



Spatial and temporal dynamics of functional groups of phytoplankton in a tropical shallow lake

Dinâmica espaço-temporal dos grupos funcionais do fitoplâncton em lago raso tropical

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Abstract: Aim: To evaluate the structure and dynamics of functional phytoplankton groups (FGs) over a macrophyte cover gradient and their relations with environmental variable in small, shallow clear-water lake. **Methods:** Physical, chemical and phytoplankton analyses were made between August 2014 and June 2015 at three points on the Santa Lucia lake (Paraiba, Brazil). Tukey and Wilcoxon tests were applied to the data followed by CCA and Anova. **Results:** The submerged macrophyte cover and phytoplankton biomass presented high spatial and temporal uniformity. The increase in rainfall induced small variations in functional groups, promoting increase the N group and reduction of the SN. **Conclusion:** The homogeneity in the composition and structure functional groups along macrophyte cover confirm the tendency that in small and shallow lakes communities of limnetic and shoreline zones tend to be similar.

Keywords: environmental variables; homogeneity; macrophytes; phytoplankton; shallow lakes.

Resumo: Objetivo: Avaliar a estrutura e dinâmica de grupos funcionais do fitoplâncton (GFs) ao longo de um gradiente de cobertura de macrófitas e suas relações com as variáveis ambientais em lago pequeno e raso de águas claras. **Métodos:** Análises de variáveis físicas, químicas e da comunidade fitoplancônica foram realizadas entre agosto 2014 a junho 2015, em três pontos distribuídos ao longo lago Santa Lúcia (Paraíba-Brasil). Testes de Tukey, Wilcoxon, seguido da CCA e Anova foram realizados. **Resultados:** A cobertura de macrofitas submersas e a biomassa fitoplancônica apresentaram distribuição espaço-temporal uniforme. O aumento da precipitação pluviométrica promoveu aumento da participação do grupo N e redução do grupo SN, provavelmente associados a alterações na estabilidade da coluna d'água. **Conclusão:** A uniformidade na composição e estrutura dos grupos funcionais ao longo da cobertura de macrófitas confirmam a tendência de que em lagos pequenos e rasos as comunidades de zonas limnéticas e litorâneas tendem a ser semelhantes.

Palavras-chave: variáveis ambientais; homogeneidade; macrófitas; fitoplâncton; lagos rasos.



1. Introduction

The capacity to store and maintain water internally, susceptibility to any anthropic or even natural factors and vulnerability to seasonal events are characteristics of shallow lakes subject to abrupt changes in the quality of the water. Shifting in shallow lakes may be due to different mechanisms, such as a drastic perturbation on the system, or a stepwise change in some external condition (Scheffer & Jeppesen, 2007).

The mechanisms stabilizing clear-water conditions are still misunderstood, however, the submersed macrophytes is supposed important mechanisms to the stabilization of sediments (Hilt, 2015) and have unfavourable effect on phytoplankton biomass through various mechanisms such as the provision of refuge from predation and high nutrient absorption (Scheffer et al., 1993).

Studies have reported that submerged macrophytes play a key role in the clear-water state of shallow lakes (Hilt, 2015; Sánchez et al., 2015), performing as regulatory agents, highly sensitive to any changes and enhancing stability on the cascade effect. The submerged vegetation increases water transparency and, consequently, the local water quality (Hilt et al., 2010), by reducing the re-suspension of sediment nutrients. Besides, it produces allelopathic compounds that inhibit phytoplankton growth (Hilt & Gross, 2008).

Considering the wide variety of phytoplankton species and their functional role, many studies have adopted a functional approach in order to understand changes in aquatic ecosystems based on morpho-physiological aspects and abiotic variables (Fonseca & Bicudo, 2011; Crossetti et al., 2013). Those approaches have indicated possible patterns of co-occurrence of species that act as environmental predictors in relation to changes in the equilibrium state (Reynolds et al., 2002; Padišák et al., 2009).

In this context, this study aimed to evaluate the structure and dynamics of functional groups of the phytoplankton along a gradient of macrophyte cover and their relations with the environmental variables in a small, shallow, clear-water lake. The mainly question of this study was: Are there any differences in the composition or structure of functional groups (FGs) along the macrophyte cover?

