# Spatial and temporal fluctuations in bacterioplankton and correlated abiotic variables in eutrophic environments of the Brazilian semi-arid region

Flutuações espaciais e temporais do bacterioplâncton e variáveis limnológicas em ambientes eutrofizados de região semi-árida brasileira

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**Abstract:** During the dry and rainy periods, fluctuations on bacterioplankton and trophic state indexes were studied in lotic and lentic environments of the Piranhas-Assu river hydrographic basin. Mean total bacterial densities varied in a magnitude from $10^6$ to $10^7$ organisms $mL^{-1}$ and, they were higher in the rainy period (*t*-Test: p = 0.0025). No significant variation of bacterioplankton occurred between sampling sites. Cocci bacteria were numerically predominant in all sampling stations, affecting the total abundance of bacterioplankton. Total bacterial biomass varied from 659 to 1,997.3 $\mu gC.L^{-1}$ due to the high values of filament cellular volume. Total phosphorus amounted to 108 $\mu g.L^{-1}$ and presented a positive correlation with chlorophyll "a" ($r = 0.94$; $p < 0.05$) during dry periods, when presented higher concentrations. Low transparency of water and phosphorus and chlorophyll concentrations indicated eutrophic or hypereutrophic levels in the studied stations of reservoir. Considering this condition, associated with high density and biomass values found, it is necessary a constant monitoring of the semi-arid aquatic ecosystems, since the quality of water is affected by drought occurrence.

**Keywords:** water quality, bacterioplankton, eutrophic environments, semi-arid.

**Resumo:** Variações no bacterioplâncton e nos índices de estado trófico em ambientes lótico e lêntico de trechos da bacia hidrográfica do rio Piranhas-Assu foram estudadas nos períodos seco e chuvoso. As médias das densidades bacterianas totais oscilaram na ordem $10^6$ a $10^7$ organismos por mL de amostra, sendo mais elevadas no período de chuva (Teste-*t*: p = 0,0025). Não houve variação espacial significativa. As células em forma de cocos foram numericamente predominantes em todos os locais, influenciando a abundância total do bacterioplâncton. A biomassa bacteriana total variou de 659 a 1997,3 $\mu gC.L^{-1}$ em função dos altos valores de biovolume dos filamentos. O fósforo total atingiu 108 $\mu g.L^{-1}$ e teve uma correlação positiva com a clorofila "a" ($r = 0,94$; $p < 0,05$) no período de estiagem, quando estas duas variáveis apresentaram concentrações mais elevadas.. A baixa transparência da água e as concentrações de fósforo e clorofila indicaram níveis eutrófico ou hipereutrófico para os locais estudados no reservatório. Considerando esta condição, associada aos altos valores de densidade e biomassa encontrados, faz-se necessário um freqüente monitoramento dos ecossistemas aquáticos de região semi-árida visto que a qualidade da água é afetada pela ocorrência de seca.

**Palavras-chave:** qualidade de água, bacterioplâncton, ambientes eutrofizados, semi-árido.



## 1. Introduction

Accumulated knowledge on the climate of the Brazilian semi-arid region points to variations in the rainfall distribution during the year, associated with high rates of evaporation due to very high thermal coefficients, determines severe drought periods which ravage the regional population.

Riverine communities of the semi-arid region of northeastern Brazil are affected by water shortage imposed by the annual long periods of drought. Therefore, the maintenance of the water quality in rivers and reservoirs of the region contribute significantly to improvement on life quality of the population. Water shortage during drought periods highlights the problem of water quality loss that is used by people to care of their basic needs. The use of hydric resource with poor quality results in a growing serious threat to the health and welfare of the people who have direct contact with the polluted and eutrophic waters of

rivers and reservoirs in the semi-arid region (Soares et al., 2001; Proença et al., 2003).

The presence and diversity of microorganisms are important factors to the operation of these environments. The organisms are a basic component in the aquatic food webs and they contribute significantly to nutrients cycling and flow of energy (Azam et al., 1983; Bettez et al., 2002; Gurung et al., 2002). They also maintain vital and refined relationships with other organisms in superficial water bodies (Rosado and Duarte, 2002) and, play a key role in the conservation and biological restoration of environmental degraded areas (Young, 1997).

The bacterioplankton is an abundant component (Lewis et al., 1986; Lindström, 2001) and ecologically important both, in the oceans and in the inland waters (Lindström and Bergström, 2005). Heterotrophic planktonic bacteria are associated with the carbon metabolism in pelagic environments (Gurung et al., 2002) and a large part of dissolved organic matter can be consumed by these organisms (Bouvy et al., 1998). However, the excessive degradation of organic carbon by bacteria can reduce the dissolved oxygen concentrations to levels harmful to other organisms (Eiler and Bertilsson, 2004).

