.* 2002). Due to its similarity to the ecology of Oscillatoriales, Pádisák & Reynolds (1998) moved this species to a new assemblage (denominated Sn), characterized by living in hot, de-stratified systems, while capable of tolerating low luminosity and low nitrogen concentrations. The strategies facilitating dominance of this taxa include: 1) proliferation at high temperatures; 2) first choosing NH₃ and NO₃ (Saker *et al.* 1999); 3) affinity and stocking of phosphorus (Istvánovics *et al.* 2000); 4) frequently reported as herbivore resistant (Fabbro & Duivenvoorden 1996); and 5) the ability to regulate its position in the water column, mostly during thermally stratified periods (Pádisák 1997). We may therefore consider this species an R-strategist, which has developed under the favorable conditions in the reservoir investigated.

The most representative colony-forming taxa of cyanobacteria in the Mundaú reservoir belong to the *Microcystis* genus. The blooming formation of species from this genus is related to the occurrence of anoxia near the sediment (Reynolds 1984). Sediment anoxia is responsible for the non-stop release of phosphorus from the sediment, which favors the maintenance of *Microcystis* blooms at the subsurface of the system (Calijuri & Dos Santos 1996). *Microcystis* dominance in tropical systems may be favored by changes in the mixture throughout the day (Reynolds *et al.* 1987). *Microcystis* species are well known to be generally highly toxic algae, responsible for a number of public health problems. The most worldwide-known incidents took place in the northeastern region of Brazil, where *Microcystis* blooms killed fish and shrimp in the state of Rio Grande do Norte (Chellappa *et al.* 2000) and led to death over 70 patients in a dialysis clinic in Caruaru, Pernambuco (Jochimsen *et al.* 1998). However, blooms of species from the *Microcystis* genus were massively replaced by *Cylindrospermopsis raciborskii*, particularly in the southeastern region of Brazil, as observed in the Juturnaíba reservoir, Rio de Janeiro (Marinho & Huszar 2002) and the Garças reservoir in São Paulo (Tucci & Sant'Anna 2003). This species has been well documented as the cause of blooms in the northeastern region (Bouv

et al. 2000; Huszar *et al.* 2000), including the Mundaú reservoir (Moura *et al.* 2007).

Chlorophyta were represented particularly by Chlorococcales, which are generally small in size while having a high surface/volume ratio. This favors the nutrient absorption, thereby allowing adaptive advantages, especially in oligotrophic waters (Negro *et al.* 2000). Based on the phytosociological assemblages proposed by Reynolds (1997), the green algae found in the Mundaú reservoir, such as *Chlorella vulgaris* and *Monoraphidium contortum*, are grouped within the X₁ assemblages. Therefore, they are found in shallow, mixed, stratified environments and are not sensitive to nutrient shortages.

The importance of Bacillariophyta in eutrophic systems is enhanced by changes in nutrient availability and water transparency (Sommer 1988). *S. rumpens* and *C. meneghiniana* (the taxa present in the reservoir investigated) are typical of shallow, turbid, enriched systems (especially *S. rumpens*), but are generally sensitive to nutrient depletion. Sommer (1988) states that diatoms are excellent competitors for reactive soluble phosphorus and this could explain the occurrence of higher densities of these algae in the dry seasons. Tilman & Kilham (1976) found that *Cyclotella meneghiniana* has a greater dependency on phosphorus when compared to silicates. This corroborates our observations in the Mundaú reservoir, particularly in the dry season.

Cryptomonas ovata had the highest greater number of individuals among the flagellates. This species belongs to the Y functional group (Reynolds 1997), which is usually found in eutrophic systems and is resistant to poor luminosity. A greater biomass of this taxon in the reservoir investigated occurred in the rainy season, when thermal stratification is absent. This finding is in agreement with Romo & Miracle (1995), who observed that the development of *Cryptomonas* populations come about immediately following the occurrence of rains, as rain is responsible for the circulation of water throughout the water column and the re-suspension of nutrients trapped in the sediment.

The Canonical Correspondence Analysis revealed that the development of the phytoplankton community in the dry season was mainly influenced by the availability of phosphorus. The positive correlations between biotic variables and phosphorus products strongly suggest that bottom-up effects play a role in phytoplankton biomass control.

In the dry season, measurements of water temperature, dissolved oxygen, turbidity and pH exhibited differences as a function of depth, with higher values found at the subsurface. These variables influence the spatial distribution of the phytoplankton community. Cyanobacteria, which are dominant in the pelagic zone,

had biomasses with significant vertical differences between depths, with higher values at the subsurface, particularly for *Cylindrospermopsis raciborskii*. Although the dominance of *C. raciborskii* persisted in the littoral zone, a higher abundance of diatoms was observed, particularly *Synedra rumpens* and cocoid chlorophyta.

The algae biomass decrease in the rainy season was driven by events associated to thermal de-stratification and chemical stratification, especially dissolved oxygen and nitrogen. Phytoplankton development was influenced by an increase in allochthonous particulate nutrients, which gave rise to community reorganization events, thereby contributing to the establishment of *C. raciborskii* and species from the *Microcystis* genus.

Water temperature and phosphorus were generally the abiotic variables with a greater influence over both spatial distribution (pelagic/littoral zones and depths) and temporal distributions (times of the day and seasons) of the phytoplankton community in the Mundaú reservoir in northeastern Brazil. In the present study, the demineralization of phosphorus during the dry season contributed toward the re-suspension of diatom frustules. In the rainy season, the circulation of the water column and increase in particulate elements, which were responsible for the low availability of resources, explained the development of the large biomass of *Cryptomonas ovata* and *Microcystis* species. *C. raciborskii* was the species that most stood out in the Mundaú reservoir for being predominant in both seasons. The establishment of cyanobacteria blooms, mainly made up of *C. raciborskii*, was more pronounced in the dry season, which certainly occurred due to the high availability of phosphorus, low NO₃ levels, limited nitrogen, alkaline pH and thermal stability of the system.

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