# Diel dynamic of phytoplankton functional groups in a tropical water supply, Extremoz Lake, northeastern Brazil

## Dinâmica Nictemeral dos grupos funcionais fitoplanctônicos de um manancial tropical, Lagoa de Extremoz, nordeste do Brasil

Thársia da Silva Pinto and Vanessa Becker

Laboratório de Engenharia Sanitária e Recursos Hídricos, Universidade Federal do Rio Grande do Norte – UFRN, Avenida Senador Salgado Filho, 3000, Lagoa Nova, CEP 59078-970, Natal, RN, Brazil
email: tharsia.silva@gmail.com; becker.vs@gmail.com

**Abstract: Aim**: This study analyzed - the diel and vertical dynamics of phytoplankton functional groups in a natural tropical lake (Extremoz Lake, northeast Brazil), to investigate and understand the driver factors of the community during a severe drought period. **Methods**: Sampling of the abiotic variables and phytoplankton was performed at intervals of 6 hours over 24 hours in vertical profiles, in dry and rainy seasons (according to the historical average). The phytoplankton species were grouped according to the functional groups' approach *sensu* Reynolds et al. (2002). **Results**: October/12 was considered as a dry period (18.4 mm), while March/13, due to the historical average, as a rainy season, due to the low rainfall during the study period (15.7 mm), it was called severe drought. The lake showed thermal and chemical destratification in both periods. Phytoplankton biomass was higher in the dry season and their vertical distribution was stratified in both periods. In both samplings there were less algal biomass during the night. Phytoplankton functional groups of mixed and shallow systems ($\mathbf{S_1}$, $\mathbf{L_0}$ and **K**) were descriptors throughout the study period with higher biomass always registered in the group $\mathbf{S_1}$, represented by *Planktolyngbya limnetica* (Cyanobacteria) **Conclusion**: The lack of seasonality observed in this study, due to prolonged drought, may have influenced the pattern of homogeneous behavior in both samplings. This pattern strongly influenced the vertical distribution of phytoplankton in the two periods, with a constancy of dominance of functional descriptors groups.

**Keywords:** shallow lake, vertical distribution, cyanobacteria, functional groups.

**Resumo: Objetivo**: O nosso trabalho teve como objetivo avaliar a dinâmica nictemeral e vertical dos grupos funcionais fitoplanctônicos em uma lagoa natural tropical (Lagoa de Extremoz, nordeste do Brasil), para investigar e compreender os fatores direcionadores da comunidade em um período de seca severa. **Métodos**: As amostragens das variáveis abióticas e do fitoplâncton foram realizadas a intervalos de 6 horas ao longo de um ciclo de 24 horas em perfis verticais nas estações de seca e chuva. As espécies fitoplanctônicas foram agrupadas de acordo com a abordagem de grupos funcionais *sensu* Reynolds et al. (2002). **Resultados**: O mês de outubro/12 foi caracterizado como período seco (18,4 mm), enquanto que março/13, pela média histórica era caracterizado período chuvoso, devido a baixa precipitação no período de estudo (15,7 mm), foi denominado seca severa. A lagoa apresentou desestratificação térmica e química em ambos períodos. A biomassa do fitoplâncton foi maior na estação seca e a distribuição vertical da mesma foi estratificada em ambas os períodos. Em ambas as amostragens houve menor biomassa algal nos períodos noturnos. Grupos funcionais fitoplanctônicos típicos de ambientes rasos e misturados ($\mathbf{S_1}$, $\mathbf{L_0}$ e **K**) foram descritores durante todo o período do estudo, com maior biomassa registrada sempre no grupo $\mathbf{S_1}$, representado pela *Planktolyngbya limnetica* (Cyanobacteria). **Conclusão**: A falta de sazonalidade observada no estudo, devido ao período de seca prolongada, pode ter influenciado no padrão de comportamento homogêneo em ambas as amostragens. Esse padrão influenciou fortemente a distribuição vertical da comunidade fitoplanctônica nos dois períodos, havendo uma constância de dominância de grupos funcionais descritores.

**Palavras-chave:** lago raso, distribuição vertical, cianobactérias, grupos funcionais.

## 1. Introduction

Diel and vertical distribution of phytoplankton communities may contribute to better understanding of the factors regulating key species (Becker et al., 2009). The knowledge of the phytoplankton community, through spatial and temporal fluctuations in their composition and biomass, can be an efficient indicator of natural and anthropogenic changes in aquatic ecosystems (Reynolds, 2006; Brasil and Huszar, 2011). Furthermore, analyzing the limnological variables, the concentrations of nutrients and phytoplankton, in time and space, can provide a diagnosis of the ecological conditions of the environment, helping to prevent and to identify processes that may alter water quality, enabling to increase the life cycle of these systems (Barbosa, 2002).

This information combined with the nature of phytoplankton organisms in response to environmental changes, dependent on the time scale, frequency and duration (Reynolds, 1990), gives the choice of scale of sampling to the interpretation of processes and mechanisms operating in the system (Rojo and Álvarez-Cobelas, 2001).

This fact coupled with the short period of time (hours or days) in which the algae are generated makes it possible to understand important processes, such as ecological succession, and can provide an effective model for understanding the communities and ecosystems in general (Moura et al., 2007). Studies on daily scale in phytoplankton promote the approach of the sensibilities in population growth, changes in size, fast processes of invasion and collapse of populations, and the pressure of herbivory (Rojo and Álvarez-Cobelas, 2001).

Diel studies enable a scale sample that can describe the factors that influence the phytoplankton community. Studies generally describe the variations of diel phytoplankton usually depend on the mixing pattern, the occurrence of self-regulating populations and the presence of fast-growing species (Melo and Huszar, 2000; Rangel et al., 2009; Becker et al., 2009).

Phytoplankton species have development morphological and physiological adaptive strategies for surviving in different environments (Reynolds, 1998), including adaptations to particular diel and vertical variations. These are related to morphological (size, shape) and physiological (nutritional status, buoyancy) changes which influence essential processes such as growth, sedimentation and nutrient acquisition (Reynolds, 2006). Compared to individual species responses, functional characteristics provide a better understanding of how communities respond to the environment (Souza et al., 2008) and vice versa. Therefore, the approach to classification of phytoplankton functional groups proposed by Reynolds et al. (2002) had been commonly utilized, with more than 130 citations reviewed in Padisák et al. (2009). These groups are often polyphyletic and share adaptive features, based on the physiological, morphological and ecological attributes of the species. At the present time, the phytoplankton functional groups approach uses 40 assemblages, identified by alpha-numeric codes according to their sensitivities and tolerances (updated by Padisák et al., 2009).