Microorganisms in aquatic systems vary qualitatively and quantitatively over long periods or in a short time scale (Regali-Seleghim, 1992). Thus, temporal variations affect the ecology of specific populations and modify the structure and function of the microbial community (Liu and Leff, 2002).

The study on bacterial composition alterations can lead to the elucidation of important variations in the density and biomass of bacterioplankton in aquatic systems (Kirschner and Velimirov, 1997). Furthermore, the analysis of the trophic state indicators as total phosphorus, chlorophyll-*a*, and water transparency may show relations between biotic and abiotic factors (Matthews et al., 2002). In this regard, monitoring of aquatic ecosystems may be extremely relevant to known the functioning of these systems.

This work aimed to detect spatial and temporal fluctuations in density and biomass of bacterioplankton in upstream and downstream sites of the Engenheiro Armando Ribeiro Gonçalves dam and in dry and wet periods considering the variation on trophic state of the reservoir.

Variations of bacterioplankton have been the focus of investigation in many works (Kirschner and Velimirov, 1997; Gurung et al., 2002; Liu and Leff, 2002; Eiler and Bertilsson, 2004; Lindström and Bergström, 2005). But such studies are related, to a large extent, to the aquatic environments of temperate regions.

## 2. Material and Methods

### *2.1. Study area*

The Piranhas-Assu river hydrographic basin, which supplies 148 cities of the Rio Grande do Norte and Paraíba states, is entirely located in the Brazilian semi-arid region, where there is extreme irregularity of rainfalls and, high evaporation rates.

The annual average temperature is around 28 °C, with a maximum of 33 °C in the hottest months and a minimum of 21 °C during the coolest ones. Precipitations are extremely concentrated between February and May with an annual average of about 600 mm (Figure 1).

In the Rio Grande do Norte state, it is located a great reservoir with a total capacity of 2.4 billion cubic meters of water (Figure 2). The Engenheiro Armando Ribeiro Gonçalves dam is located geographically by coordinates 05° 40' 09.48" S and 36° 52' 44.34" W, in northeastern Brazil.

The annual average of water pH varies from 8.0 to 8.5 and dissolved oxygen in the dam presents an annual average concentration of approximately 5.5 $mg.L^{-1}$ (Costa et al., 1998). Characteristics of the drainage basin and dam are shown in Table 1.

### *2.2. Sampling*

Samples were carried out in two dry periods (Sept./06 and Nov./06) and two rainy periods (Mar./07 and June-July/07), considering the annual distribution of precipitation (Figure 1).

Water samples were collected from two stations in the dam (at 5° 40' 31.70" S and 36° 53' 00.01" W, and at 05° 47' 50.38" S and 36° 55' 33.38" W), and, one on a stretch of the river (at 05° 36' 16.43" S and 36° 53' 41.99" W). The sampling stations were located at proximity of São Rafael, Itajá and Assu cities, respectively.

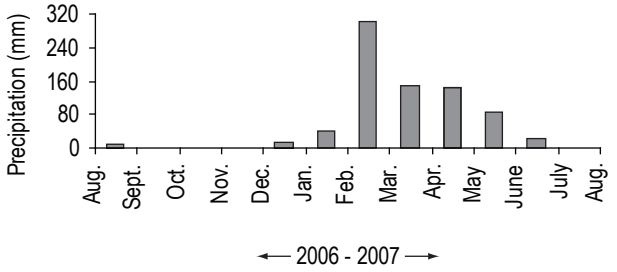


**Figure 1.** Monthly variation on precipitation from Aug./06 to July/07. Source: EMPARN

**Table 1.** Hydrologic and morphometric characteristics of drainage basin and dam.

| |
|---|
| Drainage Basin 36,770 $Km^2$ |
| Hydraulic Basin 19,500 ha |
| Maximum operational level of dam 35 m |
| Output of water (max) 13,200 $m^3/s$ |
| Water input (max) 47.5 $m^3/s$ |
| Maximum volume of dam 2.4 x $10^9$ $m^3$ |
| Flood area 19,200 ha |

Source: DNOCS.