2. Material and Methods

2.1. Study area

The Basin of the Mamanguape River is in the extreme eastern of the Paraíba state (6° 36' 49"–7° 11' 08" S; 34° 54' 42"–35° 57' 51" W).

The climate is tropical, with temperatures ranging from 28 to 35 °C (Alvares et al., 2013).

The Santa Lucia lake (06° 50' 14.2" S, 35° 19' 51.4" W), has 444 m long by 128 m in width and extensive formations of submerged macrophytes (*Nitella cernua* A. Braun). The lake is designed for multiple uses, including irrigation, fishing and recreation.

2.2. Sampling

Samples were collected between August 2014 and July 2015 (monthly frequency) from three sampling sites located at the lake (Figure 1). Rainfall data were provided by the Executive Water Management Agency of the State of Paraíba (AESA).

2.3. Limnological parameters

Water temperature, dissolved oxygen, electric conductivity and pH were measured 'in situ' with a multiparameter probe. Water samples were collected from the sub-surface of the lake. Total phosphorus and orthophosphate were assessed using methodology described by APHA (2005).

Transparency of the water was estimated with a Secchi disk (Cole, 1994). Euphotic zone (Z_{eu}) was calculated as 2.7 times the Secchi depth (Cole, 1994).

The euphotic zone (Z_{eu}):mixing zone (Z_{mix}) ratio was used as an index for light availability in the mixing zone (Jensen et al., 1994). Due to isothermal profile and shallower depth, the mixture zone (Z_{mix}) was considered as the equivalent to maximum zone (Z_{max}). The coefficient of vertical attenuation of the light (k) was calculated by the expression $k = 1.7 \times Z_{DS}^{-1}$ (Poole & Atkins, 1929).

2.4. Submerged macrophyte cover

The cover of each macrophyte species was estimated visually as a percentage within a square meter area. Their abundance was estimated as a percentage of the volume of infestation (PVI) under the water (Canfield Junior et al., 1984).

2.5. Phytoplankton

Quantitative analysis of phytoplankton was performed according to the method described by Utermöhl (1958) by using samples fixed with aqueous acetic Lugol (1%). A minimum of 100 individuals of the most frequent species were counted (Lund et al., 1958), and density was calculated according to the method described by Ros (1979).

Biovolume (mm³ L⁻¹) was estimated using geometric formulas (Sun & Liu, 2003;