In Brazil, studies on phytoplankton in short sampling intervals (24 hours cycle) have been carried out with his approach (Araújo et al., 2000; Barbosa, 2002; Melo and Huszar, 2000; Nabout and Nogueira, 2007; Becker et al., 2009; Barbosa et al., 2011; Cunha and Calijuri, 2011; Cruz, 2011; Dantas et al., 2009; Dantas et al., 2011). Natural coastal lagoons in Rio Grande do Norte systems are important, especially when using as water supply for the city of Natal, as in Extremoz Lake (Raposo and Gurgel, 2003). The innovative nature of the work lies in the gap generated in this region of Brazil, especially in studies of natural lagoons that serve as sources of supply on the assessment of the phytoplankton community. Thus, the aim of this study was to analyze the diel and vertical dynamics of phytoplankton in Extremoz Lake, in order to understand which driver factors direct the community during a severe drought. When considering the standard mixing polymictic and available knowledge on the reservoir, it is expected to be found the following behavior of the phytoplankton community: i) uniform vertical distribution of phytoplankton in the water column during the rainy season, when it is expected circulation; ii) decreasing of algal biomass during the night, likely due to predation and absence of light; iii) predominance of phytoplankton groups typical of shallow and mesotrophic environments.

## 2. Material e Methods

### *2.1. Study area*

The Extremoz Lake (05° 42' 76" S; 35° 17 69" W) is an important source of the metropolitan region of Natal City, located in the northeast of Brazil (Figure 1). It is used to water supply of the 60-80% population of the Northern zone (Raposo and

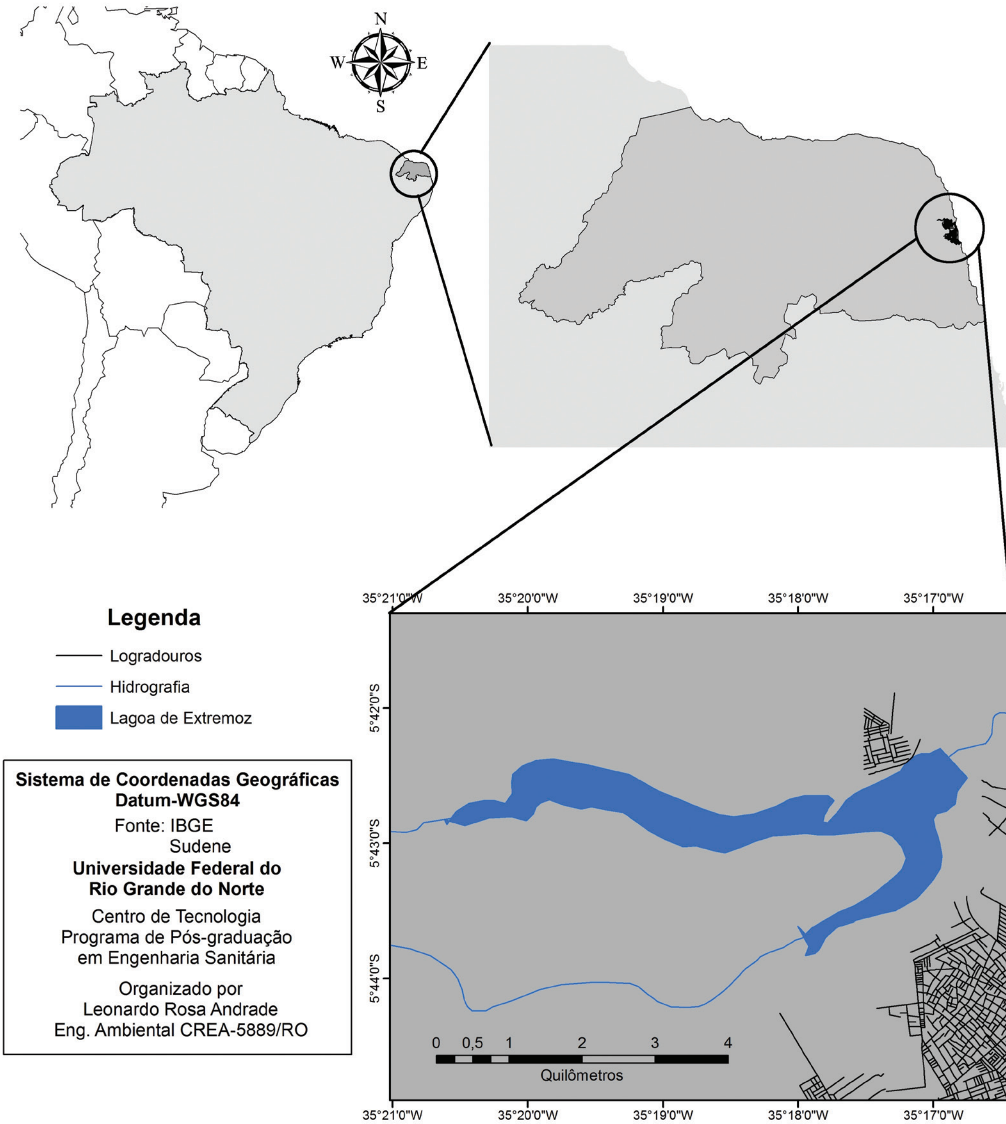


**Figure 1.** Map of Extremoz Lake, showing the tributaries and the sampling point.

Gurgel, 2003) belonging to the Rio Doce River Basin. Industries, agriculture and livestock activities are common near the lake, offering potential health risks to the population through water pollution (Raposo and Gurgel, 2003; Barbosa et al., 2010).

*2.2. Sampling*

Samples were collected at the at the deepest part of the lake (Zmax 5.8 m, located near the site of uptake of water supply in the convergence zone (center), as shown in Figure 1. The samplings were performed during the dry season ($26^{th}$- $27^{th}$ October/12) and rainy season ($15^{th}$-$16^{th}$ March/13) along a vertical profile (surface, middle, bottom) every 6 hours during a 24h period.

