The role of nutrient dynamics on the phytoplankton biomass (chlorophyll-*a*) of a reservoir-channel continuum in a semi-arid tropical region

Papel da dinâmica de nutrientes na biomassa fitoplanctônica em um continuum reservatório-canal na região tropical semi-árida

Câmara, FRA.[1], Lima, AKA.[1], Rocha, O.[2] and Chellappa, NT.[1]

[1]Departamento de Oceanografia e Limnologia, Universidade Federal Rio Grande do Norte – UFRN, CP 1524, CEP 59072-970, Natal, RN, Brazil
e-mail: fabirac@gmail.com; andressaklima@gmail.com; chellappa@dol.ufrn.br

[2]Departamento de Ecologia e Biologia Evolutiva, Centro de Ciências Biológicas e Saúde, Universidade Federal de São Carlos – UFSCar, Rodovia Washington Luís, km 235, SP-310, CEP 13565-905, São Carlos, SP, Brazil
e-mail: doro@power.ufscar.br

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Abstract: Aim: The aim of this study was to evaluate the role dissolved inorganic nutrients and phytoplankton biomass in a "continuum" reservoir-channel, a system of drinking water supply in the semi-arid Rio Grande do Norte State, Brazil; **Methods:** Phytoplankton samples were taken with plankton net (mesh size 20 µm) for qualitative analyses and the Utermöhl method was used to quantify the microalgae. In situ measurements were made for temperature, pH, electrical conductivity and dissolved oxygen with multi-parameter water quality monitoring probe. Secchi disc and turbidity readings were made. Nutrients and chlorophyll-*a* concentrations were analyzed in the laboratory following the specifics spectrophotometric methods. A Canonical Correspondence Analysis (CCA) was used to investigate the response of each phytoplankton group to the environmental variables; **Results:** The results show that the spatial and temporal alterations in the structure of the phytoplankton community and in chlorophyll-*a* concentration were associated to fluctuations in inorganic nutrient levels. The potentially toxic species, such as, *Anabaena planctonica* Brunnthaler, *Microcystis aeruginosa* (Kūtzing) Lemmermann, *Microcystis protocystis* Lemmermann, *Microcystis panniformis* Lemmermann, *Oscillatoria* sp. and *Planktothrix agardhii* Smith were found in high densities. The data was compared to the value of 10.000 cell.mL^{-1} of cyanobacteria counts established by World Health Organization for public drinking water supply system. The results of canonical correspondence analysis reveal a significant relation between orthophosphate content and Secchi disc depth to cyanobacteria dominance in the reservoir-channel gradient on temporal scale. Chlorophyll-*a* concentrations were strongly related to the relative dominance and densities of cyanobacteria; **Conclusions:** Spatial and temporal distribution over reservoir-channel "continuum" resulted in a significant phytoplankton functional change (chlorophyll-*a*) with useful implications to the design of water supply systems in semiarid regions.

Keywords: biomass, phytoplankton, drinking water, freshwater system.

Resumo: Objetivo: O objetivo deste estudo foi avaliar a biomassa fitoplanctônica em um "continuum" reservatório-canal, que consiste em um sistema de suprimento de água potável no semi-árido do Rio Grande do Norte, Brasil; **Métodos:** Para a obtenção dos dados foram colhidas amostras do fitoplâncton em rede de plâncton (20 µm) e o método Utermöhl foi utilizado para quantificar as microalgas. Foram mensurados alguns parâmetros físicos e químicos in situ, tais como: condutividade elétrica, temperatura, pH, oxigênio dissolvido e transparência da água utilizando uma sonda multi-paramétrica. Leituras de disco de Secchi e turbidez foram feitas. Os nutrientes e clorofila-*a* foram analisados de acordo com metodologias espectrofotométricas específicas. Análise de Correspondência Canônica (CCA) foi utilizada para investigar a resposta de cada grupo fitoplanctônico em relação às variáveis ambientais analisadas; **Resultados:** Os resultados mostraram que as alterações espaciais e temporais na estrutura da comunidade fitoplanctônica e nas concentrações de clorofila *a* estiveram associadas às flutuações nos níveis de nutrientes inorgânicos ao longo do "continuum" reservatório-canal, durante o período de estudo. As espécies potencialmente tóxicas, tais como *Anabaena planctonica* Brunnthaler, *Microcystis aeruginosa* Kūtzing, *Microcystis protocystis* Lemmermann, *Microcystis panniformis* Lemmermann, *Oscillatoria* sp. and *Planktothrix agardhii* Smith, foram encontradas em elevadas densidades, de acordo com o estabelecido pela Organização Mundial da Saúde (OMS) que estabelece o limite de 10.000 cel.mL^{-1} de cianobactérias em água para abastecimento público. A forte influência exercida pelo ortofosfato sob a dominância de cianobactérias foi evidente na análise de correspondência canônica no gradiente reservatório-canal em escala temporal, ao lado da profundidade do disco de Secchi. A concentração de clorofila *a* esteve fortemente relacionada com a densidade de cianobactérias; **Conclusões:** A distribuição espacial e temporal da biomassa fitoplanctônica ao longo do "continuum" reservatório-canal resulta em uma significante mudança funcional (clorofila-*a*) da comunidade fitoplanctônica e em implicações úteis para a concepção de sistemas de abastecimento de água em regiões semi-áridas.

