Spatial and seasonal variations of planktonic protists (Mastigophora, Sarcodina and Ciliophora) in a river-lacustrine system in northeast Brazil

Variações espaciais e temporais de protozoários planctônicos (Mastigophora, Sarcodina e Ciliophora) em um sistema fluvial-lacustre do nordeste brasileiro.

Araújo, MFF.[1] and Godinho, MJL.[2]

[1]Centro de Biociências, Departamento de Microbiologia e Parasitologia, Campus Universitário Lagoa Nova, Universidade Federal do Rio Grande do Norte – UFRN,
BR 101, Lagoa Nova, CEP 59072-970, Natal, RN, Brazil
e-mail: mag@cb.ufrn.br

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

Abstract: Seasonal and spatial variations of protozooplankton (Mastigophora, Sarcodina and Ciliophora) of a river-lacustrine system were studied in Rio Grande do Norte state, in northeast Brazil (5° 50' and 6° 00'S and 35° 05' and 35° 25' W). Three sampling sites at Pitimbu River and one in the deepest part of the Jiqui Lake were selected and sampled from June/2001 through December/2002. Data obtained confirmed that the lake is less eutrophic in relation to the river, but one of the river sites was eutrophized. A discriminant analysis showed to be the lake trophically different from the other sampling sites. Compared to the river sites, the lake presented higher levels of dissolved oxygen and lower levels of total phosphorus. Phototrophic flagellates predominated quantitatively at all the sites, followed by sarcodines and ciliates. *Cryptomonas* and *Chroomonas* were the predominant among flagellates, and *Arcella*, *Difflugia* and, a small unidentified heliozoan dominated among sarcodines. *Limnostrombidium* and *Rimostrombidium* were the dominant ciliates genera at the less eutrophic site. The study showed that quantitative variations of the organisms were influenced by the trophic state as well as by the climatic conditions.

Keywords: protists, tropical region, spatial and temporal fluctuations.

Resumo: Foram estudadas as variações espaciais e temporais do protozooplâncton (Mastigophora, Sarcodina e Ciliophora) de um sistema fluvial-lagunar localizado no estado do Rio Grande do Norte, no Nordeste do Brasil (5° 50' e 6° 00' S e 35° 05' e 35° 25' W). Três locais de amostragem no Rio Pitimbu e um na região mais profunda da Lagoa do Jiqui foram amostrados entre Junho de 2001 e Dezembro de 2002. Variáveis limnológicas foram analisadas e relacionadas aos dados bióticos para comparar as regiões lótica e lêntica do sistema, em diferentes períodos climáticos. A Lagoa foi considerada menos eutrofizada em relação ao rio, e um dos locais de coleta do rio foi considerado eutrófico. Quando comparada aos locais do rio, a lagoa apresentou níveis mais elevados de oxigênio dissolvido e menores níveis de fósforo total. Os flagelados predominaram quantitativamente em todos os locais, seguidos por sarcodinos e ciliados. *Cryptomonas* e *Chroomonas* foram predominantes entre os flagelados e *Arcella*, *Difflugia* e um pequeno heliozoário não identificado dominaram entre os sarcodinos. *Limnostrombidium* e *Rimostrombidium* foram os ciliados predominantes nos locais menos eutrofizados. O estudo mostrou que as variações quantitativas dos organismos foram influenciadas tanto pelo estado trófico do ambiente, como pela variação climática.

Palavras-chave: protozoários, região tropical, variações espaciais e temporais.

1. Introduction

The abundance and the ubiquity of protists in aquatic ecosystems have led to the recognition of this group as an important element in the complex processes of microbial interactions. They are actively involved in essential food webs, mineralization of nutrients and control of the bacterial growth, being able still to be used as bioindicators or biomonitors of pollution (Corliss, 2001). Even though more and more studies have sought to understand the ecological role that protozoans play in the aquatic environment (Stensdotter-Blomberg, 1998), more gaps are open, generating the need for more knowledge of the free-living protozoa. Mixotrophic protists have received more attention in these studies (Jones, 2000; Hitchman and Jones, 2000; Modenutti and Balseiro, 2002), because they have a series of adaptative alimentary strategies, combining autotrophy and heterotrophy, that give them an advantage when competing with other groups. This determines the success of the maintenance of their populations in all kind of environments, throughout the world (Corliss, 2002).

The effect of the increasing concentrations of nutrients on nanoflagellates and ciliates in laboratorial experiments or through artificial fertilizations of lakes is well known (Bettez et al., 2002), but comparative studies on the community structure of protozoa in rivers and lakes with different trophic states can be considered scarce. There is still little information about the influence of the trophic state of a river or a lake on the taxonomic structure and the distribution of protozoa in natural environments (Auer and Arndt, 2001). Protozoa populations have been commonly characterized as less abundant in oligotrophic waters and more abundant in eutrophized environments (Hwang and Heath, 1997). The ciliates are the most frequent indicators of this relation (Riemann and Christoffersen, 1993; Foissner and Berger, 1996), but there are also studies relating heterotrophic nanoflagellates (Krstulovic et al., 1997, Zhao et al., 2003) and phototrophic flagellates (Barone and Nasseli-Flores, 2003) to the environment trophic degree.

In this study we observed seasonal and spatial patterns of variations in the protozooplankton (Mastigophora, Sarcodina and Ciliophora) of a river-lacustrine system located in a hot and equatorial region, where studies are scarce. The aim of this research was to describe possible influences of the environment trophic characteristics on protozoan distribution during rainy and dry periods.

2. Material and Methods

2.1. Study site

Pitimbu River constitutes a sub-basin of Pirangi River and it is located in eastern Rio Grande do Norte state between the 5° 50' and 6° parallels 00' of southern latitude and meridians 35° 05' and 35° 25' of West longitude. The predominant climate in the region is the dry sub-humid type (tropical rainy with dry summers). The Pitimbu River is perennial in all its extension, despite the water level being inferior to 0.5 m, in many sites, during the dry period. Pitimbu River contributes to the formation of Jiqui Lake (Figure 1), an important manantial which supplies about 190,000 inhabitants. Tables 1 and 2 show, respectively, morphometric characteristics of Pitimbu River and Jiqui Lake and the anthropic activities that occur at the studied environment.