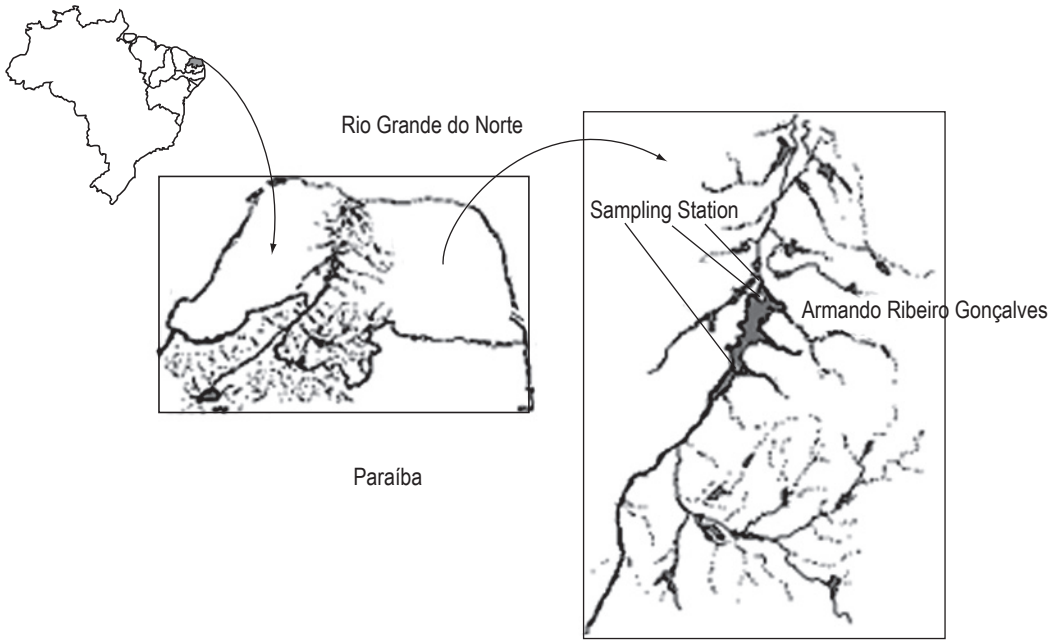


**Figure 2.** Piranhas-Assu river hydrographic basin and sampling stations.

Samples were collected on the surface, in the middle, and on the bottom of water column using a 0.5 L Van Dorn bottle. Subsamples were taken from integrated samples for analysis of bacterioplankton, total phosphorus, and chlorophyll-*a*. Water transparency was measured at each site using a 30 cm Secchi disk.

Total phosphorus was determined by colorimetry, using the method of ascorbic acid after digestion of the samples in potassium persulfate (APHA, 2000). For the extraction of chlorophyll-*a*, concentrated ethanol (90 to 95%) was used (Marker et al., 1980; Jespersen and Christoffersen, 1987).

*2.3. Bacterioplankton analyses*

Duplicated samples for bacterial analysis were fixed with tamponated formaldehyde (2%; pH 7.4). Subsamples (1 or 2 mL) were stained with acridine orange (0.01%) (Hobbie et al., 1977) and filtered in a black polycarbonate membrane filter (Millipore, GTBP; 0.2 µm pore size), using a support filter (Poretics; 0.45 µm) to distribute the samples uniformly. Filters were mounted between the cover and the coverslip, covered with a non-fluorescent immersion oil and counted in an epifluorescence microscope (Olympus BX41; magnification x1250; dichroic mirror DM500; excitement filter BP460-490 and barrier filter BA520IF). At least 300 bacterial cells were counted in each filter in 15 to 20 microscopical fields. Length and width of cells were obtained with a micrometric ocular. The bacteria were classified in four groups, on the basis of their morphology: coccid, rods, vibrios, and filaments. The cellular volumes were calculated through the formula: $(\pi/4) \times [W^2 \times (L - (W/3))]$, where W is width and L is the length of the cell. For the coccid cells, W=L (Bratbak, 1993). An allometric conversion formula was used in the calculation of the cellular carbon content: CC (fgC) = $120. V^{0.72}$, where: CC = carbon content and V = cellular volume ($\mu m^3$). This formula, proposed by Simon and Azam (1989) and modified by Norland (1993), was considered by Posch et al. (2001) to be better adjusted to cells dyed with acridine orange.

*2.4. Trophic state in the dam*

Total phosphorus and chlorophyll *a* concentrations and water transparency in the dam were used to compute the OECD (Organization for Economic Cooperation and Development) indexes (Tundisi et al., 1988), Trophic State Indexes (TSI; Carlson, 1977), and the TSI indexes (Cullen and Small, 1981).

*2.5. Statistical analysis*

Pearson correlation matrices were constructed to determine the relations between different biotic and abiotic variables. The *t*-test was used to show significant differences ($p < 0.05$) in the variables of reservoir and river between the dry and rainy periods.

## 3. Results

*3.1. Bacterioplankton*

Total bacterial density varied significantly between the dry and rainy periods ($p = 0.0025$). It was slightly higher in the lentic than in the lotic environments. Mean numbers of

organisms per mL of sample ranged from 1.85 to 2.45 x $10^7$ in the river and, from 1.95 to 3.17 x $10^7$ in the reservoir.