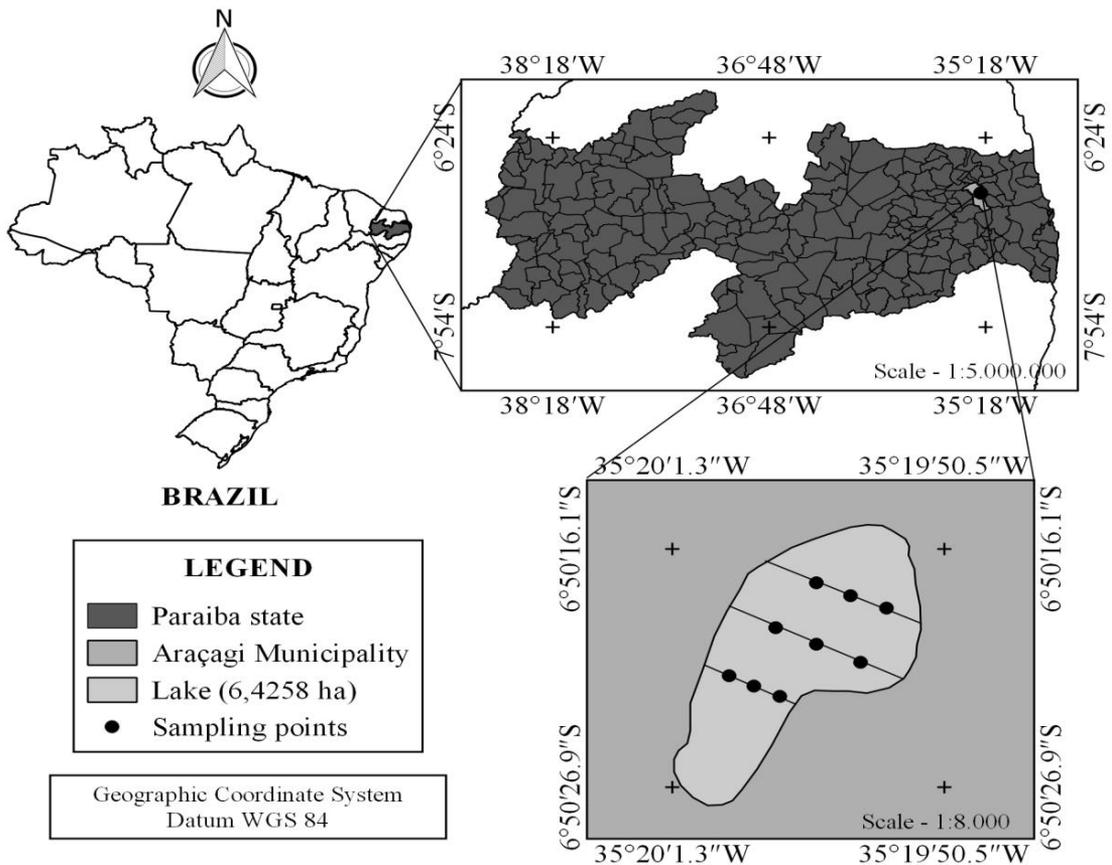


Figure 1. Location of the Santa Lucia Lake in the Paraíba state (Brazil) and the respective transects.

Hillebrand et al., 1999) with the mean values of the measurements of 20–30 individuals expressed in units of wet weight, where $1 \text{ mm}^3 \text{ L}^{-1} = 1 \text{ mg L}^{-1}$ (Wetzel & Likens, 2000).

2.6. Data analysis

The phytoplankton species were classified according to their relative frequencies of occurrence, which is defined as the number of sample units in which the species was observed as a percentage of the total number of sample units (Matteucci & Colma, 1982).

The Tukey test, using a probability of value of 5%, was applied to identify whether there were any spatial-temporal differences in the limnological variables and submerged macrophytes. Tests for significant differences of total phytoplankton biomass along the transects were performed using the Wilcoxon test. Canonical correspondence analysis (CCA) was used to assess the relationships between species of phytoplankton species and environmental variables. The CCA followed by Anova to verify the relations between the abiotic

variable and the functional groups. The analyses were performed through R 3.2.2.

3. Results

The air temperature ranged from 27.9 °C (September/2016) to 34.6 °C (January/2017) (Figure 2). The rainfall ranged from 26.5 mm (February) to 271.4 mm (March).

The analysis of the selected abiotic variables showed that the Santa Lúcia lake has no limitation about light with $Z_{\text{mix}} > 1$, the pH remained alkaline (> 7) and total phosphorus values were generally low ($< 43.5 \mu\text{g L}^{-1}$). Water temperatures showed an isothermal profile with a complete mixture of the water column ($Z_{\text{max}} = Z_{\text{mix}}$) and high concentrations of dissolved oxygen. In regard to temporal variation, statistically significant variations were only found for the water temperature, orthophosphate and conductivity, in the year 2015.

The values of macrophytes infestation potential (PVI) ranging from 78.7 to 81.3%, associated with submersed species *Nitella cernua* A. Braun, which was

dominant throughout the lake. Significant temporal and spatial differences were not observed for PVI ($p \geq 0.05$) (Table 1).

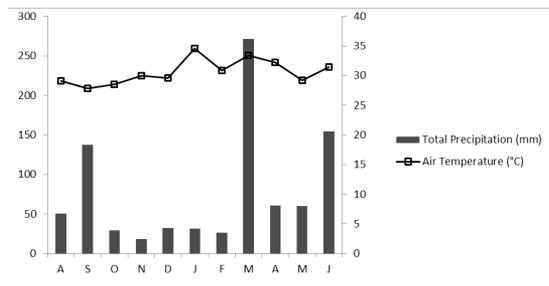


Figure 2. Total monthly rainfall (mm) and air temperature (°C) in the study area (Paraíba, Brazil). Legend: A (August), S (September), O (October), D (December), J (January), F (February), M (March), A (April), M (May), J (June), respectively.

