Seasonal variation of the phytoplankton community structure in the São João River, Iguaçu National Park, Brazil

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Abstract

The limnological characteristics and the phytoplankton community of the pelagic region of the São João River, tributary of the Iguaçu River, Iguaçu National Park were analyzed from August 2008 to July 2009. 221 taxa were identified and the Bacillariophyceae class was the most representative. Bacillariophyceae and Chrysophyceae were the dominant classes in density and Bacillariophyceae in biovolume. According to the DCA carried out for phytoplankton density and biovolume, significant differences were identified between the periods, and between the sites and study periods, respectively. The highest richness of species reached 40 taxa in September 2008 at station 1. The Shannon-Wiener diversity indexes and evenness, calculated from the density of phytoplankton, were temporally heterogeneous and spatially similar. In general, the significant temporal variations in the composition of the phytoplankton community were due to variations in limnological conditions, mainly temperature, transparency and nutrients. Spatially the structure was more similar due to the proximity among the stations. Moreover, the similarity of the distribution of communities in lotic environments were due to the unidirectional flow.

Keywords: phytoplankton, Iguaçu National Park, lotic system, seasonality, structure.

Variação sazonal da estrutura da comunidade fitoplanctônica no Rio São João, Parque Nacional do Iguaçu, Brasil

Resumo

As características limnológicas e a comunidade fitoplanctônica na região pelágica do Rio São João, tributário do Rio Iguaçu, Parque Nacional do Iguaçu, foram analisadas de agosto de 2008 a julho de 2009. Foram identificados 221 táxons, sendo Bacillariophyceae a classe mais representativa. Bacillariophyceae e Chrysophyceae foram as classes dominantes em densidade e Bacillariophyceae, em biovolume. De acordo com a DCA realizada para densidade e biovolume, foram identificadas diferenças significativas entre os períodos e entre os locais e períodos estudados, respectivamente. A maior riqueza de espécies foi alcançada em setembro de 2008 com 40 táxons na estação 1. O índice de diversidade de Shannon-Wiener e a equitabilidade, calculados a partir da densidade fitoplanctônica, foram temporalmente heterogêneos e espacialmente similares. Em geral, variações significativas na composição do fitoplâncton foram devidas às variações nas condições limnológicas, principalmente temperatura, transparência e nutrientes. Espacialmente, a estrutura foi mais similar, em razão da proximidade das estações e, também, da similaridade da distribuição da comunidade em ambientes lóticos, devido ao fluxo unidirecional.

Palavras-chave: fitoplâncton, Parque Nacional do Iguaçu, sistema lótico, sazonalidade, estrutura.

1. Introduction

The main objective of limnological research is to understand the behavior of freshwater ecosystems and it is one of the most important tools for conserving and preserving biodiversity and water resources. Lotic environments have been studied less than lentic environments (Reynolds and Descy, 1996; Huszar and Silva, 1999; Silva et al., 2001; Rodrigues et al., 2007; Soares et al., 2007).

Potamoplankton, defined as phytoplankton in rivers (Reynolds, 2006), consists of species originated from these environments and with the ability to grow and reproduce entirely in the main canal, forming dominant populations, especially along the intermediary sections (Vannote et al., 1980). The potamoplankton forms can include species of limnoplankton, which originate from lake catchments or from periphyton (Reynolds and Descy, 1996).

The higher turbulence and lower light intensity in rivers cause differentiations in the composition of the potamoplankton, promoting higher abundance of diatoms and green algae, which grow quickly and have a greater ability to thrive in turbulent environments (Reynolds, 1994). However, the lower density and biomass of these groups compared with those of lakes is one of the most relevant characteristics of phytoplankton.

Understanding potamoplankton biodiversity in connection with environmental factors is extremely important for monitoring water quality (Rodrigues et al., 2007). These systems which have been affected by an increasing human impact and other fluctuations can become efficient and clear indicators of these changes, whether natural or manmade (Huszar and Silva, 1999).

Studies that cover lotic portions in the area of the Paraná River basin focusing on ecological studies of the phytoplankton community are still rare, considering the area size and the large number of tributaries: Bonetto et al. (1979, 1982), Garcia de Emiliani (1988, 1990), Henry et al. (1998), O'Farrell et al. (1996), Train and Rodrigues (1998), Train et al. (2000), Borges et al. (2003), Ferrareze and Nogueira (2006), Rodrigues et al. (2009), Borges and Train (2009) and Perbiche-Neves et al. (2011).

Knowledge of the spatial and temporal distribution of phytoplankton in aquatic ecosystems is an important condition for adequate understanding of its structure and function. The aim of this study was to evaluate the variation of the phytoplankton structure, considering environmental factors in a subtropical river. Therefore, we considered that physical and chemical characteristics would temporally and spatially determine the modifications of composition, density and biomass of the phytoplankton community.

2. Material and Methods

Iguaçu National Park (INP) encompasses approximately 180.000 ha and it has about a 400 km perimeter, part of which boarders the Iguaçu River directly (Guimarães et al., 2003). The INP covers the largest fragment of Brazilian protected area within the Atlantic Forest and is considered one of the last remnants of this kind of vegetation in the southern region of the country (Ibama, 2008).

The São João River (25° 35.52' S and 54° 24.17' W) is a third order river. Its source is located in the Municipality of Santa Terezinha of Itaipu, Paraná, its water flows north-south and it has a total watershed area of about 79.10 km^2, 27.86 km^2 which lies in the Municipality of Santa Terezinha of Itaipu and 51.23 km^2 in Foz do Iguaçu, 28.09 km^2 located within the INP (Figure 1).

The São João River has an average flow of 0.88 m^3/s and it borders the INP on the West. Its mouth can be found in the Iguaçu River (Salamuni et al., 2002) which, in turn, is an important affluent of the Paraná River basin, the second largest hydrological system in South America