2.2. Sampling procedure

At the Jiqui Lake (JL), monthly samplings were carried out from June/2001 to December/2002 (January/2001 excluded) in the limnetic zone of its deeper region (3 m). Five intensive samplings (a set of three to five samplings in

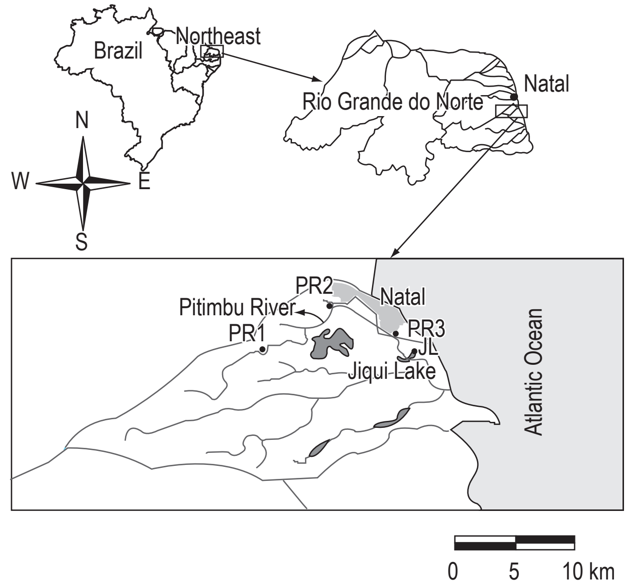

Figure 1. Sampling sites.

ten days at the most) were made at dry and rainy seasons (three rainy periods and two dry ones). At the surface, samples were obtained directly, using a 100 mL recipient, and at the bottom - 0.5 m above the interface water and sediment - a Van Dorn bottle was used.

Three sampling stations were selected at Pitimbu River, considered with different trophic conditions: A station next to the riverhead (PR1 - not impacted site); a station located next to residential areas and industries (PR2 - impacted site) and a station precedent to the Jiqui Lake (PR3 - recovering site), near (20 m) banks of macrophytes. Only intensive samplings were carried out at Pitimbu River, in the same periods and with the same frequency as the lake. Samples were directly collected at central sites between the two margins.

During the samplings, water aliquots for physical, chemical and biological analyses were removed.

2.3. Meteorological, physical and chemical analyses

Meteorological data of rainfall, evaporation, wind speed, solar radiation and air temperature were supplied by the Main Meteorological Station of UFRN (Federal University of Rio Grande do Norte), 6-12 km away from the sampling sites.

Water temperature and dissolved oxygen were measured using a portable digital oxymeter (Digimed, model DM4) which was periodically surveyed by the Winkler method (Golterman et al., 1978). A digital portable potenciometer (WTM, model pH330i) was used to measure pH. Concentrations of total nitrogen (total-N) and total phosphorus (total-P) were measured according to the method of Valderrama (1981). Chlorophyll-*a* was determined following Lorenzen (1967) using hot ethanol 90%

Table 1. Morphometric characteristics of Pitimbu River and Jiqui Lake.

Characteristics	Pitimbu River	Jiqui Lake
Length	31 km	1,210 m
Width	-	200 m
Water volume	-	466,093 m^3
Total area	126.45 km^2	15.25 he
Maximum depth	1.5 m	5.5 m
Minimum depth	0.1 m	0.5 m
Mean depth	0.5 m	2.5 m
Outflow	3.1 m^3s	-

Table 2. Anthropogenic activities observed at the collection points or near them.

Sampling sites	Place/city	Activities/use
PR1	Lamarão/Macaíba	Agricultural; pecuaristic
PR2	Planalto/Natal	Recreation; cars and animals washing; trash deposition; clothes washing; industrial activities (textile, cosmetics).
PR3	Emparn/Parnamirim	Agricultural; fishing; recreation
JL	Parnamirim	Urban supply

PR1: Pitimbu River station 1; PR2: Pitimbu River station 2; PR3: Pitimbu River station 3; JL: Jiqui Lake station.

for extraction and the quantification was made through a spectrophotometer (Unico UV 2100).

2.4. Biological analysis

For quantitative analysis of protozooplankton, 200 mL of the sample were immediately fixed with a saturated mercuric chloride solution and dyed with bromophenol blue 0.04% (Pace and Orcutt, 1981). The counting of the organisms was carried out through an inverted microscope Olympus (IX70) equipped with phase contrast, dark field and differential interference-contrast (DIC). A sub-sample of 10 mL was sedimented for 24 hours, at least, and random fields were counted, throughout the chamber, according to recommendations of Lund et al. (1958). Due to difficulties in identifying fixed organisms, that can have the cellular contour modified by the clamp or not resisting the fixation process, live samples for identification were obtained through filtration of the water in nets of 10 µm of mesh opening, after pre-filtration in net of 65 µm. The identification was based on Edmondson (1959), Foissner and Berger (1996), Foissner et al. (1999), Lee et al. (1985), Patterson (1996), Pennak (1953) and the Protist Information Server, URL: (http://protist.i.hosei.ac.jp/protist_menuE.html).

2.5. Statistical analysis

Pearson's and Spearman correlation tests were conducted to determine relationships between the different variables in the studied period. Mann Whitney and Student's *t*-tests were used to check for possible significant differences in the variables between dry and rainy seasons. Kruskal-Wallis test was used to look for significant differences between sampling sites, seasons and months, during intensive samplings. A Discriminant Function Analysis was conducted to identify variables that could discriminate the sampling points.

3. Results

It was observed an annual pattern of rainy periods (June to August/2001; March to August/2002) and dry periods (September/2001 to February/2002; September to December/2002). This pattern with two characteristic rainy and dry periods is typical of northeast Brazil (Table 3).

The general descriptive statistics of the analysed variables at Jiqui Lake and Pitimbu River are shown in Tables 4 and 5, respectively. As the surface-bottom fluctuations of lake data were not significant, samples of these strata were treated as replicas.

Water temperature followed the variation of the air temperature, falling during rainy periods. Dissolved oxygen was higher at the lake than at the river, and PR2 was the least oxygenated site. The pH tended to acidity and, lower levels were detected on rainy days at the river as well as at the lake. Water transparency at the Jiqui Lake was high during all the studied period.