3.1. Functional groups of the phytoplankton

The phytoplankton species were classified into eight functional groups: N, K, X1, W2, TD, SN, S1 and P. Significant differences ($P \geq 0.05$) were not observed for total biomass.

Figure 3 shows that the S1 exhibited high values of biomass, reaching 99.9% of the total biomass during September. The most frequent species were *Planktoniolyngbia* sp., *Phormidium* sp. and *Planktothrix agardhii*. The K group accounted for 97% of the biomass in October and the main species encountered was *Aphanocapsa annulata*, whereas other species (*Aphanocapsa delicatissima*, *Aphanocapsa* sp., *Synechococcus elongatus*) were considered rare. In January, February and April the N group contributed with 73.8%, 81.8% and 97.4%, respectively. The composition of the group was associated to desmids (*Cosmarium regnellii* e

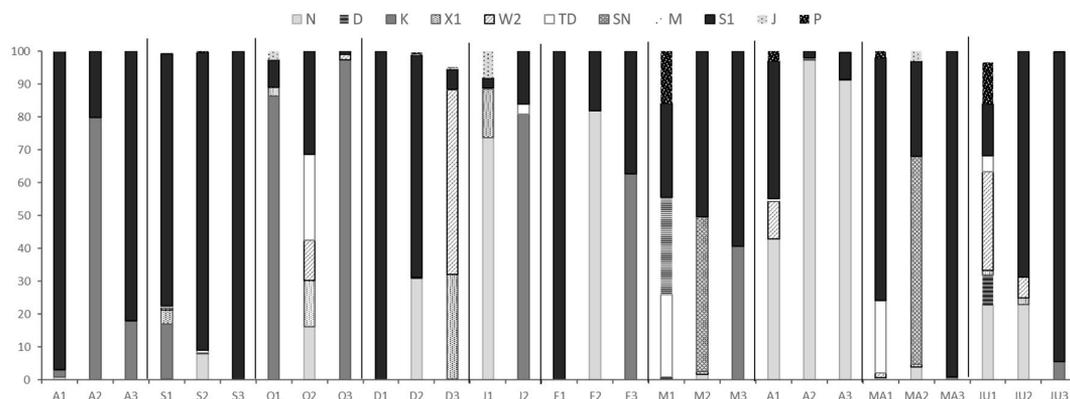


Figure 3. Contributions of those phytoplankton functional groups representing 10% or more of the total biomass in the Santa Lúcia lake from August 2014 to June 2015. Legend: A (August), S (September), O (October), D (December), J (January), F (February), M (March), A (April), MA (May), JU (June), respectively. Numbers 1,2,3: sampling points.

Table 1. Average values for the limnological variables and the macrophytes in the Santa Lúcia Lake (Paraiba, Brazil).

Variables	2014				2015					
	August	September	October	December	January	February	March	April	May	June
Trans	1.13 ^a	1.14 ^a	1.18 ^a	0.82 ^a	1.07 ^a	1.00 ^a	1.16 ^a	1.16 ^a	1.00 ^a	1.11 ^a
Zeü	3.0 ^a	3.0 ^a	3.2 ^a	2.2 ^a	2.9 ^a	2.7 ^a	3.1 ^a	3.1 ^a	2.7 ^a	3.0 ^a
K	1.4 ^a	1.4 ^a	1.4 ^a	0.9 ^a	1.5 ^a	1.7 ^a	1.4 ^a	1.4 ^a	1.7 ^a	1.5 ^a
Twater	29.2 ^a	27.8 ^a	28.9 ^a	19.6 ^a	28.6 ^b	32.9 ^a	30.4 ^{ab}	32.1 ^a	31.0 ^{ab}	28.7 ^b
pH	7.5 ^a	7.5 ^a	7.7 ^a	5.3 ^a	7.9 ^a	8.0 ^a	8.3 ^a	8.7 ^a	8.5 ^a	7.6 ^a
PT water	40.1 ^a	40.0 ^a	32.8 ^a	16.2 ^a	19.4 ^a	20.1 ^a	21.8 ^a	16.8 ^a	15.2 ^a	15.7 ^a
P-orto	21.5 ^a	22.0 ^a	21.2 ^a	10.8 ^a	11.9 ^{ab}	18.7 ^a	14.8 ^{ab}	11.5 ^{ab}	7.5 ^b	12.0 ^{ab}
Cond	-	-	-	-	166.0 ^a	163.6 ^a	122.0 ^b	131.0 ^b	147.3 ^b	105.6 ^c
OD	7.6 ^a	5.5 ^a	8.9 ^a	7.5 ^a	5.9 ^a	9.9 ^a	7.4 ^a	13.8 ^a	13.9 ^a	3.2 ^a
PVI	-	75.3 ^a	76.1 ^a	81.4 ^a	81.1 ^a	81.7 ^a	82.3 ^a	82.5 ^a	84.0 ^a	81.3 ^a