Palavras-chave: biomassa, fitoplâncton, abastecimento público, sistema dulcícola.

1. Introduction

The water balance in freshwater aquatic ecosystems is considered one of the important problems taken into serious consideration for management practices to maintain water quality and quantity to meet the demands of increased population density (Tundisi, 2001; Souza, 2002). In arid and semi-arid regions, it assumes serious proportion as the rainfall is dwindling, infrequent, unpredictable and disproportionally distributed. The situation forces an extreme scarcity of water resource for northeast Brazil, and the freshwater resource now facing a threat from cultural eutrophication and frequent bloom formation of potentially toxic cyanobacteria (Bouvy et al., 2003; Chellappa and Costa, 2003). To ensure supply of water to the population of the region, a number of water resource management programs has been implemented, such as the construction of reservoirs, channels and pipelines (SERHID, 2008). However, studies conducted in the northeastern Brazil have demonstrated frequent impacts of varying eutrophication degree on the water quality, with ecological, economic and social consequences that are reflected in human health (Bouvy et al*.,* 2003; Costa et al., 2006).

Much of the research has focused on assessing the water quality of rivers, streams and reservoirs, using physical and chemical analyses, with phytoplankton algae receiving special attention in limnological studies in assessing the effects of eutrophication and freshwater related pollution effects (Coste et al., 1991; Moss, 2008; Harper, 1992). In Brazil, studies on the structure and ecology of phytoplankton, their density and biomass along with hydrological variables were developed by Huszar and Reynolds (1997), Ibañez (1998), Dellamano-Oliveira et al. (2003), Figueredo et al. (2007), Crossetti et al. (2008), among others. On the other hand, Rangel et al. (2009) reported seasonally fluctuating higher phytoplankton biomass in a shallow eutrophic lake of São Paulo in warm-rainy season and the varying degree of distribution during stratified times of rainy and dry seasons. These studies demonstrated how spatial and temporal patterns of distribution in the phytoplankton community are influenced by environmental drivers in favour of increased or decreased diversity culminating in cyanobacterial dominance. Chlorophyll-*a* is a photosynthetic pigment present both in eukaryotic and prokaryotic species of phytoplankton and a reliable proxy for the measurement of total phytoplankton biomass in reservoir waters and addressed how the biomass correlated to rapid responses within the short time intervals (Gregor and Marsálek, 2004). Chlorophyll-*a* is often used as an indicator of active biomass in primary producers responding positively to variation in solar radiation and the fluctuations of inorganic nutrients. Both these drivers influence the physiological activities of phytoplankton cells, thus enhancing or decreasing the concentrations depending on the forces of the drivers (Wilhelm et al*.,* 2004; Clarke et al., 2006). Functional traits along environmental gradients have been successfully applied to community ecological studies in terrestrial plants, in which photosynthetic rates have been applied to functional traits (McGill et al., 2006). Thus, studies using this approach may detect possible alterations in water quality, as well as to assess tendencies over time that could lead to a better understanding of functional aspect of phytoplankton in reservoir-channel environmental gradient.

The aim of this study was to assess the phytoplankton biomass by analyzing chlorophyll-*a* and phytoplankton community in relation to the spatial and temporal dynamics in a reservoir-channel "continuum" during one seasonal cycle, observing the existing relations between nutrient availability and the phytoplankton groups along horizontal gradient.

2. Material and Methods

2.1. Study site

The Armando Ribeiro Gonçalves (ARG) Reservoir supplies the Pataxo Channel through a system of pipelines that maintain the water flow at 2.2 m^3/s. The Channel is 9 km long and carries the ARG Reservoir water to the Pataxo River/Ipanguaçu, Rio Grande do Norte State, Brazil.

The study was conducted at three different sites during the dry season (January, February and November, 2006) and rainy season (March, April, May and June, 2006). The first site was the Armando Ribeiro Gonçalves (ARG) Reservoir situated in the city of Assu, RN (5° 40' 12.10" S and 36° 52' 43.18" W). The second, the Pataxo Channel, is located at Itaja, RN, 8 km from the reservoir and 80 m from the capture site of Water treatment station (WTS) (5° 38' 36.32" S and 36° 52' 54.58" W). The third site, the WTS is where the water is treated with chemical additives by the water sewage company of Rio Grande do Norte (CAERN) before supplying water to more than forty thousand inhabitants in the semi-arid region through a system of pipelines, which increases the irrigated area of the state by more than 2,500 ha (Figure 1).