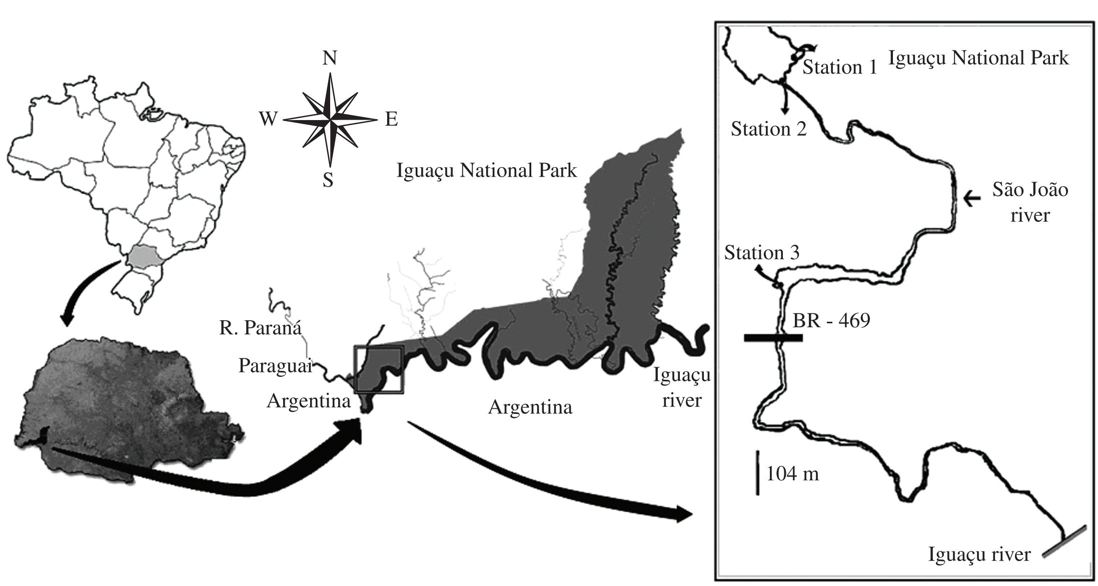

Figure 1. Location of the São João River, Iguaçu National Park, Paraná, Brazil.

and the fifth largest in the world (Devercelli, 2006). The sampling stations are located in regions with dense surrounding vegetation and a few aquatic macrophytes, among them are Poaceae, Cyperaceae and Pontederiaceae.

The phytoplankton was collected monthly (August 2008 to July 2009) from three sampling stations in longitudinal sections, in the pelagic region of the São João River, INP, Paraná, Brazil. Samples were obtained directly with bottles 20 cm below the surface of the water and fixed with a 1% acetic Lugol solution. The samples themselves were collected using a plankton net with a 25 µm mesh, which was towed horizontally in the subsurface of the column of water in order to concentrate the biological material to add to the floristic inventory. The phytoplankton net samples were stored in 500 mL bottles of polyethylene and preserved in a Transeau solution (Bicudo and Menezes, 2006).

The Round (1965, 1971) classification system, proposed by Bicudo and Menezes (2006), was adopted for the class level. The species richness took into consideration the total number of taxa per quantitative sample. The density was estimated according to the method described by Utermöhl (1958). The density calculation was made in accordance with APHA (1995), taking into account individual cells, colonies, cenobia or filaments, depending on the form in which the algae occur in nature. The diversity index (Shannon and Weanner, 1963) and evenness (Pielou, 1984) was applied to the density data. The phytoplankton biomass was estimated by the biovolume, multiplying the density of each taxon by its respective volume (Sun and Liu, 2003). The phytoplankton net samples were analysed in a binocular microscope coupled with a drawing tube and ocular micrometer, always magnified by 400 and 1000×. All the samples were deposited at the UNOP herbarium, Unioeste/Cascavel, Paraná, Brazil.

The physical and chemical analyses of the water from the São João River were done at the Iguaçu National Park laboratory of environmental analysis, Paraná, Brazil in the AquaIguaçu program. Measurements of water temperature (°C), dissolved oxygen ($mg.L^{-1}$), pH and electrical conductivity ($\mu S.cm^{-1}$) were obtained with portable digital potentiometers. Water transparency (m) was obtained by a Secchi disk. The ammonium concentration (NH_4^+), nitrite (NO_2^-), nitrate (NO_3^-) and total phosphorus – PT were determined according to APHA (1995). Meteorological data regarding precipitation and air temperature were supplied by the Meteorological Institute of Paraná (SIMEPAR/CURITIBA). A period in which no precipitation was recorded in the ten days preceding the collection was considered a dry period. In contrast, when rainfall was recorded it was considered a rainy period.

The abiotic variable (except for precipitation and air temperature) was summarized using the PCA (Principal Components Analysis). Species data (density and biovolume) were summarized by means of DCA (Detrended Correspondence Analysis). Possible spatial and temporal differences were tested by two-way ANOVA, using the first two axes of DCA created by density and biovolume. In the case of significant differences, Tukey posteriori tests were performed. The relationship between environmental variables and the density and biovolume data of the phytoplankton classes were tested using the Spearman correlation (McCune and Grace, 2002). The numerical analyses were conducted using the Pc-Ord program (McCune and Mefford, 1999) and Statistica versão 7.1 (Statisoft, 2005).

3. Results

The air temperature during the study period ranged from 27.5 °C in March 2009 to 13.1 °C in July 2009. The highest rainfall occurred in January and May 2009, 254 and 243 mm, respectively, and the minimum in November 2008 (0 mm). The water temperature ranged from 30.8 °C in March 2009, station 3, to 19 °C in August 2008, station 3. The warmest water temperatures coincided with the period of lowest rainfall and highest atmospheric temperature. The concentration of dissolved oxygen (DO) ranged from 8.8 $mg.L^{-1}$ in August 2008 and July 2009, both at station 3, to 5.4 $mg.L^{-1}$ in March 2009, at station 3. The higher temperatures caused depletion of oxygen and the lower temperature conditions caused an increase in the availability of dissolved oxygen.

The water transparency ranged from 1.28 m in January 2009, station 3, to 0.82 m in April 2009, station 1, with the highest values recorded during the period of greatest precipitation. The pH was moderately basic with a maximum value of 8.8 in July 2009, station 3 and slightly acidic with a minimum value of 6.6 in September and November 2008, stations 1 and 2, respectively. The lowest values occurred during the period of low rainfall. The electrical conductivity showed a range of 38.5 $\mu S.cm^{-1}$ in March 2009, station 2, to 57.5 $\mu S.cm^{-1}$ in July 2009, station 3.

With regards to nutrients, extremely low concentrations were found. The concentrations of ammonium (NH_4^+) showed a high variability (CV 213.5%) with the highest values recorded in January 2009, station 3. The concentration of nitrite (NO_2^-) showed less variability among the nutrients (CV 53.7%) with the highest values recorded in November 2008, stations 1 and 2. The nitrate (NO_3^-) also showed low variability (CV 55.1%) with the highest values recorded in November 2008, station 1. The total phosphorus (TP) had the second highest variability among the nutrients (CV 112.2%), with the highest values recorded in January 2009, station 3 (Table 1).

The first two axes generated by Principal Components Analysis explained 58.8% of the total variability of the abiotic data in the São João River. Axis 1 was influenced positively by electrical conductivity (0.47) and dissolved oxygen (0.44) and negatively by water temperature (–0.45) and total phosphorus (–0.40). The distribution from the sampling stations tend to be in the top left table during the months with the highest water temperature and total phosphorus values, and in the bottom right table during the months with larger dissolved oxygen values. In axis 2, the variables that better correlated variables were nitrate (–0.51), nitrite (–0.46) and ammonium (–0.39), which mainly affected the distribution tendency of the rainy months (Figure 2).