Total-N concentrations did not show a clear pattern at the Jiqui Lake or at Pitimbu River. The range between the sampling sites and the climatic periods was from 112 to 784 μgL^{-1} at the lake and, from 161 to 887 μgL^{-1} at the river, with peaks occurring at isolated places and moments. Total-P levels varied from 4.1 to 17 μgL^{-1} at the lake and 3.2 to 24.9 μgL^{-1} at the river and were higher at PR2, as much in the dry as the rainy periods.

Data of Jiqui Lake varied significantly between dry and rainy periods in relation to total-N (Mann Whitney: $U = 12$; $p = 0.016$) and dissolved oxygen (Mann Whitney: $U = 12.5$; $p = 0.018$). These variables were negatively correlated (Pearson: $r = -0.562$; $p = 0.029$; and Spearman: $R = 0.663$; $p = 0.003$). Flagellates were positively correlated to pH (Pearson: $r = 0.552$; $p = 0.033$ and Spearman: $R = 0.535$; $p = 0.022$). A negative correlation between total-P and total-N (Pearson; $r = -0.50$; $p = 0.05$; Spearman: $R = -0.67$, $p = 0.006$) and a positive one between the Sarcodines and Chlorophyll-*a* (Pearson: $r = 0.55$; $p = 0.03$/Spearman: $R = 0.44$; $p = 0.06$) were detected.

The dissolved oxygen was considered the most significantly different variable between the sampling sites (Kruskal-Wallis, $P < 0.016$). In relation to the climatic period, the temperature (Kruskal-Wallis, $P < 0.006$) and pH (Kruskal-Wallis, $P < 0.006$) presented significant variations. Positive significant correlations occurred between Ciliates and Sarcodines (Pearson $r = 0.755$; $p = 0.000$) and Ciliates and Flagellates (Pearson: $r = 0.525$; $p = 0.025$).

3.1. Protozooplankton

A total of 95 fixed samples and 84 live samples were analyzed for the determination of the protozooplankton composition in the studied area of Pitimbu-Jiqui system. The methodology used did not allow to obtain an exhaustive count of flagellates, especially heterotrophic ones, that were sub estimate in this study. Forty-four taxa of Phylum Ciliophora and 45 of Sub-Phylum Sarcodina were observed (Figure 2a). In the Sub-Phylum Mastigophora 30 taxa were identified, of which 7 taxa are heterotrophic species. Most of them are autotrophic or possibly mixotrophic forms as *Cryptomonas* and *Chroomonas*. Ciliophora was represented by 12 groups in terms of classes, subclasses or orders (Figure 2b); Mastigophora by six groups (Figure 2c) and Sarcodina by four groups (Figure 2d). Among the identified taxa, 60% were less frequent species, occurring in less than 10% of the samples, found in only one event, or in the live samples, but not in the fixed ones. A problem due to conservation and fixative could explain the absence of some species in fixed samples. Protozooplankton occurrence was higher during rainy periods (17-44 org.mL^{-1}) than in dry periods (8-24 org.mL^{-1}), with minimum and maximum

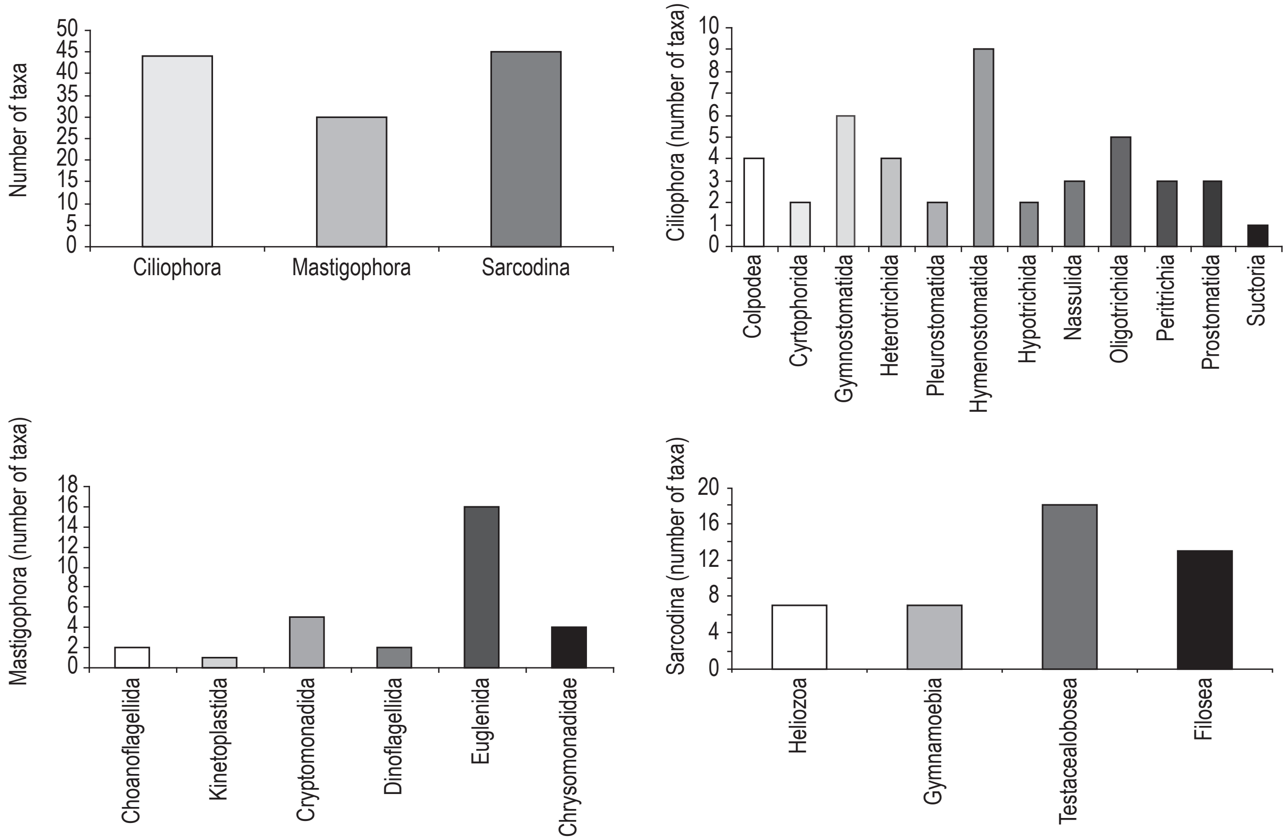

Figure 2. Protozooplankton taxa identified in the Pitimbu-Jiqui System. a) Total number of taxa; b) Ciliophora groups; c) Mastigophora groups; and d) Sarcodina groups.