2.2. Sampling and sample analysis

Integrated samples collected at the reservoir were pooled from subsurface depth (1 m), middle column (7 m) and from the bottom (15 m) at the lacustrine zone, very near to the capture point of water destined to the Pataxo Channel. Five liter Van Dorn's bottle sampler was used throughout the study period. In the Pataxo Channel, the average current of the water was 0.5 $m.s^{-1}$ and maximum depth never exceeded beyond 1.5 m. At the Water Treatment Station, the collections were taken from a faucet. In all the sites, pH, temperature, electrical conductivity and dissolved oxygen were measured using a WTW Multi 340i Multi-parameter probe. Turbidity was analyzed with a LaMotte 2020 tur-

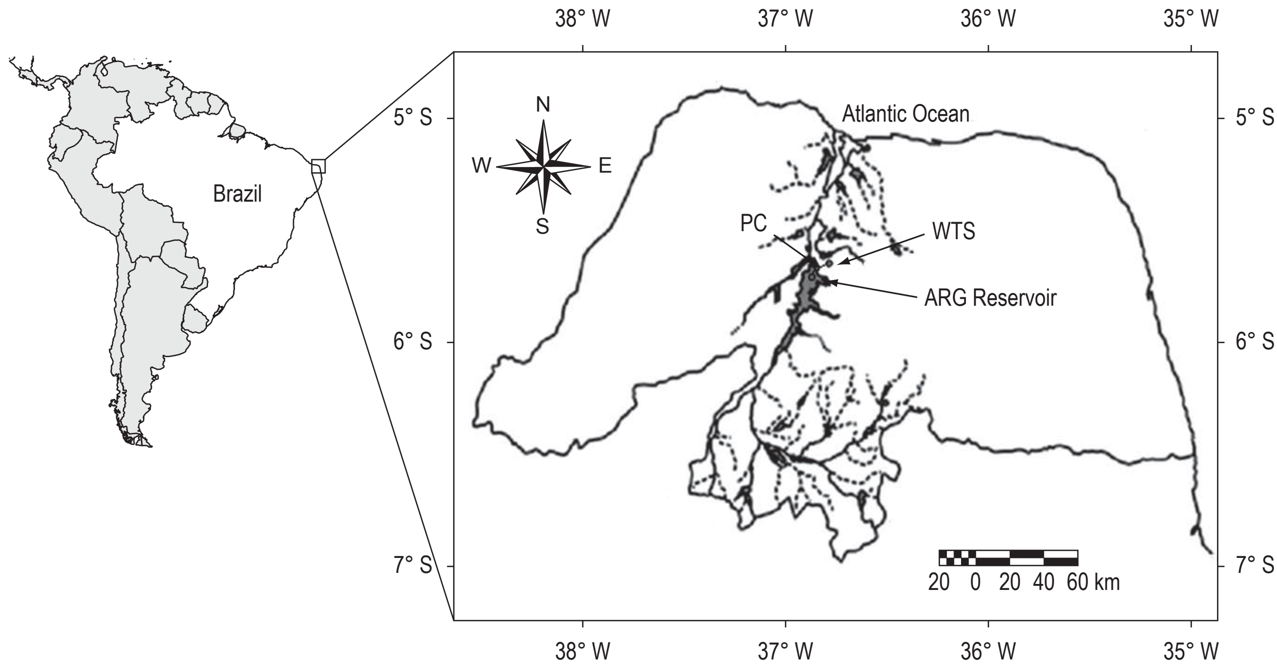

Figure 1. Study area: Armando Ribeiro Gonçalves (ARG) Reservoir, Pataxo Channel (PC) and the Water Treatment Station (WTS) (Source: SERHID, 2008).

bidimeter. For analysis of inorganic nutrients, the water was initially filtered using Whatman GF/F filters, which was followed by analysis of nitrate (Goltermann et al., 1978), orthophosphate (APHA, 1985) and ammonium concentrations (Goltermann et al., 1978). Total phosphorous (Strickland and Parsons, 1960) and total nitrogen (Valderrama, 1981) were also analyzed.

Water transparency as well as total phosphorous, orthophosphate and chlorophyll-*a* concentrations were used to calculate the trophic status index of Carlson (1977) modified by Toledo et al. (1983) for its use in tropical environments.

Information on spatial and temporal changes of the phytoplankton community and the physiological status of its cells were obtained from quantitative analyses of phytoplankton and chlorophyll-*a*. Water samples were packed and protected from the light. Filtration was done through 0.7 mm Whatman filters (GF/F) to estimate total chlorophyll-*a*. After filtration, the pigments were extracted with 90% acetone at 4 °C in the dark. The samples were analyzed on a Libra S6 spectrophotometer (Biochrom), at wavelengths of 665 and 750 nm. The absorption values corresponding to the analysis of chlorophyll-*a* were later inserted in the formula described by Marker et al. (1980), to obtain concentration in $\mu g.L^{-1}$.

Phytoplankton samples were preserved in 4% Lugol-formaldeyde solution in the field. It was sedimented and analyzed using an optical microscope down to the species level or to the highest possible taxonomic resolution using the specific literature (Barber and Haworth, 1981; Komárek and Anagnostidis, 1999; Sant'Anna and Azevedo, 2000; Wehr and Sheath, 2003; Bicudo and Menezes, 2005). Aliquots of 50 mL of water were colleted from the ARG Reservoir, Pataxo Channel and WTS for quantitative analyze. Phytoplankton was counted using an inverted microscope according to the Utermöhl method (Lund et al., 1958).

2.3. Statistics

We used canonical correspondence analysis (CCA) to determine the relationships between phytoplankton group composition and physics-chemical environmental variables (Ter Braak and Verdonschot, 1995). The ordination analyses were performed with the program CANOCO version 4.5. To evaluate the significance of CCA axes and of the variables which defined these axes, Monte Carlo tests were performed with 499 unrestricted permutations. Thus, it was possible to test the significance of the environmental variables in determining the ordination patterns of relative abundance phytoplankton groups in ARG reservoir, Pataxó channel and WTS.