A total of 221 taxa were identified (Table 2), distributed among 9 taxonomic classes: Bacillariophyceae (30.3%), Chlorophyceae (20.8%), Zygnemaphyceae (17.6 %), Euglenophyceae (16.7%), Cyanophyceae (7.2%), Dinophyceae (2.7%), Chrysophyceae (2.2%), Cryptophyceae (1.3%) e Xantophyceae (0.9%). The *Desmodesmus* (Chlorophyceae), *Euglena* (Euglenophyceae), *Closterium* (Zygnemaphyceae) and *Trachelomonas* (Euglenophyceae) genera were the most representative in relation to the number of taxa, with 13, 11, 9 and 9 respectively. Temporally, the richness of the species ranged from 13 taxa (December 2008, station 3) to 40 taxa (September 2008, station 1). Spatially, the average richness values were very similar: 26 taxa (station 1) 24 taxa (station 2) and 22 taxa (station 3).

The highest values of phytoplankton density were observed in March 2009, station 1 (465 ind.mL^{-1}), August 2008, station 2 (377 ind.mL^{-1}) and September 2008, station 2 (279 ind.mL^{-1}). The lowest values were recorded in October 2008, station 3 (19 ind.mL^{-1}) and November 2008, station 3 (24 ind.mL^{-1}). The Bacillariophyceae, Chlorophyceae and Euglenophyceae classes contributed most to the density values, and *Aulacoseira granulata* (Bacillariophyceae), *Monoraphidium arcuatum* (Chlorophyceae) and *Trachelomonas hispida* (Euglenophyceae) were the

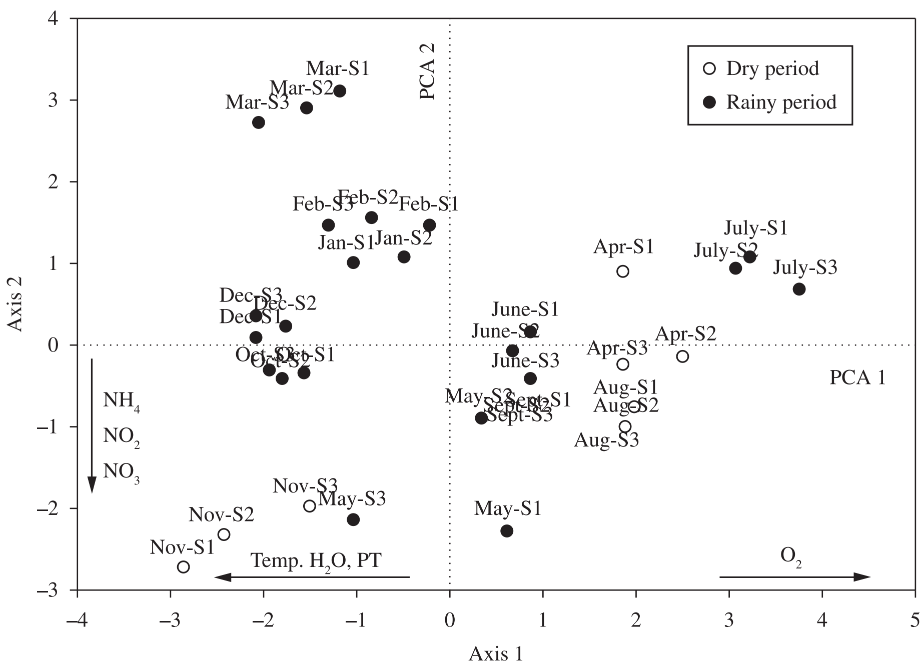

Figure 2. Dispersion of the month-station scores along the first two axes of the PCA, conducted for the São João River (S1-station 1; S2-station 2; S3-station 3; Ago-August; Sep-September; Oct-October; Nov-November; Dec-December; Jan-January; Fev-February; Mar-March; Apr-April; May-May; Jun-June; Jul-July; Temp.H2O-Water Temperature; PT-Phosphorus; NH4$^+$ Ammonium; NO_2^-Nitrite; NO_3^-Nitrate; O_2-Dissolved Oxygen).

Table 1. Descriptive statistics of the environmental variables of the São João River between August 2008 and July 2009.

Variable	Mean and standard deviation	Minimum	Maximum	CV (%)
Water temperature (°C)	23.9 ± 3.5	19	30.8	14.7
Air temperature (°C)	22.2 ± 4.3	13.1	27.5	19.4
Dissolved oxygen (mg.L^{-1})	7.3 ± 1.1	5.4	8.8	15.3
pH	7.1 ± 0.4	6.6	8.8	5.9
Conductivity (µS.cm^{-1})	44.1 ± 5.2	38.5	57.5	11.9
Transparency (m)	1.01 ± 10.7	0.82	1.28	10.5
Precipitation (mm)	67.9 ± 82.8	0	254	122
NH_4^+(µg.L^{-1})	0.11 ± 0.25	0.02	1.55	213.5
NO_2^- (µg.L^{-1})	0.07 ± 0.03	0.01	0.16	53.7
NO_3^-(µg.L^{-1})	0.82 ± 0.45	0.02	1.95	55.1
PT(µg.L^{-1})	0.46 ± 0.52	0.04	3.17	112.2

Table 2. Phytoplankton taxa identified in the São João River during the period of August 2008 to July 2009.