Bacterial morphotypes density did not vary significantly among sampling sites, but evident fluctuations occurred between dry and rainy periods. Cocci cells were numerically predominant at all the stations, affecting considerably the total abundance of bacterioplankton. The rods were the second most abundant group, followed by filaments and vibrios (Figure 3). The cocci and vibrio bacteria densities did not vary significantly; on the other hand, rods and filaments presented a strong temporal variation, ($p = 0.006$) and ($p = 0.0047$), respectively.

In both systems, the bacteria amount was higher in the rainy period (Figure 4), when the chlorophyll *a* and total phosphorus concentrations were lower. During the drought, when the bacterial abundance was lower, the concentrations of chlorophyll *a* and total phosphorus were higher. A positive correlation was found between these two variables in the dry period ($r = 0.94$; $p \leq 0.05$).

Mean values of bacterial biomass are shown in Figure 5. Filaments predominated and, influenced remarkably the high values of total biomass. Cocci, rods, and vibrio biomass ranged from 47.0 to 122.9 μgC.$L^{-1}$, and for the filament the oscillation was from 629.4 to 1,295.7 μgC.$L^{-1}$. These means were higher during the drought.

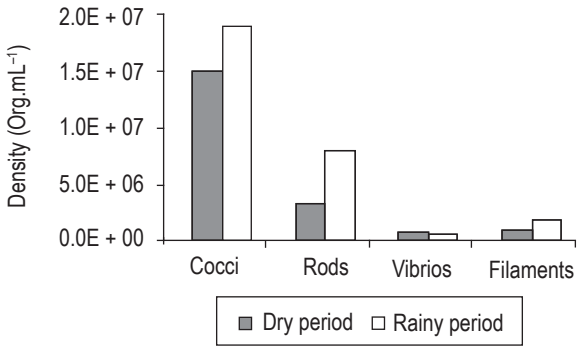


**Figure 3.** Bacterial morphotype density means in dry and rainy periods.

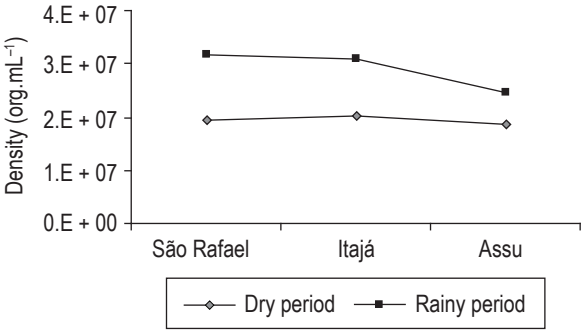


**Figure 4.** Total density of bacterioplankton in the three sampling sites.

Cocci biomass varied between 31.7 and 75.3 μgC.$L^{-1}$ and had the lower means among the bacterial morphotypes in the three sampling stations, in spite of appearing with higher density values. The opposite occurred with the filaments, which, despite their lower densities, presented the highest biomass values, reaching 1,734.1 μgC.$L^{-1}$ due to their high cellular volumes. Filament biomass varied significantly between the dry and rainy periods ($p = 0.0011$) and the same occurred for the rod ($p = 0.0099$) and vibrio biomasses ($p = 0.0015$).

### *3.2. Total Phosphorus, chlorophyll a, and water transparency*

During the sampling periods, total phosphorus and chlorophyll *a* concentrations and water transparency values were above the Trophic State Indexes (TSI) presented by Carlson (1977), and Cullen and Small (1981) to eutrophic aquatic environments, thus indicating eutrophic or hypereutrophic levels in Engenheiro Armando Ribeiro Gonçalves reservoir.

Total phosphorus varied from 41.3 to 91.3 μg.$L^{-1}$ in the rainy period and from 99.7 to 108.0 μg.$L^{-1}$ in the dry period ($p = 0.0009$). Chlorophyll-*a* concentrations were between 39.6 and 70.7 μg.$L^{-1}$ during the drought and between 25.3 and 47.9 μg.$L^{-1}$ in the rainy period. Water transparency was lower in the dry period ($p = 0{,}0028$), coinciding with the occurrence of stronger winds and high levels of total phosphorus and chlorophyll-*a* at this time. Means, standard deviations, and *t*-test values of the measured variables are shown in Table 2.