Averages followed by the same letter in the line do not differ from one another according to the Tukey test at 5% probability. Trans = water transparency; Zeü = Euphotic zone; pH, Twater = water temperature; PT water = Total phosphorus; PVI = macrophyte infestation percentage; P-orto = dissolved phosphorus; Cond = Conductivity; K = light attenuation coefficient; OD = Dissolved oxygen.

Staurastrum taylori) and diatoms (*Synedra* sp. and *Pennales* sp.), most abundant in the central region of the lake.

The other groups, **P**, **W2**, **SN**, **TD** and **X1**, were less representative than the two most dominant groups (Figure 3).

To explain the eight functional groups, seven variables were selected and the Canonic Correspondence Analysis (CCA) explained 76.6% of the variability of the data obtained for the first two axes in which water temperature, orthophosphate, total phosphorus and pH were the variables with greatest influence on the functional group dynamics. The most important groups

in the ordination of axis 1 were total phosphate and orthophosphate which influenced functional groups **X1**, **S1** and **K**, largely associated to the shoreline zones of the lake (Table 2). As regards axis 2 the most important variable in determining ordination were water temperature and pH and the related functional groups **N**, **SN** and **TD** were also associated to sample units taken from the zone near the shore (Figure 4).

4. Discussion

The presence of the macrophytes is highly relevant insofar as they promote an increase in spatial heterogeneity (Costa & Dantas, 2011;

Table 2. Summary of the Canonic Correspondence Analysis showing correlation coefficients among the phytoplankton functional groups and the environmental variables of the Santa Lucia Lake for the period August 2014 to June 2015.

Variables	CCA 1	CCA 2	r ²	P
pH	-0.98861	-0.15052	0.2111	0.053
Twater	-0.99803	0.06282	0.2860	0.017*
Pt water	0.97277	-0.23179	0.2044	0.071
P.orto	0.97699	0.21329	0.2368	0.042*
Zmix	-0.99656	-0.08290	0.0395	0.596
Zeus_Zmix	0.91991	0.39212	0.0778	0.359
Cond	-0.95199	0.30612	0.1669	0.114
Explained variation (%)	45.7	30.9	-	-

*Level of significance.