Table 3. Average (minimum; maximum) of meteorological variables from Pitimbu River and Jiqui Lake.

Climatic Period	Precipitation (mm)	Air Temperature (°C)	Wind (ms)
June-Ago./2001 (Rainy Period)	260 (104; 374)	25.8 (24.9; 25.9)	4.6 (3.8; 5.4)
Sept.-Feb./2002 (Dry period)	51 (14; 114)	28,5 (26.2; 29.7)	4,5 (3.6; 5.2)
Mar.-Ago./2002 (Rainy period)	281 (123; 480)	26 (25.1; 26.9)	3.8 (3.1; 4.3)
Sept.-Dec./2002 (Dry period)	39 (10; 98)	28,2 (26.4; 29.3)	4.6 (4.5; 4.7)

variations observed always at the same collection sites (PR3 and JL, respectively).

The Sub-phylum Mastigophora, mainly represented by pigmented flagellates, was widely predominant in the intensive samplings (dry and rainy periods), in relation to the other groups, as much in the river as in the lake (Figure 3). There was a proeminent occurrence of this group at the Lake (143 to 955 org.mL^{-1}) compared to the river (84 to 406 org.mL^{-1}). As the methodology used was not well adapted to the counting of heterotrophic flagellates, and the observation of live samples, after filtration on 10 μm pore size probably induced an important loss of them (usually lesser than 10 μm), the predominance of phototrophic flagellates could be partly due to these methodological aspects.

The Sarcodina was configured as the second most abundant group (26 to 207 org.mL^{-1} at the lake and 41 to 388 org.mL^{-1} at the river) and the Sub-phylum Ciliophora occurred on a lower quantitative scale (33 to 143 org.mL^{-1} at the lake and 29 to 224 org.mL^{-1} at the river).

During monthly samplings at the lake (Figure 4), a predominance of flagellates in dry months (September to February) was observed, while during rainy months (April to July) they were reduced to up to 60%. Sarcodines occurred in larger or smaller number regardless of the climatic period and ciliates presented less variations, even at dry periods, when reductions of their populations were observed. The highest annual density of the total number of protozooplankton was observed in December, the dryest month of each year of the collection.

3.2. Predominant taxa

Flagellates always presented quantitative predominance and occurrence frequency, at all the sampling sites. Sometimes, due to their small size, it was difficult to identify Cryptomonadida group during the analyses, even at the genus level. Thus, the organisms of this group are treated here as a set, in which *Cryptomonas* sp. and *Chroomonas* sp. were quantitatively predominant. During the intensive samplings, the average abundance of this group was always higher during rainy periods, especially at PR2 and at the Lake. *Peridinium* occurred in high densities in RP2 and JL during dry periods, and in low densities or none at all in rainy periods.

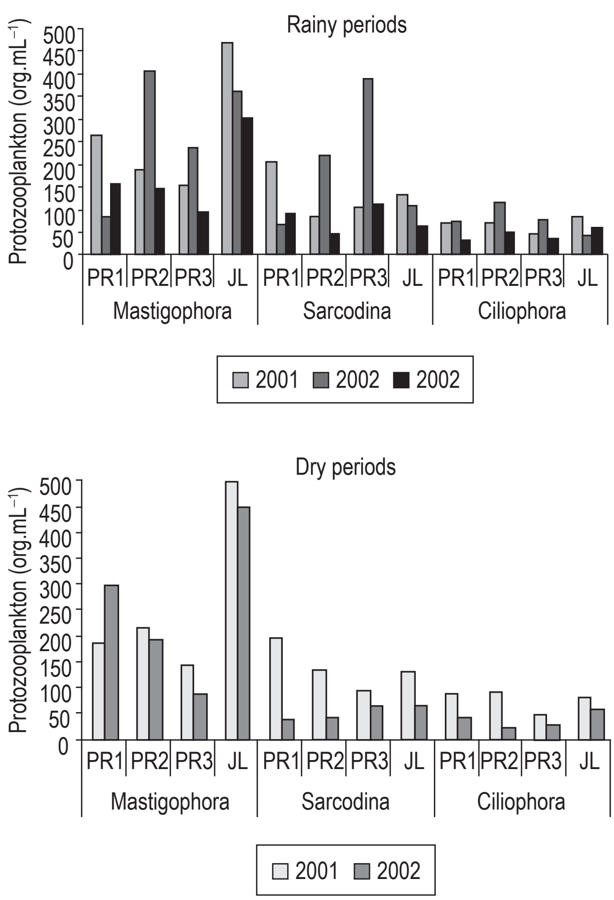

Figure 3. Means of Protozooplankton densities (org.mL^{-1}), during the intensive samplings. a) Rainy periods. b) Dry periods. PR1: Pitimbu River 1 station 1; PR2: Pitimbu River station 2; PR3: Pitimbu River station 3; JL: Jiqui Lake.

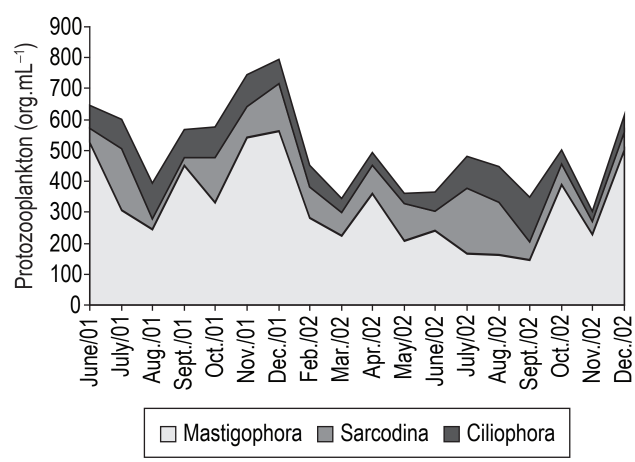

Figure 4. Monthly Variation of Protozooplankton (org. mL^{-1}) and rain at the Jiqui Lake during 18 months (June/2001 to December/2002).