Vertical profiles of temperature, dissolved oxygen were measured with oximeter (Instrutherm MO – 900), at 0.5 m intervals from the surface to the bottom. Water transparency was measured with a Secchi disk. Samples for analyses of inorganic nutrients and phytoplankton were collected at the surface, with a Van Dorn bottle (2 L). Phytoplankton samples were fixed with neutral Lugol´s solution.

*2.3. Samples analysis*

Turbidity (NTU) was measured with a turbidimeter (AP2000 PoliControl) an pH by pHmeter (Homis). Total phosphorus was estimated by spectrophotometric (Valderrama, 1981). Dissolved inorganic nutrients – soluble reactive phosphorus (SRP), nitrate ($NO_3$) and ammonia ($NH_3$) - were analyzed in filtered samples (membranes glass fiber of 0.45 µm) and measured spectrophotometrically. SRP followed the method Murphy and Riley (1962), $NO_3$ was measured by Müller and Wiedemann (1955), and $NH_3$ by Solorzano (1969).

Phytoplankton populations were enumerated in random fields (Uhelinger, 1964) using settling technique (Utermöhl, 1958) by inverted microscope Olympus with at 400x magnification. The units (cells, colonies, and filaments) were enumerated to at least 100 specimens of the most frequent species were counted ($p<0.05$, Lund et al., 1958).

### *2.4. Data analysis*

Data of monthly rainfall and historical average were obtained from the National Institute of Meteorology (INMET). The rainy month in question showed equal or above precipitation compared to the historical average rainfall for the region, while the dry month showed equal or below precipitation compared to the historical average.

The euphotic zone ($z_{eu}$) was calculated as 2.7 times the Secchi depth (Cole, 1994). The phytoplankton was grouped by Functional groups approach *sensu* Reynolds et al. (2002) (updated by Padisák et al., 2009). Algal biovolume was calculated using formulae for geometric shapes (Hillebrand et al., 1999), and assuming the fresh weight unit as expressed in mass, where $1\ mm^3.L^{-1} = 1\ mg.L^{-1}$ (Wetzel and Likens, 2000). Species contributing >5% to the total biomass were grouped into functional groups, using the criteria of Reynolds et al. (2002).

In a first approach it were performed descriptive statistics, parametric correlation analysis (Pearson) using the Statistica® (Statsoft Inc. 1996) using all abiotic and biotic data to determine the relationships among them. ANOVA test (STATISTICA® ver. 5.0) was used to test differences between the sampling periods. A multivariate analysis of principal components (Principal Component Analysis - PCA) was performed to determine the spatial and temporal changes in physical and chemical conditions of the ecosystem. These ordinations were performed using the software PC-ORD® v.6 (McCune and Mefford, 2011).

## 3. Results

### *3.1. Meteorological scenario*

According to the historical average the month of October 2012 was characterized as dry period (**dry 2012**), with a precipitation of 18.4 mm, while the month of March 2013, which would be characterized as a rainy season according to the historical average (212.6 mm), showed a much lower rainfall (15.7 mm), being considered a period of severe drought (**severe drought 2013**) (Figure 2).

### *3.2. Limnological scenario*

Extremoz Lake showed a homogeneous temperature profile (mixed) throughout the study, with an average of 27 °C (Figures 3-4). The behavior of the temperature and DO were the same in both campaigns, higher values during the day with a slight decrease at night, especially at 3:00 a.m., keeping uniformity throughout the water column in the beginning of the day, 9:00 a.m. (Figures 3-4).

Extremoz was shallow in both periods. In the dry season the maximum depth was 5.6 m, decreasing to 3.8 m during the severe drought/ 2013. The lake proved to be an environment with fully illuminated water column in both samples, with the euphotic zone reaching the entire water column.

The behavior of dissolved nutrients and chlorophyll-*a* were similar in vertical distribution in both samplings campaigns, however, different temporal patterns were observed. In the period of severe drought it was recorded lower values of soluble reactive phosphorus and higher concentrations of NID. But in depths the concentrations were homogeneous.

The ANOVA carried out showed no significant variation between the dry season/12 and severe drought/13 for limnological variables.

The Principal Component Analysis (PCA) using nine limnological variables explained 74.4% of the variability of the data in the two axes (axis 1 = 65.2%, axis 2 = 9.2%). The most important

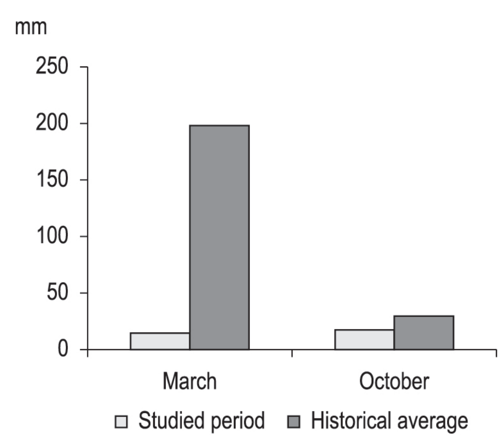


**Figure 2.** Monthly precipitation accumulating in October/2012 and March/2013 and the average monthly rainfall for the period between 2000 and 2012 for the region. (Source: EMPARN)

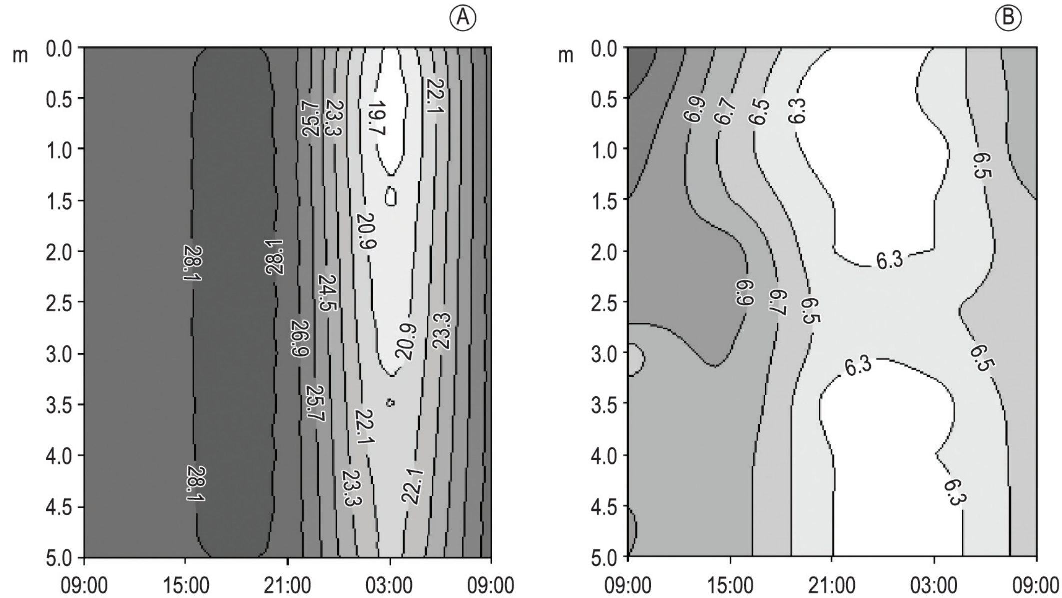


**Figure 3.** Depth-time diagrams of water temperature (A) and dissolved oxygen (B) during the 24 hours cycle in Extremoz Lake during a dry period (October/12).