Linear regression analyses were applied to detect relations between chlorophyll-*a* and orthophosphate and between chlorophyll-*a* and phytoplankton groups. Comparisons of the mean values of the three study sites were carried out using Analysis of Variance (One-Way ANOVA) and the Kruskal-Wallis test using SigmaStat 3.1 after log transformation of data.

3. Results

Annual rainfall in the study area was 350-650 mm. The rainy season is in April and May and the dry season between November and February. Water temperature did not vary significantly during the study period (ANOVA; $p < 0.05$). Mean wind speed was fairly constant over the months, with higher values in the rainy season (2.8 $m.s^{-1}$) than in the dry season (0.8 $m.s^{-1}$). Tukey's test ($\alpha = 0.05$) considered these variables to be similar at the three study sites.

Water conductivity was similar (ANOVA; $p < 0.05$) at the three sites as a result of high nutrient values, even after dilution due to water flow in the channel and rainfall. Higher ammonium values were recorded in the rainy season and may have contributed to the high conductivity in the studied area. Dissolved oxygen concentrations decreased whereas ammonium concentration increased between the Reservoir and the WTS (Table 1).

The inorganic nutrient concentrations were high. However, lower values were recorded after water treatment. There was a significant difference (ANOVA; $p < 0.05$) in the orthophosphate values between the Reservoir and the WTS, mainly during the rainy season. Similar results between the Reservoir and the WTS were found for nitrate (ANOVA, $p > 0.05$) total phosphorus (TP) (ANOVA; $p > 0.05$) and total nitrogen (TN) (ANOVA; $p > 0.001$). At all the study sites, the total nitrogen concentrations were very high, likely owing to the elevated nitrate and ammonium concentrations found during the entire period (Table 1). At the Reservoir and in the Pataxo Channel, ammonium and orthophosphate showed a positive correlation ($r^2 = 0.89$ and $r^2 = 0.92$, respectively; $p < 0.01$) with chlorophyll-*a* during the dry season.

The Table 2 shows changes in phytoplankton chlorophyll-*a* concentration revealing that higher concentrations were found in ARG Reservoir and lower recorded in WTS. Spatial differences, between stations, of chlorophyll-*a* were highly significant (Kruskal-Wallis; $p < 0.01$). The interaction effect between month and station has also highly significant (ANOVA two way; $p < 0.01$). Cyanobacterial density was high at the three sites (Figure 2), and strongly related to the of chlorophyll-*a* concentration in ARG Reservoir ($r^2 = 0.74$; $p < 0.01$) during the study period. On the other hand, a significant correlation with the cyanobacteria and chlorophyceae ($r^2 = 0.81$ and $r^2 = 0.77$; $p < 0.05$) was recorded in the Channel water. In WTS, there was no significant relationship between chlorophyll-*a* and phytoplankton groups in general (Table 3).

The results of Table 4 are derived from a regression of annual maximum chlorophyll-*a* concentration on annual mean orthophosphate concentrations, applied to data from the reservoir, channel and WST, with 95% confidence intervals. The relation between chlorophyll-*a* and orthophosphate demonstrated more evident in the ARG Reservoir and a low relation in WTS.

Forty two (42) taxa were identified in the phytoplankton community, distributed into 4 classes (Cyanobacteria, Chlorophyceae, Euglenophyceae and Bacillariophyceae). The class with the highest number of species was Cyanobacteria (21 species), followed by Chlorophyceae (11 species), Bacillariophyceae (7 species) and Euglenophyceae (3 species). A total of 38 taxa were identified at the ARG Reservoir, 32 in the Pataxo Channel and 15 at the Treatment Station. The species densities ($cell.mL^{-1}$), that represented more than 80% of total density at the three study sites are shown in Figure 3.

Among the taxa found at the reservoir, channel and WTS, the Cyanobacteria group was represented by the genera *Anabaena, Aphanizomenon, Chrococcus, Coelomoron, Coelosphaerium, Cylindrospermopsis, Cylindrospermum, Gomphosphaeria, Lyngbya, Merismopedia, Microcystis, Nostoc,*

Table 1. Mean and standard deviation (n = 24) of physical and chemical variables of the three selected sites: ARG Reservoir; PC. Pataxó Channel; WTS. Water Treatment Station at dry and rainy periods.