Table 4. Descriptive statistics of general data of Jiqui Lake from June 2001 to December 2002.

Variable	Mean	Minimum	Maximum	SD	SE
Temperature (°C)	27.8	26.20	30.7	1.06	0.25
Oxygen (mg L^{-1})	5.9	5.10	6.8	0.43	0.10
pH	6.2	5.50	6.6	0.29	0.06
Transparency (m)	2.1	1.70	2.8	0.30	0.07
Total-N (μg L^{-1})	352.0	112.00	784.0	146	34.4
Total-P (μgL^{-1})	10.2	4.10	17.0	3.43	0.88
Chlorophyll-*a* (μg L^{-1})	5.8	1.83	10.1	2.46	0.58
Mastigophora (org mL^{-1})	349.0	143.00	955.0	199	46,9
Sarcodina (org.mL^{-1})	96.0	26.00	207.0	56.2	13.2
Ciliophora (org.mL^{-1})	77.0	33.00	143.0	32.1	7.58

SD = standard deviation; SE = standard error; N = 18.

Table 5. Descriptive statistics of data of samplings sites from Pitimbu River (5 intensive samplings from June 2001 to December 2002, including 3 rainy periods and 2 dry periods).

Sampling sites	Statistics	Temperature (°C)	Oxygen (mg.L-1)	pH	Total-N (μg.L^{-1})	Total-P (μg.L^{-1})	Mastigophora (org.mL^{-1})	Sarcodina (org.mL^{-1})	Ciliophora (org.mL^{-1})
PR1	Mean	27.3	4.8	5.8	245	10.4	198	120	62
	Minimum	25.8	3.9	5.5	161	6.9	84	41	30
	Maximum	28.8	6	6.1	405	16.9	300	203	90
	SD	1.21	0.75	0.23	107	3.9	86	75	24
	SE	0.54	0.34	0.10	55	1.7	3	33	11
PR2	Mean	27.1	4.3	6.1	370	13.6	231	106	71
	Minimum	25.8	3.8	5.9	164	5	147	44	224
	Maximum	28	4.6	6.3	835	24.9	406	220	116
	SD	0.98	0.34	0.17	272	7.8	101	74	36
	SE	0.44	0.15	0.08	122	3.5	45	33	16
PR3	Mean	27.7	4.9	6.1	420	7.6	143	153	48
	Minimum	26.6	4.4	5.9	205	3.2	90	67	29
	Maximum	28.5	5.6	6.4	887	11.4	234	388	78
	SD	0.84	0.58	0.20	315	3.1	59	132	19
	SE	0.37	0.26	0.08	157	1.4	26	59	9

SD = standard deviation; SE = standard error; N = 5. PR1: Pitimbu River station 1; PR2: Pitimbu River station 2; PR3: Pitimbu River station 3.

The ciliates *Halteria grandinella*, *Rimostrombidium* and *Limnostrombidium* were predominant in the occurrence frequency (Figure 5). *Halteria grandinella* was the most abundant species in this group, mainly in PR2. The densities of *Rimostrombidium* and *Limnostrombidium* were higher in PR3 and in JL.

Among the sarcodines, the species with higher density was a small-unidentified heliozoan (11.1 μm of diameter). *Arcella* and *Difflugia* had a high occurrence frequency (100 and 90%, respectively) either in rainy or dry periods, but without quantitative predominance.

A discriminant analysis was carried out to determine the variables that better characterized the sampling sites. The first discriminant function (root 1) was more positively correlated with oxygen and negatively correlated with total-P. Total-N was also positively correlated with this function. The second function was more influenced, in a negative way, by the Mastigophora variable, and positively by the Sarcodina (Table 6). Eigenvalues found for each discriminant function and the cumulative ratio of the explained variance show that the first discriminant function (root 1) was responsible for 63% of data variance and, cumulatively to function 2 (root 2), the explanation of the variance increased by 89% .

The averages of canonical variables (Table 7) show that the first discriminant function separated the Jiqui Lake from the Pitimbu River. This means that highest levels of oxygen and the low concentrations of total-P characterized the environment of the lake, which was discriminated out of the river. The PR2 station was separated by this function too, but unlike the Jiqui Lake, seemed impacted, with lower levels of oxygen and higher levels of total-P. The Second discriminant function separated PR3 station from the other ones because this stretch of the river had a significant minor occurrence of Mastigophora and a greater one of Sarcodina.

Table 6. Standardized Coefficients for Canonical Variables.

Variables	Root 1	Root 2
Temperature	0.57998	0.44181
Oxygen	1.2583	0.62220
pH	–0.55433	0.57472
Total-N	0.95147	0.49204
Total-P	–1.2984	–0.77451
Mastigophora	0.60264	–1.0498
Sarcodina	0.09368	0.91074
Ciliophora	0.35431	–0.49799
Eigenvalues	7.4228	3.0256
Exp. Var.	0.63404	0.89249

Exp. Var. = explained variation.

Table 7. Means of Canonical Variables (roots x variables).

Variables	Root 1	Root 2
PR1	–0.66929	–0.7005
PR2	–2.5702	–1.1935
PR3	–0.69866	2.8277
JL	3.6645	–0.5087

PR1: Pitimbu River 1 station 1; PR2: Pitimbu River station 2; PR3: Pitimbu River station 3; JL: Jiqui Lake.