## 4. Discussion

The bacterial density found in this study ($10^7$ org.$mL^{-1}$) was higher than the values presented by Bouvy et al. (1998) for seven reservoirs in northeastern Brazil and it is among the highest cited by studies carried out in freshwater systems (Jugnia et al., 1998). Generally, the bacterial densities range between $10^5$ and $10^8$ organisms.$mL^{-1}$ and increase according to trophic state of the environment (Bouvy et al.,

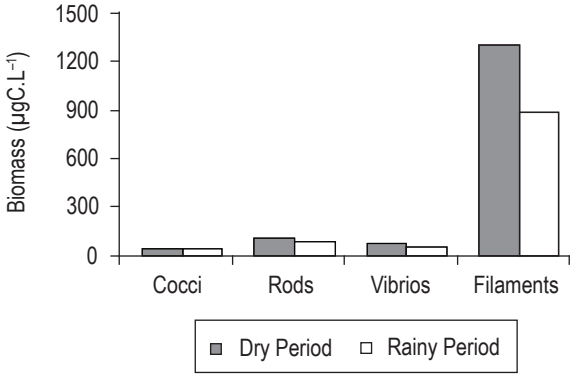


**Figure 5.** Biomass of bacterial morphotypes in dry and rainy periods.

**Table 2.** *t*-Test comparing the variables in dry and rainy periods.

| *t*-Test | Dry period | | Rainy period | | t value | p value |
|---|---|---|---|---|---|---|
| | mean | SD | mean | SD | | |
| Total density (org.mL$^{-1}$) | 1.93E + 07 | 9.04E + 06 | 3.03E + 07 | 9.17E + 06 | –3.327 | 0.0025* |
| Cocci density (org.mL$^{-1}$) | 1.48E + 07 | 1.05E + 06 | 1.88E + 07 | 5.53E + 06 | –1.748 | 0.11 |
| Rod density (org.mL$^{-1}$) | 3.17E + 06 | 4.16E + 05 | 7.83E + 06 | 3.26E + 06 | –3.467 | 0.006* |
| Vibrio density (org.mL$^{-1}$) | 6.06E + 05 | 4.75E + 05 | 5.49E + 05 | 3.29E + 05 | 0.243 | 0.81 |
| Filament density (org.mL$^{-1}$) | 7.53E + 05 | 3.61E + 05 | 1.75E + 06 | 5.71E + 05 | –3.620 | 0.0047* |
| Total biomass (µg C.L$^{-1}$) | 1,310.4 | 327.6 | 895.5 | 248.2 | 3.909 | 0.0005* |
| Cocci biomass (µg C.L$^{-1}$) | 49.1 | 8.3 | 49.0 | 15.7 | 0.026 | 0.98 |
| Rod biomass (µg C.L$^{-1}$) | 114.3 | 20.4 | 95.0 | 17.8 | 2.767 | 0.0099* |
| Vibrio biomass (µg C.L$^{-1}$) | 76.1 | 18.4 | 58.0 | 7.5 | 3.524 | 0.0015* |
| Filament biomass (µg C.L$^{-1}$) | 1,070.9 | 317.3 | 693.5 | 246.1 | 3.639 | 0.0011* |
| Total Phosphorus (µg.L$^{-1}$) | 102.3 | 4.1 | 77.0 | 19.8 | 3.955 | 0.0009* |
| Chlorophyll *a* (µg.L$^{-1}$) | 53.9 | 12.4 | 43.1 | 14.5 | 1.777 | 0.092 |
| Water transparency (m) | 0.9 | 0.1 | 1.2 | 0.12 | –4.243 | 0.0028* |

* Significant ($p < 0.05$).

1998). The aquatic communities may change in quantity and quality as a result of the eutrophization unleashed by the growth of the discharge of domestic sewage in water bodies (Biudes and Camargo, 2006). The highest density values found in March can be attributed to the contribution of allochthonous matter introduced to the aquatic systems by the rains of February. The absence of significant spatial variation is linked to the proximity of lentic and lotic studied environments that are affected by the same types of effluents.

The fluctuations observed in composition and density of microorganism populations in aquatic ecosystems are the results of the interaction of several factors such as the available food, the presence of predators, parasites, the allochthonous sources of nutrients, and microorganisms brought by soil erosion and washing and, by effluents of human activities, in addition to the local physical and chemical conditions. The possible competition between organisms that live in the same environment must also be considered.

The competition between phytoplankton and bacterioplankton seems to be less favorable to the latter, because the phytoplankton is more able to take the phosphorus in aquatic ecosystems with high availability of light (Farjalla et al., 2001). This may have influenced a lower bacterial density during the dry period in the present study.

In the study of Rodrigues et al. (2002), the phytoplankton biomass, estimated as chlorophyll-*a,* presented an inverse relation with the water level. In that work, low pigment and nutrient concentrations were detected when the water level was higher.