BACILLARIOPHYCEAE	
Achnanthes clevei Grunow	*Frustulia neomundana* Lange-Bertalot & Rumrich
Achnanthes exigua var. *constricta* (Torka) Hustedt	*Frustulia pumilio* Lange-Bertalot & Rumrich
Achnanthes microcephala (Kützing) Grunow	*Frustulia saxonica* Rabenhorst
Amphipleura lindheimeri Grunow	*Gomphonema augur* Ehrenberg
Amphora copulata (Kützing) Schoeman & Archibald	*Gomphonema brasiliense* Grunow
Amphora veneta Kützing	*Gomphonema parvalum* (Kützing) Kützing
Aulacoseira granulata (Ehrenberg) Simonsen	*Gomphonema rhombicum* Fricke
Aulacoseira granulata var. *angustíssima* (Müller) Simonsen	*Gomphonema* sp.
Aulacoseira italica (Ehrenberg) Simonsen	*Gyrosigma kuetzingii* (Grunow) Cleve
Caloneis westii (W. Smith) Hendey	*Gyrosigma obtusatum* (Sullivan & Wormley) Boyer
Cocconeis placentula Ehrenberg	*Hantzschia abruptirostrata* Lange-Bertalot & Metzeltin nov. spec.
Cocconeis placentula var. *acuta* Meister	*Hydrosera wamphoensis* (Schwartz) Deby
Cocconeis placentula var. *lineata* (Ehrenberg) Van Heurck	*Luticola peguana* (Grunow) D.G. Mann
Craticula cuspidata (Grunow) D.G. Mann	*Nitzschia dissipata* (Kützing) Grunow
Cymatopleura solea (Brébisson) W. Smith	*Pinnularia acrosphaeria* var. *acrosphaeria* W. Smith
Cymbella affinis var. *affinis* Kützing	*Pinnularia acrosphaeria* var. *undulata* (Brébisson) Cleve
Cymbella cymbiformis Agardh	*Pinnularia dispar* Metzeltin & Krammer
Cymbella tumida (Brébisson) Van Heurck	*Pinnularia divergens* var. *malayensis* Hustedt
Encyonema minutum (Hilse ex Rabenhorst) D.G. Mann	*Pinnularia tabellaria* Ehrenberg
Encyonema neomesianum Krammer	*Pinnularia viridiformis* Krammer
Encyonema silesiacum (Bleisch) D.G. Mann	*Pinnularia viridis* (Nitzsch) Ehrenberg
Eunotia camelus Ehrenberg	*Pinnularia* sp.
Eunotia didyma var. *didyma* Grunow	*Placoneis constans* (Hustedt) E.J. Cox
Eunotia minor (Kützing) Ehrenberg	*Placoneis* sp.
Eunotia neomundana Metzeltin & Lange-Bertalot	*Sellaphora laevissima* Kützing
Eunotia paludosa Grunow	*Stauroneis gracilior* Reichardt
Eunotia transfuga var. *transfuga* Metzeltin & Lange-Bertalot	*Surirella angusta* Kützing
Eunotia valida Hustedt	*Surirella apiculata* Smith
Fragilaria aff. *acus* var. *acus* Kützing	*Surirella guatimalensis* Ehrenberg
Fragilaria capuccina Desmazières	*Surirella splendida* (Ehrenberg) Kützing

Table 2. Continued...

BACILLARIOPHYCEAE	
Fragilaria cf. *tenera* (W. Smith) Lange-Bertalot	*Surirella tenera* Gregory
Fragilaria lanceolata (Kützing) Reichardt	*Synedra goulardii* (Brébisson) Lange-Bertalot
Frustulia crassinervia (Brébisson ex W. Smith) Costa	*Terpsinoë musica* Ehrenberg
	Ulnaria ulna (Nitzsch) Compère
CHLOROPHYCEAE	
Ankistrodesmus bibraianus (Reinsch) Koršikov	*Desmodesmus serratus* (Corda) An, Friedl & E. Hegewald
Ankistrodesmus densus Koršikov	*Desmodesmus* sp.
Ankistrodesmus fusiformis Corda *sensu* Koršikov	*Diacanthos belenophorus* Koršikov
Ankistrodesmus gracilis (Reinsch) Koršikov	*Dictyosphaerium elegans* Bachmann
Ankistrodesmus spiralis (Turner) Lemmermann	*Dimorphococcus lunatus* Braun
Ankistrodesmus stipitatus (Chodat) Komárková-Legnerová	*Golenkinia radiata* Chodat
Chlorella vulgaris Beijerinck	*Golenkiniopsis solitaria* (Koršikov) Koršikov
Coelastrum cambricum Archer	*Hydrodictyon reticulatum* Lagerheim
Coelastrum microporum Nägeli	*Kirchneriella lunaris* Kirchn.
Coelastrum pulchrum Schmidle	*Kirchneriella obesa* (West) Schmidle
Crucigeniela sp.	*Micractinium* sp.
Desmodesmus abundans (Kirchner) E. E. Hegewald	*Monoraphidium arcuatum* (Koršikov) Hindák
Desmodesmus armatus (Chodat) E. Hegewald	*Monoraphidium contortum* (Thuret) Komárkóva-Legnerová
Desmodesmus armatus var. *bicaudatus* (Guglielmetti) E. Hegewald	*Monoraphidium flexuosum* Komárek
Desmodesmus armatus var. *longispina* (Chodat) E. Hegewald	*Monoraphidium griffithii* (Berkeley) Komárkóva-Legnerová
Desmodesmus brasiliensis (Bohlin) E. Hegewald	*Oocystis lacustris* Chodat
Desmodesmus communis (E. Hegewald) E. Hegewald	*Pachycladella minor* (D. & H. Chudyba) Silva
Desmodesmus denticulatus var. *denticulatus* (Lagerheim) An, Friedl & E. Hegewald	*Pediastrum duplex* var. *duplex* Meyen
Desmodesmus denticulatus var. *linearis* (Hansgirg) E. Hegewald	*Pediastrum tetras* (Ehrenberg) Ralfs
Desmodesmus opoliensis (P. Richter) E. Hegewald	*Scenedesmus obliquus* (Turpin) Kützing var. *dimorphus* (Turpin) Hansgirg
Desmodesmus protuberans (Fritsch & Rich) E. Hegewald	*Scenedesmus ecornis* (Ehrenberg *ex* Ralfs) Chodat *Scenedesmus obtusus* Meyen
Desmodesmus pseudodenticulatus (E. Hegewald) E. Hegewald	*Scenedesmus securiformis* Playfair
	Treubaria triappendiculata Bernard
ZYGNEMAPHYCEAE	
Closterium closterioides (Ralfs) Louis & Peeters	*Gonatozygon kinahanii* (Archer) Rabenhorst
Closterium ehrenbergii var. *imane* (Meneghini) Wolle	*Gonatozygon monotaenium* De Bary

Table 2. Continued...

ZYGNEMAPHYCEAE	
Closterium gracile Brébisson	Krieger *In* Rabenhorst
Closterium incurvum Brébisson	*Gonatozygon pilosum* Wolle
Closterium leibleinii Kützing	*Haplotaenium minutum* (Ralfs) T. Bando
Closterium lunula (Muller) Nitzsch	*Hyalotheca dissiliensis* (Smith) Brébisson
Closterium ralfsii var. *hybridum* (Brébisson *ex* Ralfs) Rabenhorst	*Micrasterias denticulata* Brébisson ex Ralf
Closterium rostratum Ehrenberg	*Micrasterias laticeps* var. *acuminata* (Nordstedt) *Micrasterias radiosa* Agardh
Closterium setaceum Ehrenberg ex Ralfs	*Micrasterias rotata* (Greville) Ralfs *ex* Ralfs
Cosmarium candianum Delponte	*Pleurotaenium ehrenbergii* (Brébisson) De Bary
Cosmarium formosulum Hoff	*Spyrogyra* sp.
Cosmarium lundelli var. *lundelli* Delponte	*Staurastrum dilatatum* (Ehrenberg) Ralfs
Cosmarium pseudoconnatum Nordstedt	*Staurastrum leptocladum* Nordstedt
Cosmarium pseudopyramidatum Lundell	*Staurastrum minesotense* Wolle
Cosmarium trilobulatum Reinsch	*Staurastrum trifidum* var. *glabrum* (Nordstedt) Langerheim
Cosmarium vexatum West	*Staurodesmus convergens* var. *laportei*(Ehrenberg) Teiling
Desmidium cylindricum Greville	*Staurodesmus cuspidatus* (Brébisson) Ralfs
Euastrum abruptum Nordstedt	*Tetmemorus brebissonii* (Meneghini) Ralfs
Euastrum denticulatum Gay	*Xanthidium antilopaeum* (Brébisson *in* Meneghini) Kützing
	Xanthidium horridum Skuja
EUGLENOPHYCEAE	
Euglena acus (Muller) Ehrenberg	*Phacus tortus* Lemmermann Skvortzow
Euglena acus var. *longissima* Deflandre	*Phacus* sp. 1
Euglena communis Gojdics	*Phacus* sp. 2
Euglena oxyuris Schmarda	*Strombomonas fluviatilis* (Lemmermann) Deflandre
Euglena polymorpha Dangeard	*Strombomonas simplex* S.M. Alves-da-Silva & C.E. de M. Bicudo
Euglena sanguinea Ehrenberg	*Strombomonas verrucosa* (Daday) Deflandre
Euglena spyrogyra Ehrenberg	*Strombomonas* sp. 1
Euglena sp. 1	*Strombomonas* sp. 2
Euglena sp. 2	*Strombomonas* sp. 3
Euglena sp. 3	*Trachelomonas armata* (Ehrenberg) Stein
Euglena sp. 4	*Trachelomonas hispida* var. *coronata* Lemmermann
Hyalophacus ocellatus E.G. Pringsheim	*Trachelomonas hispida* var. *crenulatocolis* (Maskell) Lemmermann