4. Discussion

Shallow environments, like Jiqui Lake, are largely influenced by the sedimentary compartment on the superior

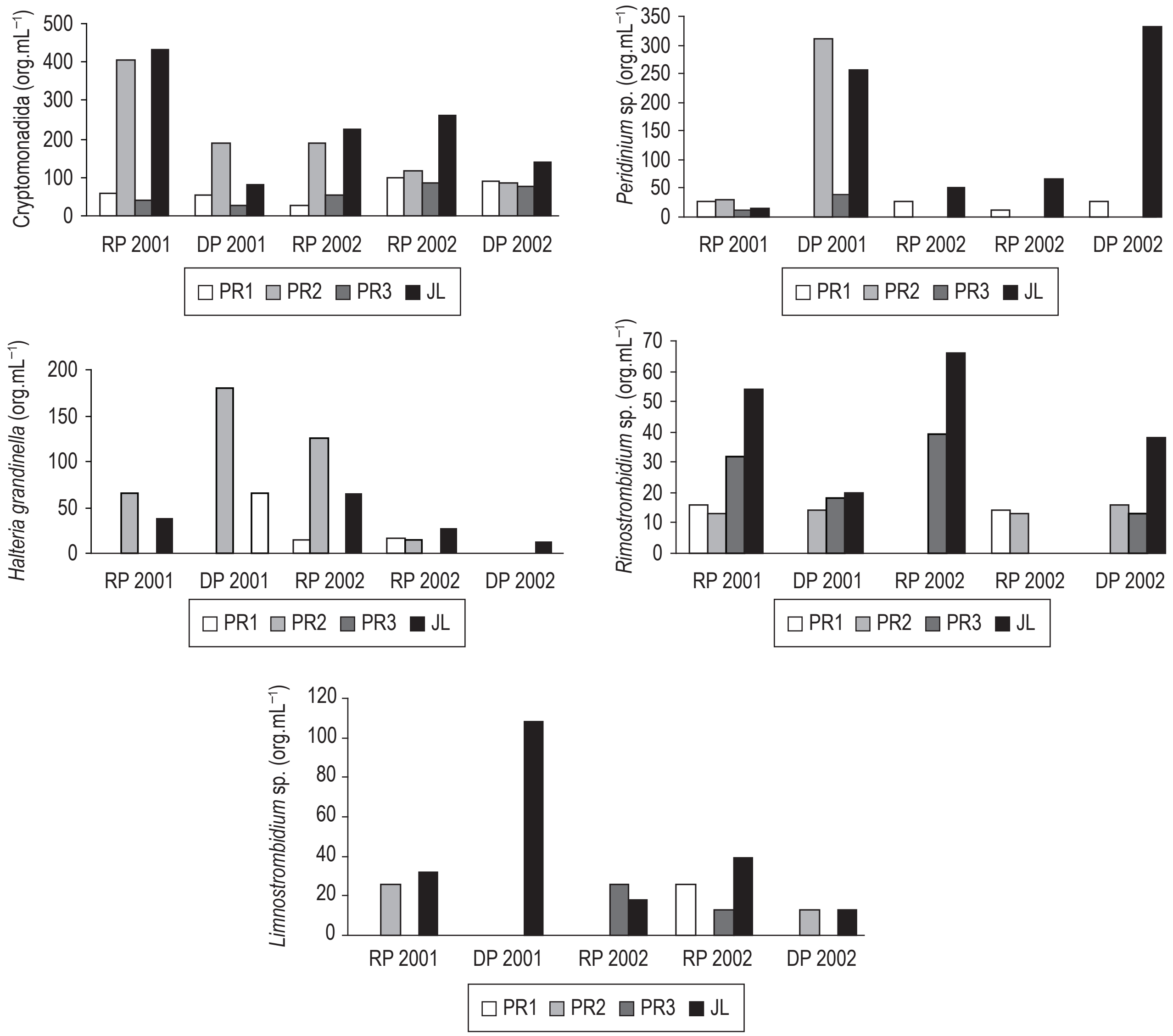

Figure 5. Seasonal variation of taxa in prominence (org.mL^{-1}) by sampling site and climatic period. PR1: Pitimbu River 1 station 1; PR2: Pitimbu River station 2; PR3: Pitimbu Rivr station 3; JL: Jiqui Lake. RP = Rainy period; DP = Dry period.

layers of water, which leads to events of autofertilization and the influence of sediment microbiota on the water column. The performance of the wind is also stronger on these environments favoring surface-bottom mixtures (Garstecki et al., 2000). At the lake, the negative correlation detected between total-P and total-N could mean these nutrients have different origins. Because it was raised in rainy periods, the total-N might have had allochotonous origin, which could have resulted from the drainage of the soil caused by rain. This arrival of organic substances in the lake favors aerobian microbial processes, lightly reducing oxygen levels during rainy periods. Phosphorus increase in the lake during dry periods could have resulted from internal processes, favored by wind action and low water level, while dilution could have occurred during rainy periods. When compared to river, oxygen levels were higher in the lake. At the PR2 station, which is a site located near residential areas and industries, lower levels of oxygen were found.

The absence of correlation between temperature and protozooplankton suggests that, in this environment, temperature does not interfere in growth of these organisms, in spite of having had a lightly thermal variation between dry and rainy periods.

There was a positive correlation between Sarcodina and chlorophyll-*a*, sugesting that photosynthetic organisms are sources of food for this group, at it was confirmed through live samples analyses in study. This relation is similar to that found by Garstecki et al. (2000) in a shallow environment, and was attributed to the positive answers of bentic populations of rizopods to the increases of chlorophyll in the water column. Positive significant correlations also occurred between ciliates and sarcodines, implying alimentary relations between these groups. They may have the same source of nutrients, or one group is the source of nutrients for the other (Hirose et al., 2003) or even still, both have their populations controlled by same factors (Medina-Sanchez et al., 1999). Similar correlations were found by Amblard et al. (1996) for a shallow reservoir, also attributed to the trophic relations between these groups.

High densities of flagellates in all stations reflect their great capacity of adaptation, even when nutrients are scarce. Possible mixotrophy of some members of this group such as *Cryptomonas* and *Chroomonas* (Isaksson, 1998; Jones, 2000) could have contributed to high density in oligotrophic regions of the system. The ubiquity and independence of flagellates in regard to trophic state of the environment (Barone and Nasseli-Flores, 2003) could be confirmed, since it succeeded in environments considered richer in nutrients as well as in oligotrophic ones.