Variables	ARG Reservoir		Pataxó Channel		WTS	
	Dry	Rainy	Dry	Rainy	Dry	Rainy
pH	8.3 ± 0.21	8.18 ± 0.23	8.5 ± 0.3	8.4 ± 0.7	7.4 ± 0.3	7.4 ± 0.2
Water Temp (°C)	29.1 ± 2.24	28.2 ± 1.92	29.5 ± 0.75	29.9 ± 1.02	29.6 ± 0.6	30.1 ± 1.3
DO ($mg.L^{-1}$)	3.8 ± 2.45	2.7 ± 1.54	2.5 ± 0.6	1.6 ± 0.6	2.0 ± 1.5	1.7 ± 0.5
Cond. ($\mu S.cm^{-1}$)	367.3 ± 12.7	212.3 ± 9.50	243.7 ± 13.3	251 ± 20.7	193.5 ± 15.2	203.4 ± 20.04
Turbidity (NTU)	8.9 ± 4.9	10.1 ± 3.57	5.8 ± 2.4	4.9 ± 3.0	2.1 ± 0.8	3.14 ± 1.7
PO_4^{3-} - P ($mg.L^{-1}$)	0.044 ± 0.01	0.237 ± 0.07	0.048 ± 0.004	0.138 ± 0.11	0.04 ± 0.006	0.032 ± 0.008
NO_3^- - N ($mg.L^{-1}$)	0.244 ± 0.007	0.354 ± 0.184	0.217 ± 0.163	0.293 ± 0.171	0.092 ± 0.005	0.204 ± 0.09
NH_4^+ - N ($mg.L^{-1}$)	0.271 ± 0.05	0.348 ± 0.06	0.208 ± 0.03	0.257 ± 0.10	0.102 ± 0.05	0.171 ± 0.07
TN ($mg.L^{-1}$)	2.85 ± 0.65	2.22 ± 0.8	2.45 ± 0.3	2.168 ± 0.8	1.162 ± 0.15	2.80 ± 0.23
TP ($mg.L^{-1}$)	0.104 ± 0.06	0.337 ± 0.16	0.164 ± 0.07	0.317 ± 0.1	0.148 ± 0.09	0.235 ± 0.14

Table 2. Mean, minimum, maximum values and standard deviation of chlorophyll concentrations (µg.L^{-1}) during dry and rainy periods of the three selected sites Abbreviation: Water Treatment Station (WTS); Standard deviation (SD).

Site/period	Min-Max		Mean ± SD	
	Dry	Rainy	Dry	Rainy
ARG Reservoir	85.2-100.1	51.0-89.2	92.6 ± 9.5	67.6 ± 7.45
Pataxo Channel	40.2-56.8	145.2-275.9	48.5 ± 4.0	198.34 ± 8.3
WTS	2.6-6.6	19.2-49	46 ± 6.2	31.16 ± 2.0

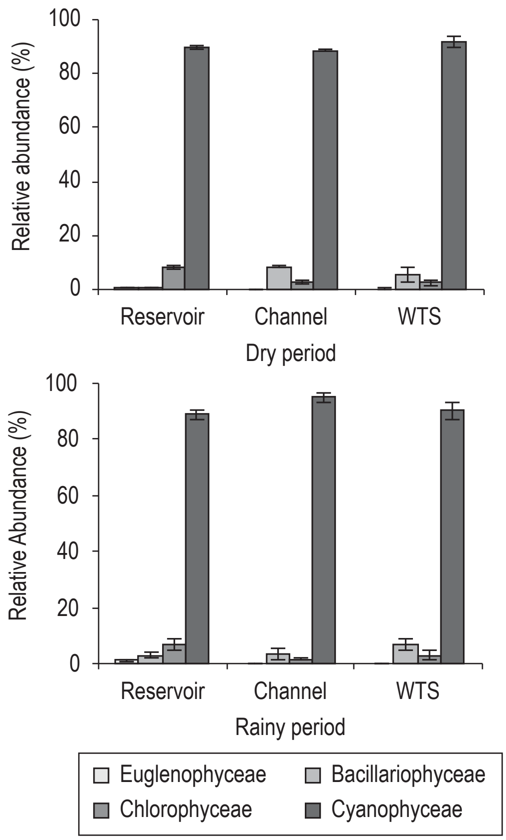

Figure 2. Mean relative abundance (%) and standard deviations of the phytoplankton groups found at the Armando Ribeiro Gonçalves Reservoir, Pataxó Channel and Water Treatment Station (WTS), during the dry and rainy seasons.

Table 3. Linear regression analysis, significant statistically, between cyanobacteria and chlorophyceae density (log. cells.mL^{-1}) with chlorophyll-*a* concentrations (log µg.L^{-1}) at the Reservoir and Pataxó Channel, during study period.

		Cyanobacteria	Chlorophyceae
ARG Reservoir	B	15.64	-
	R^2	0.74	-
	p-level	0.012	-
Pataxo Channel	B	-	1.48
	R^2	0.81	0.77
	p-level	0.006	0.009

Table 4. Chlorophyll-phosphorus regression for sites study. *C.* Chlorophyll-*a* concentration (µg.L^{-1}); *P04.* Orthophosphate concentration (mg.L^{-1}); WTS. Water Treatment Station.

Location	Equation	n	r^2	F	p-level
ARG Reservoir	ln *C* = 1.102 ln *P04* – 1.521	12	0.77	1.198	0.032
Pataxo Channel	ln *C* = 1.023 ln *P04* – 2.825	12	0.48	1.054	0.019
WTS	ln *C* = 1.023 ln *P04* – 1.768	12	0.59	1.324	0.012

Oscillatoria, Phormidium, Planktothrix, Pseudanabaena, Rhaphidiopsis and *Synecocystis*.