Table 2. Continued...

EUGLENOPHYCEAE	
Lepocinclis caudata (da Cunha) Pascher	*Trachelomonas hispida* var. *hispida* (Perty) Stein
Petalomonas sp.	*Trachelomonas lacustris* Skvortzow
Phacus hamatus Pochmann	*Trachelomonas volvocina* Ehrenberg
Phacus longicauda (Ehrenberg) Dujardin	*Trachelomonas* sp. 1
Phacus longicauda var. *attenuata* (Pochmann) Huber-Pestalozzi	*Trachelomonas* sp. 2
Phacus onyx Pochmann	*Trachelomonas* sp. 3
Phacus suecicus Lemmermann	
CYANOPHYCEAE	
Anabaena sp.	*Phormidium irriguum* (Kützing) Anagnostidis & Komárek
Chroococcus minor (Kützing) Nägeli	*Planktolyngbya limnetica* (Lemmermann) Komárková-Legnerová & Cronberg
Limnothrix planctonica (Woloszynska) Meffert	*Pseudoanabaena* sp.
Lyngbya sp.	*Snowella lacustris* (Chodat) Komárek & Hindák
Merismopedia glauca (Ehrenberg) Kützing	*Spirulina* sp.
Merismopedia tenuissima Lemmermann	*Synechococcus* sp.1
Merismopedia sp.	*Synechococcus* sp.2
Oscillatoria sp.	*Synechocystis aquatilis* Sauvag.
DINOPHYCEAE	
Gymnodinium sp.	*Peridinium* sp. 1
Peridinium pusillum (Pénard) Lemmermann	*Peridinium* sp. 2
Peridinium umbonatum Stein	*Peridinium* sp.3
CHRYSOPHYCEAE	
Dinobryon bavaricum Imhof	*Mallomonas* sp.2
Dinobryon sertularia Ehrenberg	*Monas* sp.
Mallomonas sp.1	
CRYPTOPHYCEAE	
Cryptomonas sp.1	
Cryptomonas sp. 2	
Cyanomonas americana (Davis) Oltmanns	
XANTOPHYCEAE	
Centritractus belenophorus Lemmermann	
Tetraplektron tribulus (Pascher) Fott	

most abundant taxa. Chrysophyceae had no significant contribution for density, except in March 2009 with *Dinobryon bavaricum*. Euglenophyceae contributed significantly to the phytoplankton density in April and May 2009. The Shannon-Wiener diversity indexes and evenness showed temporal heterogeneity, but spatial similarity (Figure 3a-c). The density of Bacillariophyceae had a negative correlation with the water temperature (R = –0.61), ammonium (R = –0.53), nitrite (R = –0.39) and total phosphorus (R = –0.48). Chlorophyceae had a negative correlation with nitrate (R = –0.40). Euglenophyceae had a negative correlation with transparency (R = –0.45), ammonium (R = –0.33), nitrite (R = –0.54) and total phosphorus (R = –0.41). Chrysophyceae had a negative correlation with transparency (R = –0.48), nitrite (R = –0.51) and total phosphorus (R = –0.44).

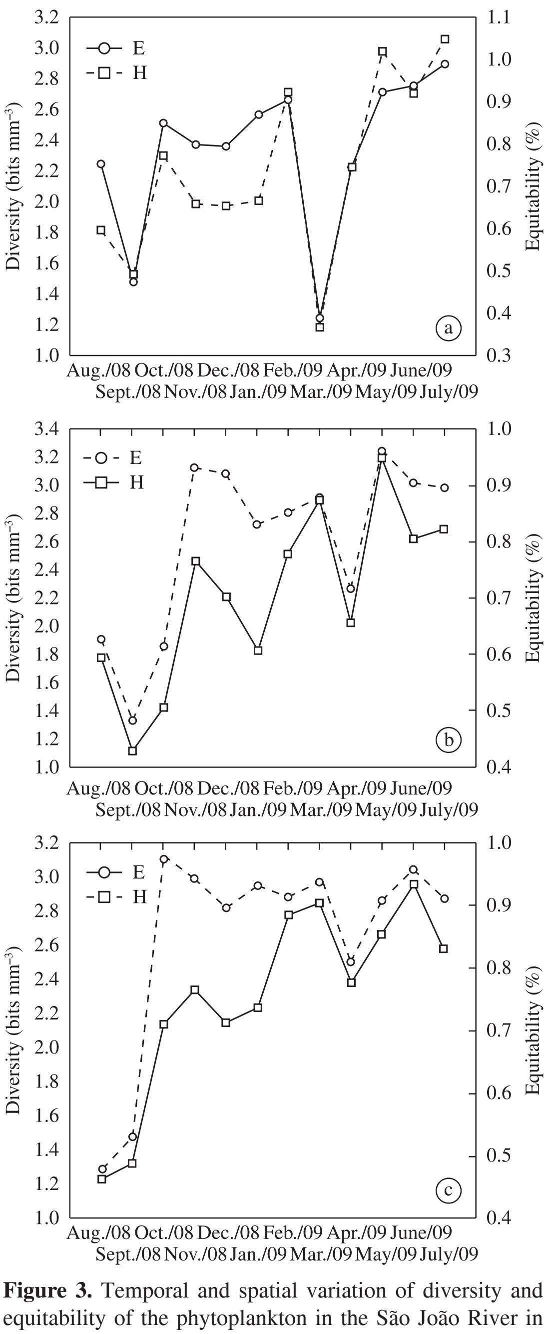

Figure 3. Temporal and spatial variation of diversity and equitability of the phytoplankton in the São João River in the period from August/2008 to July/2009 in station 1 (a), station 2 (b) and station 3 (c).