Sarcodines, especially tecamoebas, were more abundant in rainy periods in river than in lake, which can be explained by the ressuspension, promoted by rain, from the sediment into water column. On the other hand, sarcodina predominance at lake, in some occasions, was probably due to the influence of aquatic macrophytes, observed near sampling site, to which they are commonly associated, and due to the surface-bottom interactions, frequently found in Brazilian shallow reservoirs (Gomes and Godinho 2003). Although they are traditionally cited as occurring in low numbers in plankton (Laybourn-Parry, 1992), studies carried out in Brazilian environments have emphasized the importance of abundance and specific composition of tecamoebas in planktonic samples (Velho et al., 1999; Landa and Mourgués-Shurter, 2000; Velho et al., 2003) which is confirmed, in this study, since sarcodines quantitatively surpassed ciliates. In studied environment, shallow water column and the macrophytes occurrence favored elevated occurrence of sarcodines in the plankton.

Ciliates densities found in this study are situated among those reported for oligotrophic (Stendotter-Blomberg, 1998; Modenutti and Perez, 2001) and eutrophic environments (Bettarel et al., 2003, Gomes and Godinho, 2003) located in tropical or temperate regions of the world. Their abundances in the Pitimbu-Jiqui system are slightly superior to those found in mesotrophic European lakes (Bell et al., 1998; Bettarel et al., 2003) and similar to those found in reservoirs in northeast Brazil (Bouvy et al., 1998).

The first function of discriminant analysis can be characterized as a trophy discriminator, classifying the lake as an oligotrophic environment compared to the river, and the PR2 station of the river as eutrophic in relation to the other ones. The second function was related to the taxonomic groups, indicating that the PR3 station presented higher populations of sarcodines and lower populations of flagellates, in contrast to PR2 station, which presented high densities of this last group.

Higher concentrations of flagellates at the PR2 station and at lake should no be related to the trophic conditions of these sites. Barone and Nasseli-Flores (2003) suggested that Cryptomonadida occurrence, predominant in the studied environment, is independent of the local trophic state. Populations seemed to vary due to the climatic regimen, once the higher densities of flagellates occurred during rainy periods. The oligotrophic condition of PR3 in relation to PR2 stations, and with higher populations of sarcodines was probably influenced by banks of macrophytes that were observed about 20m away from this station. Ciliates, due to their small numerical variation and homogeneous presence in the samples and at sites, did not discriminate the sampling stations well. However, when evaluated separately, higher frequency and abundance of oligotrichida like *Limnostrombidium* and *Rimostrombidium* were observed. These taxa are frequently associated to the conditions of oligotrophy in tropical environments as well as in temperate ones (Hwang & Heath, 1997; Bettez et al., 2002). Beside this, higher stability supported by the lentic condition of this system and the fact that this group is euplanktonic must have favored its predominance at the lake, in regard to the points of the lotic environment (3.1 $m^3.s^{-1}$).

Cryptomonadida flagellates dominated the oligotrophic sites as well as the eutrophic ones, which might mean that factors like mixotrophic capacity keep their populations at elevated levels, regardless of the trophic state. The major occurrence of Oligotrichida ciliates as *Limnostrombidium* sp. and *Rimostrombidium* sp. in less impacted regions of the system (Lake and PR3 station) confirmed these species as indicators of oligotrophic environments. Events of ressuspension of the sediment led to sarcodines predominance in the river, during rainy periods. Thus, the trophy of study sites, probably influenced by the pluviometric regimen and type of local impact, was determining in the density variation and occurrence of organisms.

Acknowledgements

The authors are grateful to Dr. José Luiz Attayde for helping with statistical tests and Dr. Renata Panosso for their comments on earlier versions of this work. Dr. Ivaneide Soares helped with technical assistence and friendly advice. We are also grateful to Edson Santana, Karina Veras, Renata Martins and Silvana Alves for the assistance to field and laboratory work. Magnólia Araújo got a PhD scholarship from CAPES (Coordenação de Aperfeiçoamento de Pessoal do Ensino Superior – Ministério da Educação e Cultura) and financial support from Federal University of Rio Grande do Norte and Federal University of São Carlos for the accomplishment of this work. Theresa O'Brien revised the manuscript.

References

AMBLARD, C., BOURDIER G., CARRIAS, JF., MARINE N. and QUIBLIER, C. Évolution saisonnière de la structure des communautés microbiennes dans un reservoir d`eau potable. *Water Res.*, 1996, vol. 30, p. 613-624.

AUER, B. and ARNDT, H. Taxonomic composition and biomass of heterotrophic flagellates in relation to lake trophy and season. *Freshwater Biol.*, 2001, vol. 46, 959-972.

BARONE, R. and NASSELI-FLORES, L. Distribution and seasonal dynamics of cryptomonads in Sicilian water bodies. *Hydrobiologia*, 2003, vol. 502, p. 325-329.

BELL, RT., STENDOTTER U., PETTERSON, K., ISTANOVICS, V. and PIERSON, DC. Microbial dynamics and phosphorus turnover in Lake Erken. *Ergebrisse-der-Limnol.*, 1998, vol. 0, no. 51, p. 1- 20.

BETTAREL, Y., SIME-NGANDO T., AMBLARD, C., CARRIAS, JF. and PORTELLI, C. Virioplankton and microbial communities in aquatic systems: a seasonal study in two lakes of differing trophy. *Freshwater Biol.,* 2003, vol. 48, p. 810-822.

BETTEZ, ND., RUBLEE, PA., O'BRIEN, J. and MILLERS, MC. Changes in abundance, composition and controls within the plankton of a fertilized arctic lake. *Freshwater Biol.,* 2002, vol. 47, p. 303-311.

BOUVY, M., BARROS-FRANÇA, LM. and CARMOUZE, JP. Compartimento microbiano no meio pelágico de 7 açudes do estado de Pernambuco. *Acta Limnol. Bras*. 1998, vol. 10, p. 93-101.

CORLISS, JO. *Have the Protozoa been overlooked?*, 2001. [Apr. 11, 2003]. Available from: <www.findarticles.com/cf_0/m1042/6_51/77336548/print.jhtml>.

CORLISS, JO. Biodiversity and Biocomplexity of the protists and an overview of their significant roles in maintenance of our biosphere. *Acta Protozool.*, 2002, vol. 41, p. 199-219.

EDMONDSON, WT. *Freshwater Biology*. New York: John Wiley & Sons, 1959. 1248 p.

FOISSNER, W. and BERGER, H. A user-friendly guide to the ciliates (protozoa, ciliophora) commonly used by hydrobiologists as bioindicators in rivers, lakes and waste waters, with notes on their ecology. *Freshwater Biol.,* 1996, vol. 35, p. 375-482.