Bacterial biomasses of present work (>1,700 µgC.L$^{-1}$) were very high in relation to the values published by Bouvy et al. (1998). These authors considered high the biomass ranging around 51 µgC.L$^{-1}$ in a eutrophic reservoir in the semi-arid region in northeastern Brazil. Kirschner and Velimirov (1997) found maximum value of 122 µgC.L$^{-1}$ in an aquatic environment in a temperate region. Erikson et al. (1999) and Farjalla et al. (2001) detected maximum biomass values of 930 µgC.L$^{-1}$ in Xolotlán Lake (Nicaragua), and 1,432 µgC.L$^{-1}$ in lagoons of Rio de Janeiro state, respectively. In a eutrophic lake of northeastern Poland, Kalinowska (2004) found bacterial biomass around 1,700 µgC.L$^{-1}$. Wille et al. (1999) found 15.3 µgC.L$^{-1}$ as the maximum value of bacterial biomass in an oligotrophic lake in Austria.

The high values of biomass in the present study can be associated with the high temperatures, such as it was also considered by Araújo and Godinho (2008) that detected strong correlations between the temperature and the bacterial cellular volume.

Total phosphorus values were higher than those published by Costa et al. (2006), who found 41.5 µg.L$^{-1}$ in the Armando Ribeiro Gonçalves Reservoir. High concentrations of total phosphorus are probably related to the nutrients input from human activities. Intensive use of fertilizers is responsible for the increase of the phosphorus concentrations (Santos et al., 2004). In addition, human activities along the Piranhas-Assu river basin contribute to the dam eutrophication (Costa et al., 2006).

Chlorophyll-*a* concentrations were lower than the range (from 71 to 110 µg.L$^{-1}$) detected by Costa et al. (1998) in the same reservoir that were related to the high cyanobacteria concentrations. According to Bouvy et al. (1998), Costa et al. (1998), Rodrigues et al. (2002), and Ribeiro et al. (2005), chlorophyll-*a* is linked to the phytoplankton presence, and its use to estimate the trophic state is recommended because the index is based directly on algal biomass (Matthews et al., 2002).

The low values of water transparency in the reservoir are due to the influence of the continuous transport of allochthonous matter by the river (Moschini-Carlos et al., 1998), and by sediment resuspension caused by wind ac-

tion (Araújo et al., 2000; Rodrigues et al., 2002; Becker and Motta Marques, 2004). Water transparency decrease in tropical aquatic ecosystems is also due to the high sediment leaching, which directly affects the light penetration (Moschini-Carlos et al., 1998; Guarino et al., 2005; Ribeiro et al., 2005).

In summary, quantitative variations in bacterial density and biomass were influenced by the precipitation and trophic state of the environment. The limnological conditions of both environments and the high densities and biomass of bacterioplankton indicated a high microbial activity probably affected by effluents from human activities.

Data analysis indicates the need of a frequent monitoring of the water quality in Piranhas-Assu river basin. The results can be used in the development of actions directed to the conservation of rivers and reservoirs, since those waters from the reservoir are very important for coastal populations.

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## References

American Public Health Association - APHA. *Standard methods for the examination of water and wastewater*. Washington, DC., 2000. 1365p.

ARAÚJO, MFF., COSTA, IAS. and CHELLAPPA, NT. Comunidade fitoplactônica e variáveis ambientais na lagoa de extremoz, Natal-RN, Brasil. *Acta Limnol. Bras.* 2000, vol. 12, p. 127-140.

ARAÚJO, MFF. and GODINHO, MJL. Seasonal and spatial distribution of bacterioplankton in a fluvial-lagunar system of a tropical region: density, biomass, cellular volume and morphologic variation. *Braz. Arch. Biol. Technol.* 2008, vol. 51, no. 1, p. 205-214.

AZAM, F., FENCHEL, T., FIELD, JG., GRAY, JS., MEYER-REIL, LA. and THINGSTAD, F. The ecological role of water-column microbes in the sea. *Mar. Ecol. Prog. Ser.* 1983, vol. 10, p. 257-263.

BECKER, V. and MOTTA MARQUES, D. Water dynamics, phytoplankton biomass and size structure of a shallow freshwater subtropical lake (Itapeva Lake, south of Brazil). *Acta Limnol. Bras.* 2004, vol. 16, no. 2, p. 163-174.

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, no. 2, p. 303-311.

BIUDES, JFV. and CAMARGO, AFM. Changes in biomass, chemical composition and nutritive value of *Spartina alterniflora* due to organic pollution in the Itanhaém river basin (SP, Brazil). *Braz. J. Biol.* 2006, vol. 66, no. 3, p. 781-789.

BOUVY, M., BARROS-FRANCA, LM. and CARMOUZE, JP. Compartimento microbiano no meio pelágico de sete açudes do estado de Pernambuco. *Acta Limnol. Bras*. 1998, vol. 10, no. 1, p. 93-101.

BRATBAK, G. Microscopic methods for measuring bacterial: epifluorescence microscopy, scanning electron microscopy and transmission electron microscopy. In Kemp, PF., Sherr, BF., Sherr, EB. and Cole, JJ. (Eds.). *Handbook of methods in aquatic microbial ecology.* London: Lewis Publishers, 1993. p. 309-317.