The phytoplankton biovolume values were low (< 1 $mm^3.L^{-1}$). The highest values were observed in March 2009, station 2 (0.925 $mm^3.L^{-1}$) dominated by *Euglena acus* var. *longissima*, September 2008, stations 1 and 2 (0.749 and 0.744 $mm^3.L^{-1}$ respectively), dominated by *Aulacoseira granulata* and *Surirella guatimalensis*. The lowest values were observed in October and November 2008 (0.001 $mm^3.L^{-1}$), both at station 3, coinciding with the lowest phytoplankton density values. The biovolume of Bacillariophyceae had a negative correlation with water temperature (R = –0.59), ammonium (R = –0.35), nitrite (R = –0.37) and total phosphorus (R = –0.36) and a positive correlation with dissolved oxygen (R = 0.42). Euglenophyceae had a negative correlation with transparency (R = –0.33), nitrite (R = –0.48) and total phosphorus (R = –0.41). Chrysophyceae had a negative correlation with transparency (R = –0.48), nitrite (R = –0.51) and total phosphorus (R = –0.44) (Figure 4a-c).

The temporal and spatial phytoplankton density scores obtained by the DCA were interpreted using the first two axes with the highest eigenvalues (axis 1 = 0.73 and axis 2 = 0.52). The DCA diagram (Figure 5a-b) showed a temporal variation. The months corresponding to the rainy periods were separated on the left of the diagram (Figure 5a), influenced by lower values of phytoplankton density. Low spatial variation was recorded, except for August 2008, shown by the presence of *Cymbella tumida* at station 2, *Surirella guatimalensis* at station 1 and *Aulacoseira granulata* at station 3 (Figure 5b). Axis 1 of the DCA showed statistic significant values ($F = 3.3$; $p < 0.05$), and the Tukey test showed a difference in the scores only between the periods.

The spatial and temporal phytoplankton biovolume scores obtained by the DCA were interpreted using the two axes with the greatest eigenvalues (axis 1 = 0.76 and axis 2 = 0.43). The DCA diagram (Figure 6a-b) showed a temporal variation between the periods, and a slight spatial gradient (Figure 6a). Station 2 in August 2008 and station 1 in October were separated from the other stations due to the presence of *Surirella guatimalensis*. The months of November and December showed marked spatial heterogeneity. The month of September 2008 showed the highest spatial homogeneity in relation to the phytoplankton biovolume, with the presence of *Surirella guatimalensis* at both stations 1, 2 and 3. The DCA axis 1 showed statistic significant spatial ($F = 4.3$; $p < 0.05$) and temporal ($F = 7.7$; $p < 0.05$) differences.

4. Discussion

It could be observed that there was a high diversity of species in the São João River, probably due to the local

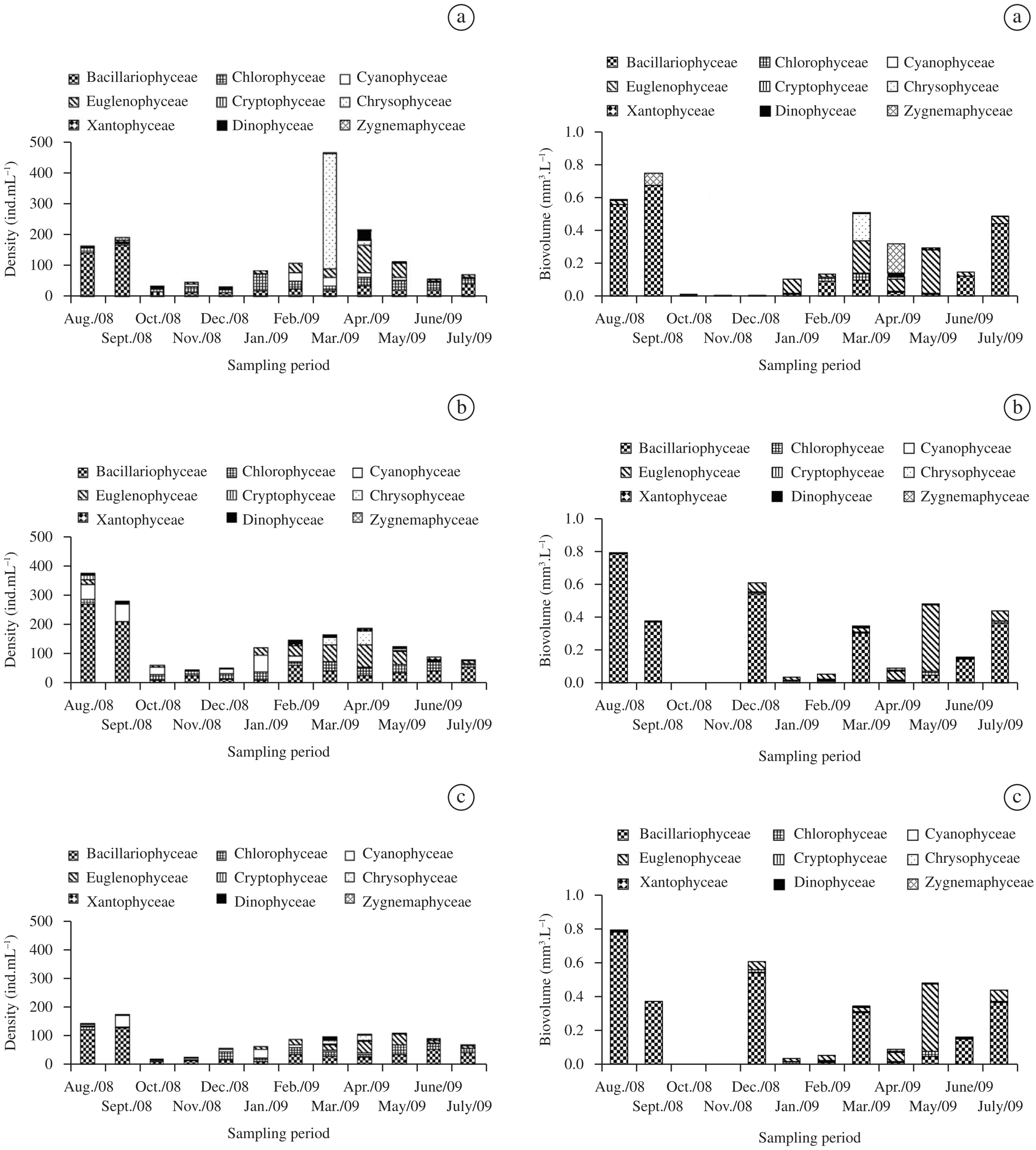

Figure 4. Seasonal variation of the density and biovolume of the phytoplankton in the São João River in the months of August 2008 to July 2009, in the stations 1(a), 2(b) and 3(c).

conditions favorable to the phytoplankton biodiversity, since it is located in one of the most important environmental protection areas in the country (INP). A large number of phytoplankton taxa were also recorded in the rivers of the Jacuí Delta, Rio Grande do Sul, studied by Rodrigues et al. (2007), with 229 in the Gravataí River, 231 in the Sinos River, 199 in the Caí River and 199 in the Jacuí River. Rodrigues et al. (2009) recorded 177 taxa in their study of the Paraná River, 288 taxa in the Baía River and 227 taxa in the Ivinhema River. Perbiche-Neves et al. (2011) recorded 149 taxa in the Iguaçu River and tributaries.