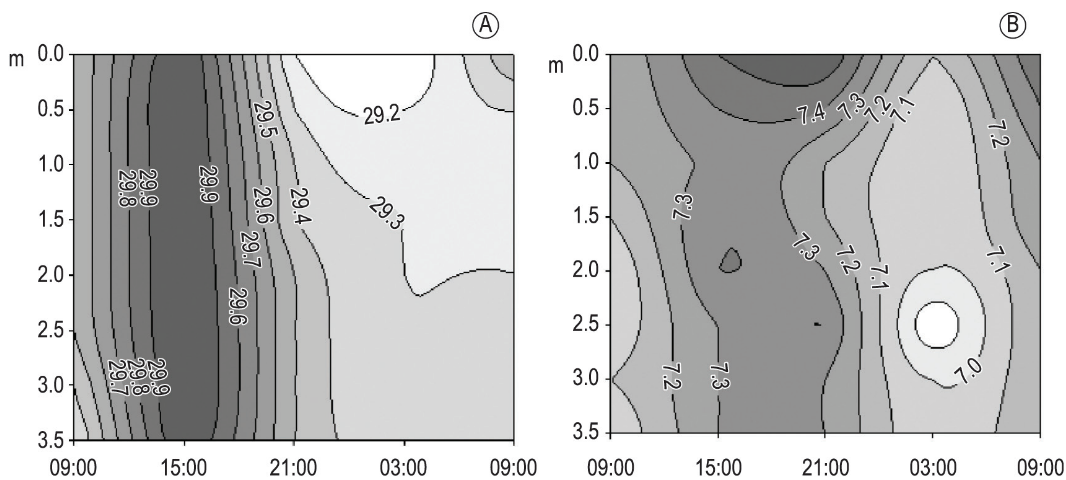


**Figure 4.** Depth-time diagrams of water temperature (A) and dissolved oxygen (B) during the 24 hours cycle in Extremoz Lake during a severe drought (March/13).

variables in the ordination axis 1 were: turbidity (0.97), temperature (0.69), DO (0.83), pH (0.55), SRP (0.95), TP (0.92), nitrate (0.67) and ammonia (0.85). Axis 2 explained only chlorophyll-a (0.74) (Figure 5).

The results of PCA show that the components reflect the temporal tendency, showing the effects of prolonged drought in the region in 2013, explained by axis 1 (Figure 5). On the positive side, the sampling units of the dry period in 2012 were correlated with the FSR and pH, while on the negative side, sampling units of the period of severe drought in 2013, presented a correlation with high turbidity, temperature and high DO concentrations, total phosphorus, ammonia and nitrate (Figure 5). The analysis found a homogeneous pattern between the shifts and depths samples, without segregations.

3.2.1.Phytoplankton dynamics

During the study, the phytoplankton assemblages included 16 species belonging to 4 taxonomic classes (Cyanobacteria, Cryptophyceae, Chlorophyceae and Bacillariophyceae).

Species that contributed at least 5% to the mean phytoplankton biomass in the dry season (October 2012) and severe drought (March 2013) were represented by three typical functional groups of shallow and/or mixed systems: **$S_1$**, **$L_0$** and **K**.

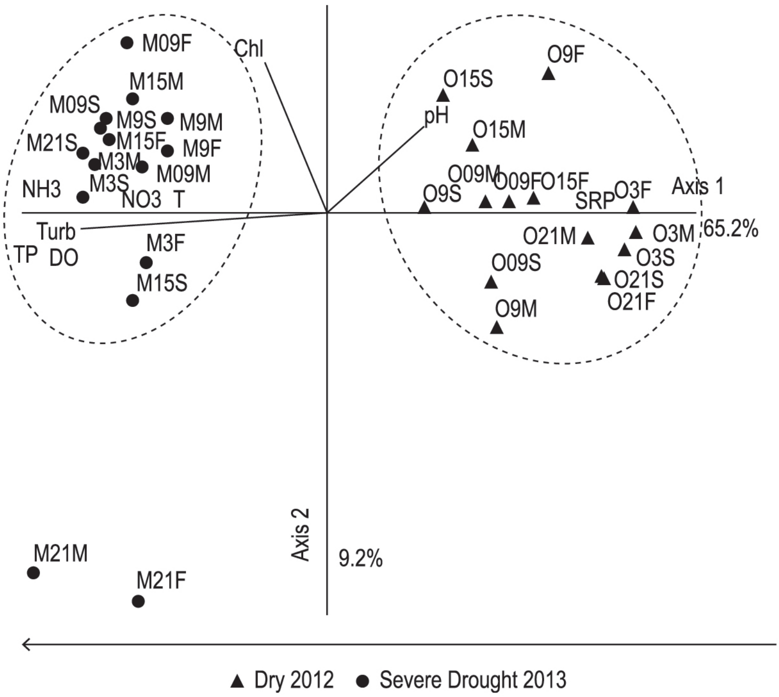


**Figure 5.** Scores derived from Principal Components Analysis (PCA) applied to environmental variables in Extremoz Lake; Sampling units: M=March; O=October; S=Surface; M=Middle; F=Bottom; T= water temperature; DO= dissolved oxygen; TP= total phosphorus; SRP = soluble reactive phosphorus; Turb= turbidity; Chl = chlorophyll *a*; $NH_3$ = ammonia e $NO_3$ = nitrate.