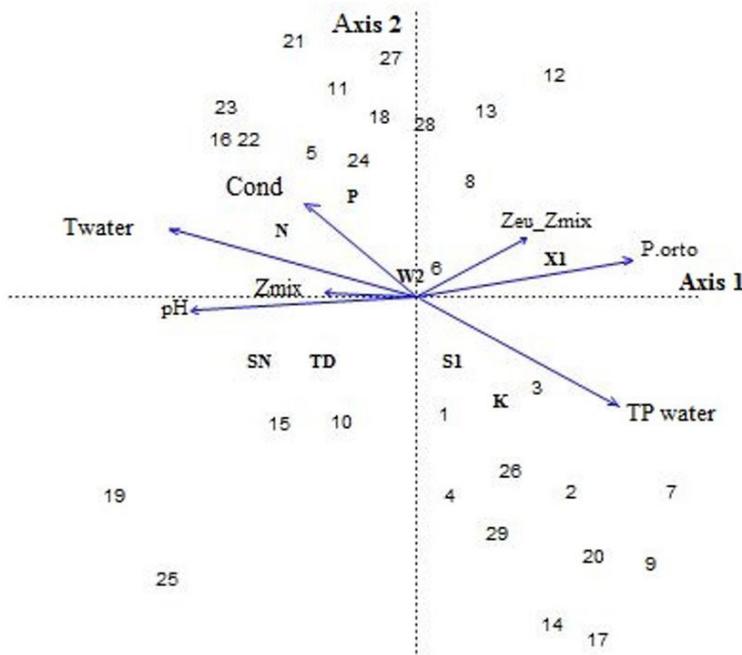


Figure 4. Canonic Correspondence Analysis (CCA) of the sample units taken from the Santa Lúcia lake generated by seven abiotic variables and the descriptive functional groups of the phytoplankton community. The numbers indicate the months and sampling points. Aug (1-3), Set (4-6), Out (7-9), Dec (10-12), Jan (13-14), Feb (15-17), Mar (18-20), Apr (21-23), May (24-26), Jun (27-29). The limnological variables: Twater = water temperature, Cond = Conductivity, pH, Zeus:Zmix, P.orto = orthophosphate, PTwater = total phosphorus, K = light attenuation coefficient.

Izaguirre et al., 2012; Pinto & O'Farrell, 2014). At the small shallow lakes, phytoplankton species from limnetic are usually similar to shoreline zones ones, commonly densely covered by macrophytes (Fonseca & Bicudo, 2011). In this study, however, limnetic and shoreline zones composition were indistinguishable, due to the high degree of macrophytes homogeneity.

The apparent spatial homogeneity of biotic and abiotic variables found in this study corroborated a previous study from lakes with similar characteristics. Ferrari (2010) attributed the low spatial heterogeneity to morphometric characteristics, like small area and shallow waters. It is known that differences among habitats affect the phytoplankton composition. However, when the micro-habitats are very similar, the phytoplankton communities also following this trend (Pereira, 2013).

The tropical Brazilian Northeast is known for its irregular rainfall patterns and long periods of drought that strongly influence the functioning of shallow lakes (Chellappa et al., 2009; Dantas et al., 2012). Environmental conditions in tropical lakes are influenced by rainfall events that modify the water volume and, consequently, the phytoplankton dynamics. Higher biomasses of algae result from the constant mixing of the water column by winds, stirring the sediment up and enabling re-alimentation, which could have enhanced the occurrence of cyanobacteria detected in this study (Borges et al., 2008; Cunha & Calijuri, 2011; Dantas et al., 2012).

The highest rainfall (occurred in March) may have led to a slight instability in water column. However, this did not affect the abiotic variables, including phosphorus concentrations. Besides, the rainfall amount was enough to promote the increase in N group biomass. The N group was constituted by desmids, diatoms commonly found in oligo-mesotrophic environments and tolerant to nutrient deficiency (Reynolds et al., 2002; Padišák et al., 2009).

The Canonical Correspondence Analysis showed that water temperature, orthophosphate, total phosphorus and pH had the greatest influence on functional groups dynamics. Other studies have attributed the predominance of those variables to the prolonged periods of drought (Cunha & Calijuri, 2011). The most important variables along axis 1 (total phosphorus and orthophosphate) directly influenced X1, S1 and K groups, showing that their occurrence is associated to warm, shallow

meso-trophic environments with well-mixed water columns (Reynolds et al., 2002).

The functional groups N, SN, and TD were associated to water temperatures and pH values (CCA), consistent with their occurrence in shallow warm waters moderately enriched and alkaline (Cunha & Calijuri, 2011; Reynolds et al., 2002; Padišák et al., 2009). The S1 group, predominant on the temporal scale, and the SN group are associated to high temperatures and able to coexist in environments with macrophytes, due to the shade provided (Araújo et al., 2009; Padišák et al., 2009).

The submerged macrophyte cover and the phytoplankton biomass remained temporally and spatially stable resulting in high spatial and temporal uniformity in the abiotic variables and functional groups. However, small seasonal fluctuations between functional groups was observed, as increase of the N group and reduction of the SN associated with the rainfall period. In conclusion, the absence of significant differences in the composition and structure of functional groups (FGs) along the macrophyte cover confirm the tendency that in small and shallow lakes communities of limnetic and coastal zones tend to be similar.

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