The phytoplankton composition of the São João River was typical of lotic environments, and Bacillariophyceae and Chlorophyceae were predominant. These algae groups grow quickly and have greater ability to succeed in turbulent environments (Reynolds, 1994). The Bacillariophyceae class showed the greatest abundance of species in lower temperatures (19-21 °C) and Chlorophyceae in higher temperatures (26-29 °C).

The Zygnemaphyceae and Euglenophyceae classes were also important for the composition of phytoplankton. The Zygnemaphyceae class, with 39 original taxa, probably originated from inocula periphyton that derivate from their source through the water flow are scattered along the river bed. The Euglenophyceae class, which had 37 recorded taxa, developed periods with a higher input of organic material into the aquatic environment due to lixiviation of surrounding vegetation during the rainy periods.

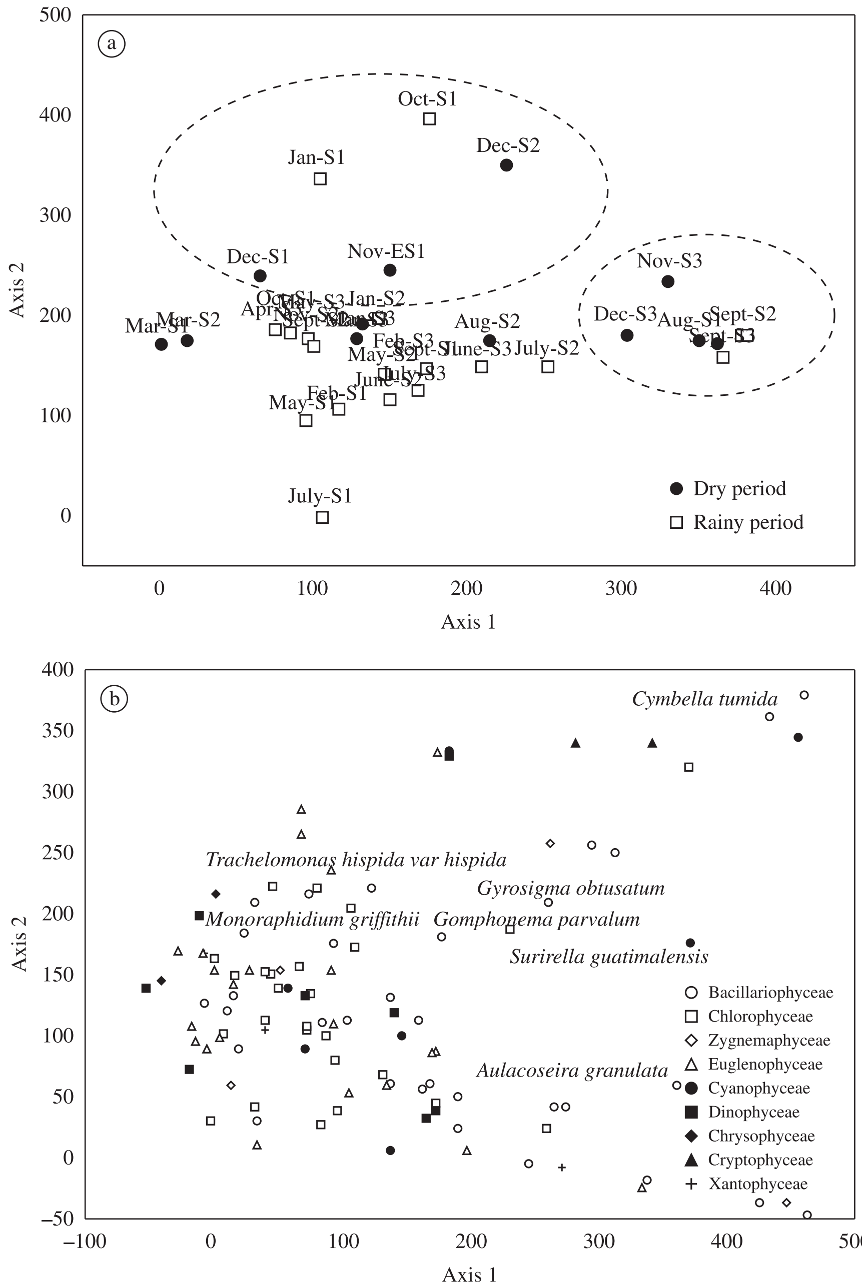

Figure 5. a) Dispersion of the month-station scores and b) the density of the phytoplankton taxa along the first two axes of the DCA (S1-station 1; S2-station 2; S3-station 3; Ago-August; Sept-September; Oct-October; Nov-November; Dec-December; Jan-January; Fev-February; Mar-March; Apr-April; May-May; Jun-June; Jul-July).

The low phytoplankton density and biovolume values recorded in the São João River are principally due to the lotic characteristics of the environment, making the maintenance of the community difficult. According to Reynolds and Descy (1996) ideal light and nutrient conditions and low current flow are necessary for the healthy development of algae. Train and Rodrigues (1998) found that Cyanobacteria contributed largely to the phytoplankton biomass in the Baía River which has a low current flow. The low abundance of Cyanobacteria reported in this study was probably due to these characteristics, as Ferrareze and Nogueira (2006) recorded in the Paranapanema basin. The Cryptophyceae, Dinophyceae and Xantophyceae classes also had a minor contribution to the abundance of phytoplankton.