These groups were represented by filamentous cyanobacteria (*Planktolyngbya limnetica*) and colonial (*Aphanocapsa* sp., *Cyanodictium imperfectum* and *Synechocystis* sp.). $\mathbf{S_1}$ is the group composed only by *Planktolyngbya limnetica* (Lemmermann) Komárková-Legnerová & Cronberg, the group $\mathbf{L_0}$ by *Merismopedia glauca* (Ehrenberg) Kützing and the group **K** by *Cyanodictyon imperfectum* (Cronberg & Weibull), *Chroococus minor* (Kützing) Nägeli, *Aphanocapsa* spp. and *Synechocystis* sp.

Over a 24-hour cycle the phytoplankton biomass showed the following pattern of behavior in both sampling periods (Figure 6): i) greater biomass during the day; ii) biomass decreased in the late evening, especially in the middle layer; iii) homogeneity along the water column.

During the dry period, the functional group $\mathbf{S_1}$ was the group with the highest biomass and it was distributed throughout the water column, with higher concentrations in the upper layers of the daytime period, lower concentrations at night, especially at 03:00 p.m. in the surface and middle layers keeping small variation along the water column. The group $\mathbf{L_0}$ and **K** were distributed similarly. They kept uniformity in most parts of the water column, with the highest concentration of biomass in the upper layer in the afternoon and the lowest concentration in the middle layer at night, at 03:00 p.m. (Figure 7).

As the drought in 2012 and despite the decrease in the depth of the lake, the group $\mathbf{S_1}$ showed higher biomass and it was distributed throughout the water column, with higher biomass in the early morning in the surface layers and environment during the afternoon on the background layer, the lower concentration during the night and in the middle layer of the water column. $\mathbf{L_0}$ was distributed throughout the water column along the sample at lower concentration overnight to two meters deep and greater concentration at the same time but at the bottom of the water column. The group **K** showed an inverse behavior compared to the dry period sampling, biomass was lower, however, in lower concentrations in the deep layers of the day periods and a higher concentration in the middle layer during the night and daytime periods in the surface layer (Figure 8).

## 4. Discussion

Our results show that during the study in Extremoz Lake there was a period of rainfall characteristic of a hydrologic cycle of the tropical region, providing a prolonged drought in the study known as severe drought.

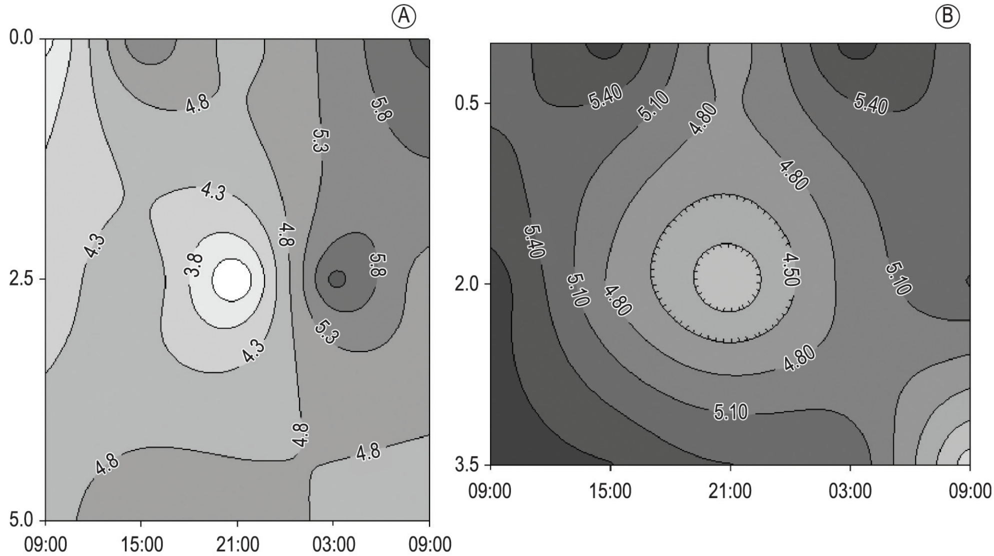


**Figure 6.** Depth-time diagrams of phytoplankton biomass (mg.L$^{-1}$) during a 24 hours cycle in Extremoz Lake: A) dry period (October/12): B) severe drought (March/13).