However, during dry season occurred a greater species abundance of *Microcystis aeruginosa* Kützing, *Microcystis protocystis* Lemmermann, *Microcystis* sp., *Microcystis panniformis* Lemmermann (31%), *Oscillatoria* sp. (21%) and *Planktothrix agardhii* Smith (29%). Among the Chlorophyceae, the species *Coelomoron tropicalis* Senna and *Staurastrum anatinum* var. *curtum*. Smith stand out with relative abundance of 8% and 6%, respectively, whereas the other Chlorophyceae species had relative abundance of less than 1%. The Bacillariophyceae were found mainly in the Pataxo Channel, predominantly represented by *Aulacoseira granulate* (Ehrenberg) Simonsen with 5% relative abundance in the dry season and 6% in the wet season.

In this study, the Pataxo Channel was considered mesotrophic owing to the high water flow, minimizing the trophic status of the ARG Reservoir water, which is eutrophic, according to the Trophic Status Index proposed by Carlson (1977) and Toledo et al. (1983), facilitating the water treatment process (Table 5).

A Canonical Correspondence Analysis (CCA) was used to investigate the response of each group to the environmental variables analyzed. Among the environmental variables, only nitrate, pH, orthophosphate, total phosphorus, total nitrogen, electrical conductivity and turbidity were selected for inclusion in the CCA regression model ($p < 0.05$), according to Monte Carlo test. The remaining variables, such as ammonium, dissolved oxygen, temperature and Secchi disc depth, did not explain any meaningful proportion of the residual variance, and were therefore excluded from the analysis.

The results of the CCA indicates that the first two axes of the ordination defined by environmental variables selected during rainy period explained 68.3% of the variance in the weighted mean of the groups. The Monte Carlo test with 499 permutations demonstrated that both the first canonical axis and the sum of all canonical axes were significant ($p = 0.034$). The ordination of phytoplankton community by CCA showed that the community variation patterns were significantly related to the environmental heterogeneity patterns observed in this study. During rainy period, the environmental variables, nitrate, orthophosphate, pH, TP and TN significantly explained the principal variations in the phytoplanktonic groups, mainly cyanobacteria in Pataxó channel and in ARG reservoir, the Euglenophyceae group was influenced by total phosphorus and total nitrogen. CCA analyses suggested that cyanobacteria group not have substantial tolerance to different environmental variables. Indeed, this group was close to the center of the CCA diagram (Figure 4a). The same occurred during dry period, where cyanobacteria were strongly influenced by all the variables used in the analysis (Figure 4b). This is probably due to the cosmopolitan and adaptative characteristics of these group that indeed, known to tolerate large ranges in water qualities.

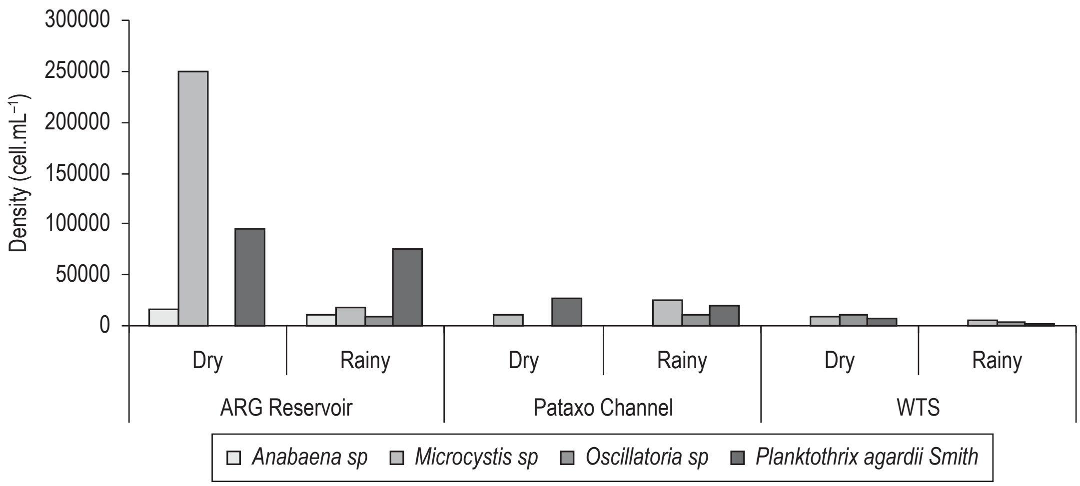

Figure 3. Density of dominant species (cells. mL-1) registered in Armando Ribeiro Gonçalves (ARG) Reservoir, Pataxo Channel and Water Treatment Station (WTS), during the dry and rainy seasons.

Table 5. Trophic State Index (TSI) of ARG Reservoir, Pataxo Channel and Water Treatment Station (WTS), during study period.

	Secchi disc (S)	TSI (TP)	TSI (PO_4)	TSI (CHL)	Mean TSI	Index of (Carlson, 1977; Toledo et al., 1983)
ARG Reservoir	60.76	58.95	60.20	58.72	59.50	Eutrophic (>54)
Pataxo Channel	54.72	54.22	54.00	50.00	53.02	Mesotrophic (44-54)
WTS	-	36.46	40.26	42.00	39.57	Oligotrophic (<44)