CARLSON, RE. A trophic state index for lakes. *Limnol. Oceanogr.* 1977, vol. 22, p. 361-380.

COSTA, IAS., ARAÚJO, MFF. and CHELLAPPA, NT. Estudo do fitoplâncton da barragem engenheiro Armando Ribeiro Gonçalves, Assu/RN. *Acta Limnol. Bras.* 1998, vol. 10, no. 1, p. 67-80.

COSTA, IAS., AZEVEDO, SMFO., SENNA, PAC., BERNARDO, RR., COSTA, SM. and CHELLAPPA, NT. Occurrence of toxin-producing cyanobacteria blooms in a Brazilian semi-arid reservoir. *Braz. J. Biol.* 2006, vol. 66, no. 1B, p. 211-219.

CULLEN, P. and SMALL, I. Eutrophication in semi-arid areas: the Australian experience. *Water Qual. Bull.* 1981, vol. 6, p. 79-83.

EILER, A. and BERTILSSON, S. Composition of freshwater bacterial communities associated with cyanobacterial blooms in four Swedish lakes. *Environ. Microbiol.* 2004, vol. 6, no. 12, p. 1228-1243.

ERIKSON, R., VAMMEN, K., ZELAYA, A. and BELL, R. Distribution and dynamics of bacterioplancton production in a polymitic tropical lake (Xolotlán Lake, Nicaragua). *Hydrobiologia,* 1999, vol. 382, p. 27-39.

FARJALLA, VF., FARIA, BM., ESTEVES, FA. and BOZELLI, RL. Bacterial density and biomass, and relations with abiotic factors in 14 coastal lagoons of Rio de Janeiro state. *Oecol. Brasil*. 2001, vol. 9, no. IX, p. 65-76.

GUARINO, AWS., BRANCO, CWC., DINIZ, GP. and ROCHA, R. Limnological characteristics of an old tropical reservoir (Ribeirão das Lages Reservoir, RJ, Brazil). *Acta Limnol Bras.* 2005, vol. 17, no. 2, p. 129-141.

GURUNG, TB., URABE, J., NOZAKI, K., YOSHIMIZU, C. and NAKANISHI, M. Bacterioplankton production in a water column of Lake Biwa. *Lakes and Reservoirs: Res. Manag.* 2002, vol. 7, no. 4, p. 317-323.

HOOBIE, JE., DALEY, RJ. and JASPER, S. Use of Nuclepore filters for counting bacteria by fluorescence microscopy. *Environ. Microbiol.* 1977, vol. 33, no. 5, p. 1225-1228.

JESPERSEN, AM. and CHRISTOFFERSEN, K. Measurements of chlorophyll-a from phytoplankton using ethanol as extraction solvent. *Arch. Hydrobiol.* 1987, vol. 109, no. 3, p. 445-454.

JUGNIA, LB., TADANLÉKÉ, RD., SIME-NGANDO, T., FOTO, SM. and KEMKA, N. Short-term variations in the

abundance and cell volume of bacterioplankton in an artificial tropical lake. *Hydrobioogia,* 1998, vol. 385, p. 113-119.

KALINOWSKA, K. Bacteria, nanoflagellates and ciliates as components of the microbial loop in three lakes oh different trophic status. *Pol. J. Ecol.* 2004, vol. 52, no. 1, p. 19-34.

KIRSCHNER, AKT. and VELIMIROV, B. A seasonal study of bacterial community succession in a backwater system, indicated by variation in morphotype numbers, biomass and secondary production. *Microb. Ecol.* 1997, vol. 34, no. 1, p. 27-38.

LEWIS, WM., FROST, T. and MORRIS, D. Studies of planktonic bacteria in lake Valencia, Venezuela. *Arch. Hydrobiol.* 1986, vol. 106, p. 289-305.

LINDSTROM, ES. Investigating influential factors on bacterioplankton community composition: results from a field study of five mesotrophic lakes. *Microb. Ecol.* 2001, vol. 42, no. 4, p. 598-605.

LINDSTROM, ES. and BERGSTROM, AK. Community composition of bacterioplankton and cell transport in lakes in two different drainage areas. *Aquat. Sci.* 2005, vol. 67, no. 2, p. 210-219.

LIU, J. and LEFF, LG. Temporal changes in the bacterioplankton of a northeast Ohio (USA) river. *Hydrobiologia,* 2002, vol. 489, no. 1-3, p. 151-159.

MARKER, AFH., NUSCH, EA., RAI, H. and REIMAN, B. The measurements of photosynthetic pigments in freshwater and standardization of methods: conclusions end recommendation. *Arch. Hydrobiol.* 1980, vol. 14, p. 91-106.