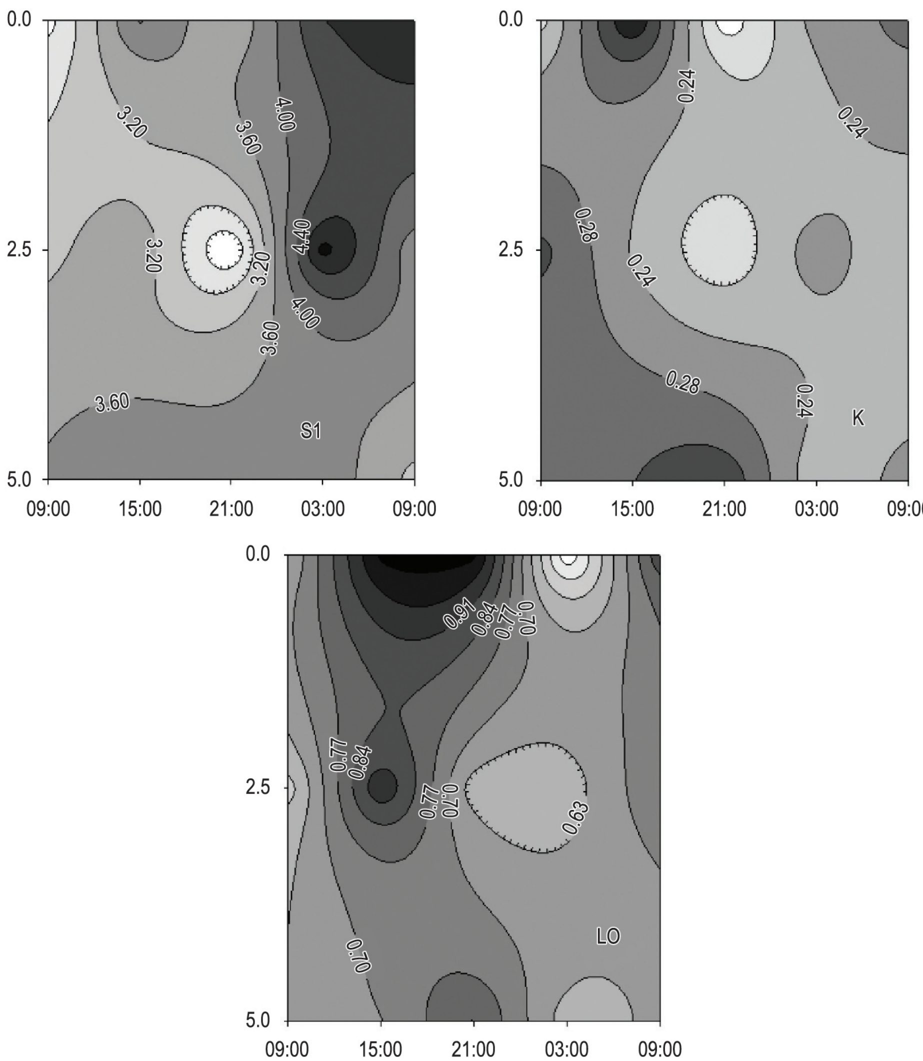


**Figure 7.** Depth-time diagrams of the biomass (mg.L$^{-1}$) of the $\mathbf{L_0}$, $\mathbf{S_1}$ and **K** functional groups during a 24 hour cycle in Extremoz Lake, during a dry period (October/12).

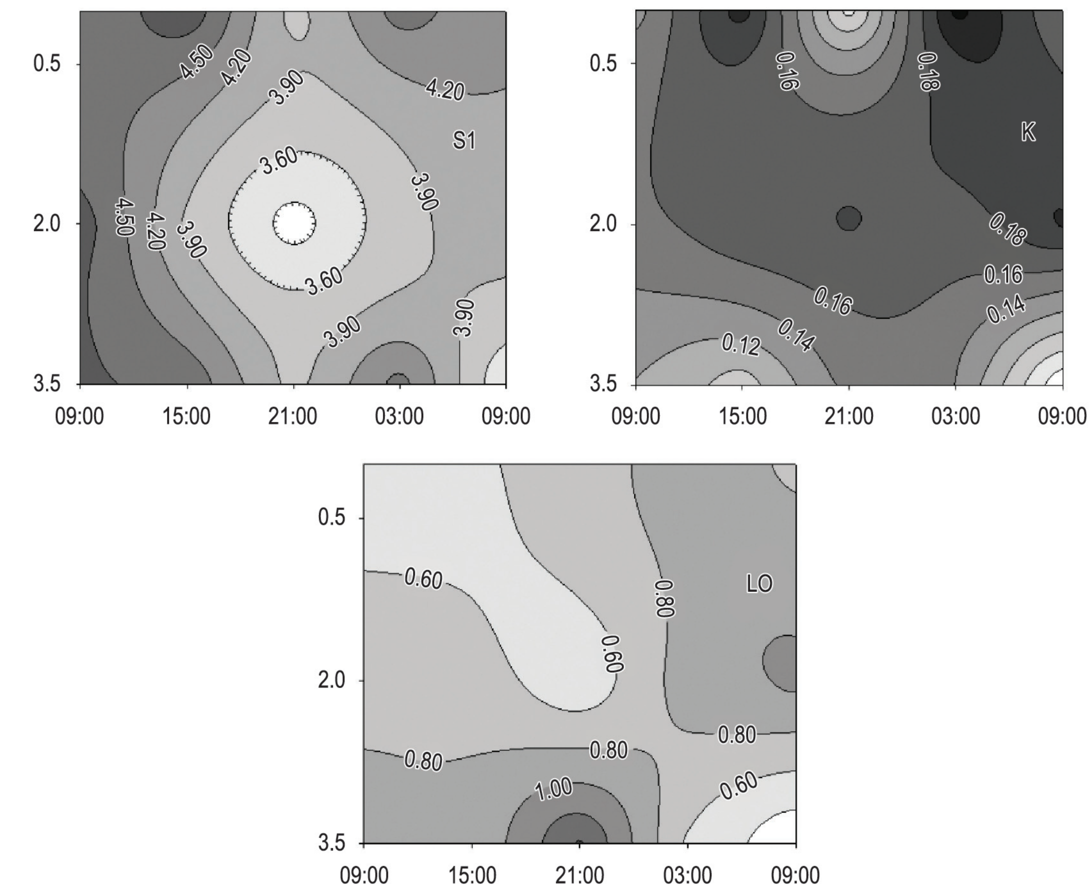


**Figure 8.** Depth-time diagrams of the biomass (mg.L$^{-1}$) of the $\mathbf{L_0}$, $\mathbf{S_1}$ and **K** functional groups during a 24 hour cycle in Extremoz Lake, during severe drought (March/13).

Climate change to drier conditions alters the hydrological properties of individual lakes and may have consequences on the thermal structure and light regime that directly affect aquatic organisms (Carpenter et al., 1992; Bouvy et al., 2003). However, in this study it was found that an unusual precipitation, becoming a homogeneous dynamics of phytoplankton functional groups $\mathbf{L_0}$, $\mathbf{S_1}$ and **K**, which are the most representative in both samplings campaigns.

The system showed to be thermally and chemically homogeneous in most of the study being classified as polymictic, especially in the period of severe drought, characteristic of shallow lakes (Scheffer, 2001). Although severe drought facilitates the concentration of nutrients by reducing the area and depth of the spring, the study revealed a homogeneous pattern condition of light, nutrients and low total biomass, with no variation in phytoplankton functional groups during sampling.

The approach of phytoplankton functional groups is the one that best portrays the relationship between environmental variability and phytoplankton community, because it takes into account tolerances and sensitivities (Reynolds, 2006). In the study of Extremoz Lake functional groups ($\mathbf{S_1}$, K and $\mathbf{L_0}$) showed similar patterns for the samplings, drought/2012 and severe drought/2013, characteristic of shallow mesotrophic environments with well-mixed layers (Padisák et al., 2009).

In this work all the species belonging to group descriptors were Cyanobacteria. The phytoplankton functional group $\mathbf{S_1}$ (filamentous cyanobacteria non-nitrogen-fixing) was dominant in biomass in both periods that belong to the most representative species, the species *Planktolyngbya limnetica*. It is a typical group of environmentwith very mixed layers, tolerant to poor conditions of high light and flow-sensitive. The characteristics of this group reinforce the results found for the studied environment. The second group that showed higher dominance was the functional group $\mathbf{L_0}$ in both samplings, composed by the species *Merismopedia glauca*. According to Reynolds et al. (2002) it represents surface environments, oligotrophic and medium lakes, similar situation to the characteristics of the Extremoz Lake, while the group **K**, the only descriptor group composed by more than one species, was the least abundant group of descriptors. According to Reynolds et al. (2002), it is a group with environmentof columns of shallow water rich in nutrients and, according to Padisák et al. (2009), polymitic environments, proving the good environment characterization by functional groups.