FOISSNER, W., BERGER, H. and SCHAUMBURG, J. Identification and ecology of limnetic plankton ciliates. Informationsber. des Bayer. *Landesamtes für Wasserwirtschaft, Heft,* 3/99, 1999.

GARSTECKI, T., VERHOEVEN, R., WICKHAM, SA. and ARNDT, H. Benthic-pelagic coupling: a comparison of the community structure of benthic and planktonic heterotrophic protists in shallow inlets of the southern Baltic. *Freshwater Biol.*, 2000, vol. 45, p. 147-16.

GOLTERMAN, HL., CLYMO, RS. and ONSTAD, MAM. *Methods for Physical and Chemical Analysis of Freshwaters*. Oxford: Blackwell Scientific Publications, 1978. 231 p.

GOMES, EAT., GODINHO, MJL. Structure of the protozooplankton community in a tropical shallow and eutrophic lake in Brazil. *Acta Oecol.*, 2003, vol. 24, p. S153-S161.

HIROSE, M., NISHIBE, Y., UEKI, M. and SHIN-ICHI, N. Seasonal changes in the abundance of autotrophic picoplankton and some environmental factors in hypereutrophic Furuic Pond. *Aquatic Ecology*, 2003, vol. 37, p. 37-43.

HITCHMAN, RB. and JONES, HLJ. The role of mixotrophic protists in the population dynamics of the microbial food web in a small artificial pond. *Freshwater Biol.,* 2000, vol. 43, p. 231-241.

HWANG, SJ. and HEATH, RT. The distribution of protozoa across a trophic gradient, factor controlling their abundance and importance in the plankton food web. *J. of Plankton Res.,* 1997, vol. 19, p. 491-518.

ISAKSSON, A. Phagotrophic phytoflagellates in lakes – a literature review. *Archives Hydrobiology Special Issues Advanced. Limnology*, 1998, vol. 51, p. 63-90.

JONES, RI. Mixotrophy in planktonic protists: an overview. *Freshwater Biol.,* 2000, vol. 45, p. 219-226.

KRSTULOVIC, N., SOLIC, M. and MARASOVIC, I. Relationship between bacteria, phytoplankton and heterotrophic nanoflagellates along the trophic gradient. *Helgol. Meeres*., 1997, vol. 51, p. 433-443.

LANDA, GG. and MOURGUÉS-SCHUTER, LR. Caracterização da comunidade zooplanctônica de um sistema artificial (represa zootecnia), no campus da Universidade Federal de Lavras-MG. *Acta Limnol. Bras.*, 2000, vol. 12, p. 69-83.

LAYBOURN-PARRY, J. *Protozoan plankton ecology.* London: Chapman and Hall, 1992. 231 p.

LEE, JJ., HUTNER, SH. and BOVEE, EC. *An illustrated Guide to the Protozoa.* Lawrence, Kansas: Society of Protozoologists, 1985.

LORENZEN, CF. Determination of chlorophyll and phaeopigments: spectrophotometric equations. *Limnol. Oceanogr.,* 1967, vol. 16, p. 990-992.

LUND, JWG., KIPLING, C. and LE CREN, ED. The inverted microscope method of estimating algal numbers and the statistical basis of estimations by counting.

Hydrobiologia, 1958, p. 143-170.

MEDINA-SANCHEZ, JM., VILLAR-ARGAIZ, M., SANCHEZ-CASTILLO, P., CRUZ-PIZARRO, L. and CARRILLO P. Structure changes in a planktonic food web: biotic and abiotic controls. *Journal of Limnology*, 1999, vol. 58, p. 213-222.

MODENUTTI, BE. and PEREZ, GL. Planktonic ciliates from an oligotrophic south Andean lake (Patagonia, Argentina). *Braz. J. Biol. = Rev. Bras. Biol.*, 2001, vol. 61, p. 389-395.

MODENUTTI, BE. and BALSEIRO, EG. Mixotrophic ciliates in an Andean lake: dependence on light and prey of an *Ophrydium naumanni* population. *Freshwater Biol.*, 2002, vol. 47, p. 121- 128.

PACE, ML. and ORCUTT, D. The relative importance of protozoans, rotifers and crustaceans in freshwater zooplankton community. *Limnology and Oceanogr.*, 1981, vol. 25, p. 943-948.

PATTERSON, DJ. *Free-living freshwater protozoa*: a colour guide. England: John Wiley & Sons, 1996. 223 p.

PENNAK, RW. *Freshwater invertebrates.* New York: Ronald, 1953. 769 p.

Protist information server. [Nov. 20, 2003]. Available from: <http://protist.i.hosei.ac.jp/protist_menuE.html>.

RIEMANN, B. and CHRISTOFFERSEN, K. Microbial trophodynamics in temperate lakes. *Mar. Microb. Food Webs*, 1993, vol. 7, p. 69-100.

STENSDOTTER-BLOMBERG, U. Factors controlling pelagic populations of ciliates and heliozoans – late summer investigations in an acid lake before and after liming. *J. Plankton Res.*, 1998, vol. 20, p. 423-442.

VALDERRAMA, JC. The simultaneous analysis of total nitrogen and total phosphorus on natural waters. *Mar. Chem.*, 1981, vol. 10, p. 109-122.

VELHO, LFM., LANSAC-TÔHA, FA. and BINI, LM. Spatial and temporal variations in densities of testate amoebae in the plankton of the upper Paraná River floodplain, Brazil. *Hydrobiologia*, 1999, vol. 411, p. 103-113.

VELHO, LFM., LANSAC-TÔHA, FA. and BINI, LM. Influence of environmental heterogeneity on the structure of testate amoebae (Protozoa, Rhizopoda) assemblages in the plankton of the upper Paraná River Floodplain, Brazil. *Int. Rev. Hydrobiol,* 2003, vol. 88, p. 154-166.

ZHAO, Y., YU, Y., FENG, W. and SHEN, Y. Growth and production of free-living heterotrophic nanoflagellates in a eutrophic lake – Lake Donghu, Wuhan, China. *Hydrobiologia*, 2003, vol. 498, p. 85-95.

Received: 19 June 2007
Accepted: 08 October 2008