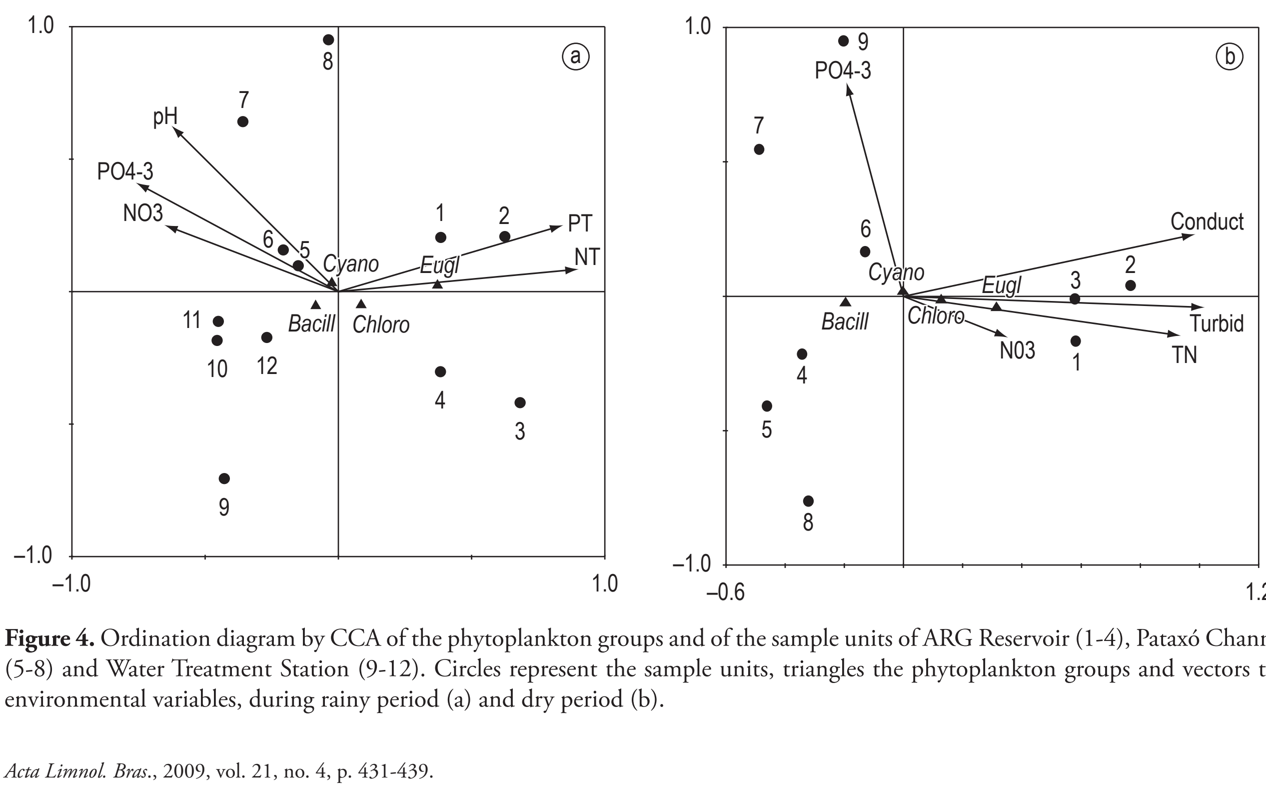

Figure 4. Ordination diagram by CCA of the phytoplankton groups and of the sample units of ARG Reservoir (1-4), Pataxó Channel (5-8) and Water Treatment Station (9-12). Circles represent the sample units, triangles the phytoplankton groups and vectors the environmental variables, during rainy period (a) and dry period (b).

4. Discussion

The twin objects had been main stay of numerous studies carried out in freshwater ecosystems (Dillon and Rigler, 1974; Goldman and Horne, 1983; Padisák et al., 1988; Piehler et al., 2004; Buyukates and Roelke, 2005) including our earlier study (Chellappa et al., 2009) that soluble reactive phosphorus or orthophosphate content significantly related to chlorophyll-*a* concentrations. Present study amply demonstrates the dominance of cyanobacterial species accounted mostly to the chlorophyll-*a* maxima and specifically to the relative dominance of *Microcystis* sp. and *Planktothrix agardhii* in Armando Ribeiro Gonçalves reservoir and Pataxo channel.

Chellappa et al. (1998) suggested that the high electrical conductivity, cyanobacterial species dominance and accentuated chlorophyll-*a* are indication of eutrophication of tropical reservoir ecosystems of Marechal Dutra Reservoir (Sertão region) of Rio Grande do Norte. In the present study, the electrical conductivity values at the ARG Reservoir were considered high on the spatial and temporal scales. These results are comparable to eutrophic environments of Taquaral Lake in Campinas, Brazil, where they ranged from 250 to 300 $\mu S.cm^{-1}$ and the reservoir at Pampulha, Brazil, with the values varying between 122 and 376 $\mu S.cm^{-1}$ (Giani et al., 1988). In the Pataxo Channel, the values remained high; because of the evaporative rate of water confined to shallow depth, smooth current and the constant mixture of the water column, in spite of the fact the environment was not eutrophicated.

Nutrient dynamics involve available dissolved nutrients and assimilated levels to determine nitrogen in the form of nitrate or ammonium and phosphorus in the form of orthophosphate to play a significant role in relation to chlorophyll-*a* concentrations. Goldman and Horne (1983), working with the phytoplankton response to wastewater nutrients, observed a consistent preferential assimilation of ammonium over nitrate among the three algal species they studied. Besides, they suggested that the larger concentrations of ammonium compared to nitrate and the consequent increase in phytoplankton biomass led to eutrophication of the environment. Similar results were found in Pataxo Channel before and after treatment, which resulted in large increase in chlorophyll-*a* especially during dry season.