In a study in the northeast semiarid dams Araújo (2009) verified the presence of the same functional groups descriptors, $\mathbf{S}_1$, $\mathbf{L}_0$ and **K**, concluding that the presence of these codons in this type of environment have climatic characteristics of sub-desert hot environments, characterized by very extended drought seasons.

Stratification occurs when there is a clear difference between the layers of water, either in temperature or dissolved oxygen. Usually this difference between the layers is caused by the temperature of atmospheric air, which tends to cool the layer of water surface (Scheffer, 2001). During the study in Extremoz Lake there was no seasonality expected by the rainy season but a prolonged period of drought which heightened the effect of drought in the following period and did not cause changes in the phytoplankton community. For the lack of renewing water in the system, the Lake showed no significant change between the periods studied, as it would be expected in shallow lakes (Rangel et al. 2009; Melo, 2012) there were changes in the characteristics limnological and phytoplankton, which behaved similarly in both the dry period and the period of severe drought, due to the lack of the rainfall.

In summary, our results confirmed that the distribution of phytoplankton functional groups in a cycle of 24 h was not related to the physical-chemical factors. The homogeneity marked the period studied in Extremoz Lake due to the severe drought during the studied period

## 5. Conclusions

i) The lack of seasonality in Extremoz Lake provided homogeneous distribution of phytoplankton throughout the study period and throughout the water column; ii) Although not displaying the presence of toxic cyanobacteria, all species descriptors of the study were cyanobacteria, showing the need for further studies of monitoring; iii) Analysis tool via functional groups was proved to be effective, once it described the system with predominant typical groups of shallow and mesotrophic environments.

## References


ARAÚJO, GJM. 2009. Grupos Funcionais da comunidade fitoplanctônica de três ecossistemas aquáticos do trópico semiárido - Brasil. In *Anais do IX Congresso de Ecologia do Brasil*, 2009. São Lourenço: SEB.

ARAÚJO, MFF., COSTA, IAS. and CHELLAPPA, NT. 2000. Comunidade fitoplanctônica e na Lagoa de Extremoz, Natal-RN, Brasil. *Acta Limnologica Brasiliensia*, vol. 12, no. 1, p. 127-140.

BARBOSA, JS., CABRAL, TM., FERREIRA, DN., AGNEZ-LIMA, LF. and BATISTUZZO DE MEDEIROS, SR. 2010. Genotoxicity assessment in aquatic environment impacted by the presence of heavy metals. *Ecotoxicology and Environmental Safety*, vol. 73, no. 3, p. 320-325. PMid:19910047. http://dx.doi.org/10.1016/j.ecoenv.2009.10.008

BARBOSA, JEL. 2002. *Dinâmica do fitoplâncton e condicionantes limnológicos nas escalas de tempo (nictemeral/sazonal) e de espaço (horizontal/vertical) no açude Taperoá II*: trópico semi-árido nordestino. São Carlos: Universidade Federal de São Carlos. [Tese de Doutorado].

BARBOSA, LG., BARBOSA, PMM. and BARBOSA, FAR. 2011. Vertical distribution of phytoplankton functional groups in a tropical shallow lake: driving forces on a diel scale. *Acta Limnologica Brasiliensia*, vol. 23, no. 1, p. 63-73. http://dx.doi.org/10.4322/actalb.2011.020

BECKER, V., CARDOSO, LSC. and HUSZAR, VLM. 2009. Diel variation of phytoplankton functional groups in a subtropical reservoir in southern Brazil during an autumnal stratification period. *Aquatic Ecology*, vol. 43, no. 2, p. 285-293. http://dx.doi.org/10.1007/s10452-008-9164-0

BOUVY, M., NASCIMENTO, SM., MOLICA, RJR., FERREIRA, A., HUSZAR, V. and AZEVEDO, SMFO. 2003. Limnological features in Tapacurá reservoir (northeast Brazil) during a severe drought. *Hydrobiologia*, vol. 493, no. 1, p. 115-130. http://dx.doi.org/10.1023/A:1025405817350

BRASIL, J. and HUSZAR, VLM. 2011. O papel dos traços funcionais na ecologia do fitoplâncton continental. *Oecologia Australis*, vol. 15, no. 4, p. 799-834. http://dx.doi.org/10.4257/oeco.2011.1504.04

CARPENTER, SRS., FISHER, G., GRIMM NB. and KITCHELL, JF. 1992. Global change and freshwater ecosystems. *Annual Review Ecolology, Evolution, and Systematics*, vol. 23, p. 119-139. http://dx.doi.org/10.1146/annurev.es.23.110192.001003

COLE, GA., 1994. *Textbook of limnology*. Illinois: Waveland Press. 412 p.

CRUZ, OS. 2011. *Grupos Funcionais fitoplanctônicos sob diferentes níveis de nutrientes*: efeitos da psicultura em abordagem experimental. Campina Grande:

Universidade Estadual da Paraíba. [Dissertação de Mestrado].

CUNHA, DGF. and CALIJURI, MC. 2011. Variação sazonal dos grupos funcionais fi toplanctônicos em braços de um reservatório tropical de usos múltiplos no estado de São Paulo (Brasil). *Acta Botanica Brasilica*, vol. 25, no. 4, p. 822-831. http://dx.doi.org/10.1590/S0102-33062011000400009

DANTAS, EW., ALMEIDA, VLS., BARBOSA, JEL., BITTENCOURT-OLIVEIRA, MC. and MOURA, NA. 2009. Efeito das variáveis abióticas e do fitoplâncton sobre a comunidade zooplanctônica em um reservatório do Nordeste brasileiro. *Iheringia: Série Zoologia*, vol. 99, no. 2, p. 132-141. http://dx.doi.org/10.1590/S0073-47212009000200003

DANTAS, EW., MOURA, A.N. and BITTENCOURT-OLIVEIRA, MC. 2011. Cyanobacterial blooms in stratified and destratified eutrophic reservoirs in semi-arid region of Brazil. *Anais da Academia Brasileira de Ciências,* vol. 83, no. 4, p. 1327-1338. PMid:22146960. http://dx.doi.org/10.1590/S0001-37652011000400019

HILLEBRAND H., DURSELEN, CD., KIRSCHTEL, D., POLLINGHER, U. and ZOHARY, T. 1999. Biovolume calculation for pelagic and benthic microalgae. *Journal of Phycology*, vol. 35, no. 2, p. 403-424. http://dx.doi.org/10.1046/j.1529-8817.1999.3520403.x

LUND, JWG., KIPLING, C. and LECREN, ED. 1958. The inverted microscope method of estimating algal number and the statistical basis of estimating by counting. *Hydrobiologia*, vol. 11, no. 2, p. 143#170. http://dx.doi.org/10.1007/BF00007865

MCCUNE, B. and MEFFORD, MJ. 2011. *PC-ORD*: multivariate analysis of ecological data. Version 6. Gleneden Beach: MjM Software Design.