The highest density of diatoms, mainly of *Aulacoseira granulata*, meroplankton algae and R-strategist, common in river plankton, reflect the suitable conditions for the development of the group, especially at lower temperatures

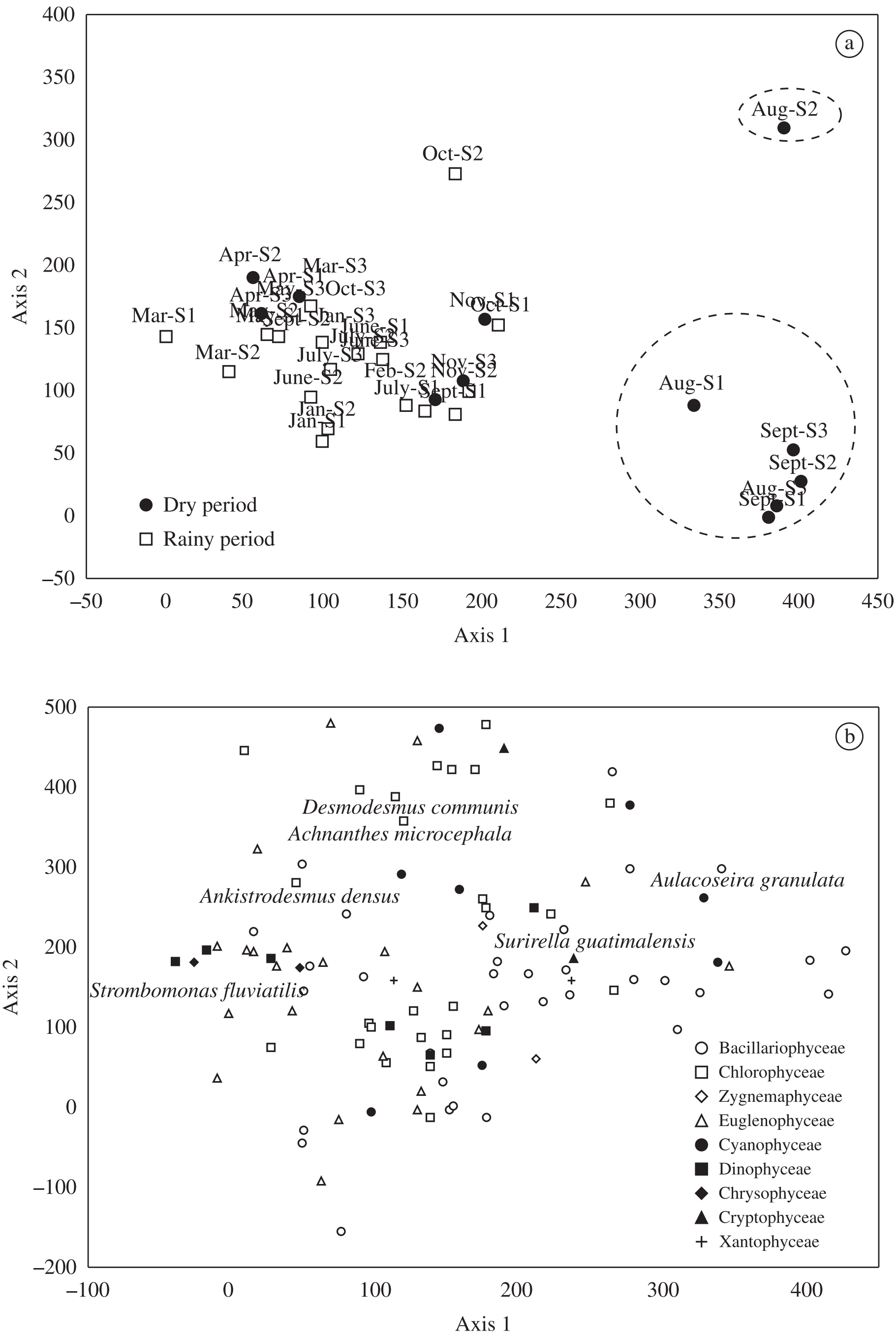

Figure 6. a) Dispersion of the month-station scores and b) of the biovolume of the phytoplankton taxa along the first two axes of the DCA (S1-station 1; S2-station 2; S3-station 3; Ago-August; Sept-September; Oct-October; Nov-November; Dec-December; Jan-January; Fev-February; Mar-March; Apr-April; May-May; Jun-June; Jul-July).

and lower concentrations of nutrients, as shown by the negative correlation with these factors. According to Reynolds (1994) the dominance of filamentous diatoms is also associated with their capacity to form inoculants, which are deposited in the sediment and are re-suspended into the water column through the turbulence.

The presence of *Dinobryon bavaricum* in March 2009 is associated with the lower transparency of the water column and low concentrations of nutrients. Both Chrysophyceae and Euglenophyceae classes had negative correlations with the transparency and nutrient values, showing evidence of their mixotrophic capabilities and, as a consequence, their capability to develop in environments with limited light.

The phytoplankton biovolume recorded in the São João River did not exceed 1 $mm^3.L^{-1}$. The Bacillariophyceae class was the most representative, as reported by Borges et al.

(2003) in the Pirapó River. Soares et al. (2007) studied the Paraibuna and Pomba River and recorded a dominance of diatoms and desmids in the biovolume in the middle and downstream stretch of Pomba River. Train and Rodrigues (1998) and Train et al. (2000) recorded the dominance of cyanobacteria in the biovolume of the Baía River, as well as in a side canal of the Alto Paraná River.

Smaller species may produce a higher density, however, in relation to the biovolume. They can contribute less to the total biomass when compared to less abundant ones, but which are larger in size, species. This occurred with the biovolume of some groups, such as the Bacillariophyceae, where *Aulacoseira granulata* predominated in density. However, *Surirella guatimalensis* was also important for the peak of biovolume, and for *Euglena acus* var. *longissima*, which was important for the phytoplankton biovolume.

In general, structural characteristics of lotic environment phytoplankton, especially diatoms and green algae dominance in the composition and of diatoms in the density and biovolume were observed. The correlations between the environmental factors, density and biovolume showed temperature, transparency and nutrients to be the main structural factors of the phytoplankton community. The negative correlation of the phytoplankton classes with transparency and nutrients is probably associated with the dilution effect during rainy periods and to the increased turbidity limiting the light in the environment.

The significant temporal variations in the structure of the phytoplankton community, between the study periods, occurred due to the limnological attributes, which brought on changes in the phytoplankton density and biovolume. However, spatially, there were only significant variations in the biovolume, due to the presence of taxa with larger cell sizes. In general, spatially, the structure of the phytoplankton community was more similar, due to the proximity of the sampling stations and the similarity in the distribution of communities in lotic environments, due to the unidirectional flow of the water. Perbiche-Neves et al. (2011) showed significant temporal differences in the phytoplankton of the Iguaçu River and tributaries due to climatic, physical and chemical variations and large spatial variation in relation to the community due to its large spatial dimension, which did not occur in the present study.

Thus, beyond the influences of geomorphic and hydrodynamic features of the lotic environment itself in determining the variations in composition, density and biomass of the phytoplankton species, factors such as temperature, transparency and nutrients also have an important role in the phytoplankton structuring, especially in the temporal organization of the community. Limnological studies in lotic environments constitute an important tool in recognizing the patterns of disruption in the phytoplankton community as a function of the environmental conditions in these ecosystems, and provide us with means for preserving and conserving the biodiversity, both locally and regionally.

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