Chlorophyll concentration is the measure of the abundance of phytoplankton and is related to dissolved orthophosphate (Reynolds, 2006). Models relating chlorophyll to nutrients and Secchi depth to chlorophyll using data from freshwater body's world over were successfully tested and developed. The models suggest that phosphorus is the primary limiting factor for phytoplankton and that total phosphorus concentration accounts for 81% of the variance in chlorophyll concentration.

Furthermore, chlorophyll-phosphorus regressions are widely used to establish an empirical relationship based on the cumulative data obtained from the temperate lakes (Dillon and Rigler, 1974) and others used the model predicatively in the water quality management and eutrophication abatement programs (Smith and Shapiro, 1981; Smith, 1982). The models also show that chlorophyll-*a* is the dominant factor determining Secchi depth and that chlorophyll concentrations account for 68% of the variance in Secchi depth. These authors believe that their models are robust and should be useful for eutrophication management in freshwater systems world over. The results of the present investigation, though tropical impounded water bodies, still indicate that the amount of chlorophyll per unit of phosphorus and Secchi depth per unit of chlorophyll are both significant in Armando Ribeiro Gonçalves reservoir of Assu/RN and Pataxo Channel for the annual cycle of 2006-2007 and are similar to models developed for freshwater lakes. We conclude therefore, nutrient to chlorophyll and chlorophyll to Secchi depth in our study are probably well suited for use in semi-arid Northeast realm.

In Brazil, the reservoirs ecosystems located at the semiarid northeast demonstrate a regional peculiarity in which negative water balance and consequently accumulation of salts leading to pH values above 8.0 or alkaline nature (Wright, 1937). In the present study, the pH at the Armando Ribeiro Gonçalves Reservoir during the dry season was always alkaline and higher than 8.0, which suggests the predominance of bicarbonate in the reservoir resulting from intense photosynthetic activity, coupled with high chlorophyll-*a* values. In the Pataxo Channel, the pH continued to be alkaline, but the situation is altered in the after treatment site (WTS), which remained neutral during the entire study period. The pH factor therefore is altered in reservoir-channel "continuum" after treatment site to make it palatable and safe drinking water source.

The present study provides insight into reservoir (lentic zone) and channel (lotic characteristic) continuum, in which environmental gradients tend to show the similarity and differences to the nature of reservoir. The changes occurred in the Pataxo Channel (before treatment) is often limited and the reduced levels of nutrients thus improved the water quality after treatment site and accordingly the changes in tropical index state. The composition of phytoplankton and the concentration of chlorophyll-*a* remained the same or some tangential differences among the three sites studied.

Nutrient enrichment by autochthonous recycling in freshwater ecosystems or through allochthonous input by feeder rivers have been considered a major stimulant for eutrophication and a threat to dwindling water resources. As a consequence of nutrient enrichment ecosystems experienced the events of toxic cyanobacterial bloom (Huszar et al., 2005; Moss, 2008). Our study centered on Armando Ribeiro Gonçalves reservoir and Pataxo Channel and is the major water resources for water scarce interior region of the Rio Grande do Norte State, which is presently impacted by the agriculture run off, effluents from Cage culture practice and nutrient enrichment source from lentic-lotic character of reservoir and channel continuum.

Costa (2003) observed low N: P ratios in the annual cycle of Armando Ribeiro Gonçalves Reservoir particularly during the periods of dominance of nitrogen-fixing cyanobacterial species. In the Pataxo Channel and at the WTS site, TN and TP concentrations were lower than those registered in the Reservoir and in Pataxo Channel. A high density of cyanobacteria has often occurred in various public reservoirs in the northeast semiarid, with a competitive dominance of species such as *Microcystis* sp., *Anabaena* sp., *Planktothrix* sp., *Aphanizomenon* sp. and *Cylindrospermopsis raciborskii (*Woloszynska) Seenayya & Subbaraju, mainly during in the dry season. This situation occurred due to longer theoretical retention time of the reservoir, which is submitted to the constant eutrophication processes. In the present study, the species *Microcystis aeruginosa* Smith*, Microcystis protocystis* Lemmermann, *Microcystis* sp., *Microcystis panniformis* Komárek, *Oscillatoria* sp. and *Planktothrix agardhii* Smith are registered frequently and accounted for more than 90% of the phytoplankton community, contributing strongly to the total biomass (chlorophyll-*a*) of the ecosystems studied. Costa et al. (2006) obtained similar results and emphasized the high concentration of cyanobacteria in the ARG Reservoir, exceeding the limits (10.000 cells.mL^{-1}) recommended by the World Health Organization. In contrast, this same study showed that the water treated from the Channel had within acceptable of limits established by the World Health Organization (Chorus and Bartram, 1999).

Our results have shown that there was a close relationship between the phytoplankton composition and biomass and the nutrient availability across a gradient encompassing the eutrophic ARG reservoir, mesotrophic in Pataxo Channel and oligotrophic in Water Treatment Station following Carlson (1977) index. These findings might have useful implications for the design of water supply systems in arid and semiarid regions.

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