MELO, KRPS. 2012. *Estratégias adaptativas do fitoplâncton e aplicação do índice de grupos funcionais: ferramentas para a conservação de ecossistemas rasos do semiárido brasileiro*. Campina Grande: Universidade Estadual da Paraíba. [Dissertação de Mestrado].

MELO, S. and HUSZAR, VLM. 2000. Phytoplankton in an Amazonian floodplain lake (Batata Lake, Brazil): diel variation and species strategies. *Journal of Plankton Research,* vol. 22, no. 1, p. 63-76. http://dx.doi.org/10.1093/plankt/22.1.63

MOURA, NA., OLIVEIRA, MCB., DANTAS, EW. and ARRUDA NETO, JDT. 2007. Phytoplanktonic associations: a tool to understanding dominance events in a tropical Brazilian reservoir. *Acta Botânica Brasilica*, vol. 21, p. 641-648.

MÜLLER, R. and WIEDEMANN, F. 1955. Die Bestimmung des Nitrats in Wasser. Jahrb. Wasserchem. Wasserreinigungstechnik. *Verlag Chimie*, vol. 12, p. 247-271.

MURPHY, J. and RILEY, JP. 1962. A modified single solution method for the determination of phosphate in natural waters. *Analytica Chimica Acta*, vol. 27, p. 31-36. http://dx.doi.org/10.1016/S0003-2670(00)88444-5

NABOUT, JC. and NOGUEIRA, IS. 2007. Spatial and temporal dynamics of phytoplankton functional group in a blocked valley (Brazil). *Acta Limnologica Brasiliensia*, vol. 19, p. 305-314.

PADISÁK, J., CROSSETTI, LO. and NASELLI-FLORES, L. 2009. Use and misuse in the application of the phytoplankton functional classification: a critical review with updates. *Hydrobiologia*, vol. 621, no. 1, p. 1-19. http://dx.doi.org/10.1007/s10750-008-9645-0

RANGEL, LM., SILVA, LHS., ARCIFA, MS. and PERTICARRARI, A. 2009. Driving forces of the diel distribution of phytoplankton functional groups in a shallow tropical lake (Lake Monte Alegre, Southeast Brazil). *Brazilian Journal of Biology*, vol. 69, no. 1, p. 75-85. PMid:19347148. http://dx.doi.org/10.1590/S1519-69842009000100009

RAPOSO, RMG. and GURGEL, LCB. 2003. Variação da alimentação natural de *Serrasalmus spilopleura* Kner, 1860 (Pisces, Serrasalmidae) em função do ciclo lunar e das estações do ano na lagoa de Extremoz, Rio Grande do Norte, Brasil. *Acta Scientiarum*, vol. 25, p. 267-272.

REYNOLDS, CS. 1990. Temporal scales of variability in pelagic environments and the response of phytoplankton. *Freshwater Biology*, vol. 23, no. 1, p. 25-53. http://dx.doi.org/10.1111/j.1365-2427.1990.tb00252.x

REYNOLDS, CS. 1998. What factors influence the species composition of phytoplankton in lakes limitation in hypereutropic waters. *Hydrobiologia,* vol. 11, p. 369-370.

REYNOLDS, CS. 2006. *The ecology of Phytoplankton*. Cambridge: Cambridge University Press.

REYNOLDS, CS., HUSZAR, VLM., KRUK, C., NASSELI-FLORES, L. and MELO, S. 2002. Towards a functional classification of the freshwater phytoplankton. *Journal of Plankton Research*, vol. 24, no. 5, p. 417-428. http://dx.doi.org/10.1093/plankt/24.5.417

ROJO, C. and ÁLVAREZ-COBELAS, M. 2001. Phytoplankton structure and dynamics at a daily temporal scale: response to the thermal overturn. *Archiv für Hydrobiologie*, vol. 151, no. 4, p. 549-569.

SCHEFFER, M. 2001. Alternative attractors of shallow lakes. *The Scientific World*, vol. 1, p. 254-253. PMid:12806081. http://dx.doi.org/10.1100/tsw.2001.62

SOLORZANO, L. 1969. Determination of ammonia in natural waters by the phenolhypochlorite method.

*Limnology and Oceanography*, vol. 14, no. 5, p. 799-801. http://dx.doi.org/10.4319/lo.1969.14.5.0799

SOUZA, MBG., BARROS, CFA., BARBOSA, F., HAJNAL, E. and PADISÁK, J. 2008. Role of atelomixis in replacement of phytoplankton assemblages in Dom Helvécio Lake, South-East Brazil. *Hydrobiologia*, vol. 607, no. 1, p. 211-224. http://dx.doi.org/10.1007/s10750-008-9392-2

UHELINGER, V. 1964. Étude statistique des méthodes de dénobrement planctonique. *Archives Sciences*, vol. 17, p. 121-123.

UTERMÖHL, H. 1958. Zur vervollkommung der quantitativen phytoplankton: methodik. *Mitteilungen der Internationale Vereinigung für Theoretische und Angewandte Limnologie*, vol. 9, p. 1-38.

VALDERRAMA, JC. 1981. The simultaneous analysis of total and phosphorus in natural waters. *Marine Chemistry*, vol. 10, no. 2, p. 109-122. http://dx.doi.org/10.1016/0304-4203(81)90027-X

WETZEL, RG. and LIKENS, GE. 2000. *Limnological analyses*. 3rd ed. New York: Springer-Verlag.

Received: 20 August 2013
Accepted: 08 October 2014