MATTHEWS, R., HILLES, M. and PELLETIER, G. Determining trophic state in Lake Whatcom, Washington (USA), a soft water lake exhibiting seasonal nitrogen limitation. *Hydrobiologia,* 2002, vol. 468, p. 107-121.

MOSCHINI-CARLOS, V., POMPÊO, MLM. and HENRY, R. Caracterização limnológica de uma bacia marginal ao rio Paranapanema (zona de desembocadura na represa de jurumirim, SP). *Acta Limnol. Bras.* 1998, vol. 10, p. 1-19.

NORLAND, S. The relationship between biomass and volume of bacteria. In: Kemp, PF., Sherr, BF., Sherr, EB. and Cole, JJ. (Eds.). *Handbook of methods in aquatic microbial ecology.* London: Lewis Publishers, 1993. p. 303-307.

POSCH, T., LOFERER-KRÖßBACHER, M., GAO, G., ALFREIDER, A., PERNTHALER, J. and PSENNER, R. Precision of bacterioplancton biomass determination: a comparison of two fluorescent dyes, and of allometric and linear volume-to-carbon conversion factors. *Aquat. Microb. Ecol.* 2001, vol. 25, no. 1, p. 55-63.

PROENÇA, CNO., MEDEIROS, YDP. and CAMPOS, VP. *Metodologia para definição de parâmetros de qualidade da água visando o enquadramento de corpos d'água em região semi-árida – UFBA.* Salvador: Departamento de Hidráulica e Saneamento – DHS, 2003. Grupo de Recursos Hídricos – GRH. Plano de Gerenciamento Integrado da Bacia do Rio Salitre. ANA/GEF/PNUMA/OEA. Relatório Final.

REGALI-SELEGHIM, MH. *Flutuações nas comunidades planctônicas e bentônicas de um ecossistema artificial raso (Represa Monjolinho – São Carlos – SP), com ênfase nas populações de protozoários e bactérias.* São Carlos: Universidade Federal de São Carlos – UFSCar, 1992. Dissertação de Mestrado.

RIBEIRO, LHL., BRANDIMARTE, AL. and KISHI, RT. Formation of the Salto Caxias reservoir (PR) – an approach on the eutrophication process. *Acta Limnol. Bras.* 2005, vol. 17, no. 2, p. 155-165.

RODRIGUES, LC., TRAIN, S., ROBERTO, MC. and PAGIORO, TA. Seasonal fluctuation of some limnological variables on a floodplain lake (Patos lagoon) of the upper Paraná river, Mato Grosso do Sul state, Brazil. *Braz. Arch. Biol. Technol.* 2002, vol. 45, no. 4, p. 499-513.

ROSADO, AS. and DUARTE, GF. Utilização de eletroforese em gel com gradiente de desnaturantes (DGGE) e gel com gradiente de temperatura (TGGE) para estudar diversidade microbiana. In Mello, IS. (Ed.). *Genética e Melhoramento de Microorganismos.* São Paulo: EdUSP, 2002.

SANTOS, LR., BAISCH, P., LIMA, GTNP. and SILVA FILHO, EV. Nutrients in surface sediments of Mirim lagoon, Brazil-Uruguay border. *Acta Limnol. Bras*. 2004, vol. 16, no. 1, p. 85-94.

SIMON, M. and AZAM, F. Protein content and protein synthesis rates of planktonic marine bacteria. *Mar. Ecol. Prog. Ser.* 1989, vol. 51, p. 201-213.

SOARES, NSC., CEBALLOS, BSO., OLIVEIRA, EM. and KÖNIG, A. Distribuição espaço temporal de bactérias indicadoras de contaminação e vírus num riacho do Trópico Semi-Árido. In *Anais do 21º Congresso Brasileiro de Engenharia Sanitária e Ambiental*, 2001. João Pessoa: ABES, 2001. p. 1-10.

TUNDISI, JG., MATSUMURA-TUNDISI, T., HENRY, R., ROCHA, O. and HINO, K. Comparação do estado trófico de 23 reservatórios do estado de São Paulo: eutrofização e manejo. In Tundisi, JG. (Ed.). *Limnologia e manejo de represas*. São Paulo: Academia de Ciências, 1988. p. 165-203.

WILLE, A., SONNTAG, B., SATTLER, B. and PSENNER, R. Abundance, biomass and size structure of the microbial assemblage in the high mountain lake Gossenköllesee (Tyrol, Austria) during the ice-free period. *J. Limnol*. 1999, vol. 58, no. 2, p. 117-126.

YOUNG, JPW. *Major microbial diversity initiative recommended*. Local de publicação: ASM News, 1997. p. 417-421.

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