

EXPERIMENTAL EVIDENCE OF THE EFFECT OF NUTRIENT ENRICHMENT ON THE ZOOPLANKTON IN A BRAZILIAN COASTAL LAGOON

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(With 3 figures)

ABSTRACT

Non-treated sewage disposal is one of the main impacts to which Imboassica Lagoon has been subjected. The aim of this study was to evaluate the effect of a potential increase in the artificial enrichment on the environmental conditions and zooplankton of this system. To this end, an experimental study was conducted in mesocosms where nutrients were added daily. Bacterial numbers, chlorophyll-*a*, and picoplanktonic cyanobacteria densities showed an increase with the availability of nutrients. Bacterio- and phytoplankton seemed to be regulated by the rotifers *Brachionus rotundiformis* and *Hexarthra brandorffi*.

Key words: coastal lagoon, enrichment, zooplankton.

RESUMO

Evidência experimental do efeito do enriquecimento por nutrientes sobre o zooplâncton em uma lagoa costeira brasileira

O despejo de esgoto não tratado é um dos principais impactos aos quais a Lagoa Imboassica está submetida. O objetivo deste estudo foi avaliar o efeito de um aumento potencial no enriquecimento artificial das condições ambientais e do zooplâncton desse sistema. Para tanto, foi realizado estudo experimental em mesocosmos aos quais foram adicionados nutrientes diariamente. O número de bactérias e de cianobactérias picoplanctônicas e a clorofila-*a* apresentaram aumento com a disponibilidade de nutrientes. Bacterio- e fitoplâncton parecem ter sido regulados pelos rotíferos *Brachionus rotundiformis* e *Hexarthra brandorffi*.

Palavras-chave: lagoa costeira, enriquecimento, zooplâncton.

INTRODUCTION

As a consequence of the input of nutrients, inorganic and organic material, relative shallowness, high penetration of solar radiation, and frequent water column mixing, coastal lagoons usually present high rates of primary and secondary productivities (Kjerfve, 1994; Castel *et al.*, 1996). Such ecosystems cover approximately 13% of coastal areas worldwide and in Brazil they occur almost all along the

coastline from the State of Rio Grande do Sul to the State of Maranhão (Schäfer, 1992).

A series of coastal lagoons located in the State of Rio de Janeiro (Brazil) has been altered during the five past decades as a consequence of various human influences (Carmouze & Vasconcelos, 1992). Non-treated sewage disposal is usually the most important disturbance. This provides the environment with excess nutrients (especially phosphorus and nitrogen), which may

enhance the eutrophication process, in several cases leading to massive phytoplanktonic development and the occurrence of dystrophic crises (Faria, 1993; Suzuki, 1997). Such crises are a result of intense biological, physical, and chemical imbalance and culminate in system anoxia. This causes a temporary disappearance of aquatic organisms (Faria, 1993).

Imboassica Lagoon, located in the city of Macaé (22°24'S, 41°42'W), northern Rio de Janeiro State, receives daily approximately 65 kg of nitrogen and 7 kg of phosphorus through its main sewage canal (Lopes-Ferreira, 1995). According to this author, the dense littoral zone situated at the canal outlet is able to reduce at least 93% of the nitrogen and phosphorus concentrations in the water column before reaching the lagoon. However, expanding urbanization in this area may lead to increased nutrient input in Imboassica Lagoon.

An enrichment experiment was conducted to evaluate the short-term outcome of nutrient load increase in Imboassica Lagoon, based on an expected reduction of macrophyte depuration capability. The purpose was to investigate the alterations in water quality and the zooplanktonic community as a predictive measure providing subsidies for future management strategies.

MATERIALS AND METHODS

Experimental setup

Six transparent 0.6 mm polyethylene enclosures, open to the atmosphere and sediment, with the following dimensions: 1.0 m height; 1.0 m width and 1.4 depth, were built in a wind-protected area in Imboassica Lagoon. They were organized for two treatments: (C) control, in which there was no nutrient addition and (E) enriched, in which there was a daily addition of 28 μM of N in ammonium form and 0.5 μM of P in orthophosphate form. These concentrations were calculated taking into account values observed by Lopes-Ferreira (1995) and others occasionally verified in Imboassica Lagoon during sandbar openings (Faria *et al.*, 1998), when dilution is reduced and nutrient concentration in the water column is increased.

Sampling and laboratory analyses

The experiment was carried out for seven days (October 27 to November 2, 1996) and samples were collected inside the enclosures and in a nearby open-water station. The first sampling was done on the first day (one day after the enclosures were built). The second sampling occurred on the same day following nutrient addition in order to verify its efficiency. The other samplings were carried out on the second day, the fourth day and the seventh day, always prior to the daily nutrient addition.

At the open-water station and in the enclosures, temperature was measured at the surface and bottom of the water column and transparency was estimated with a Secchi disc. Water samples were collected along the entire water column (from the surface to the bottom) for posterior analyses, at the field station laboratory, for the following abiotic variables: pH and electrical conductivity measured potentiometrically; total alkalinity according to Gran (1952); salinity estimated with a salinometer-refractometer; and dissolved oxygen according to Winkler's method as modified by Golterman *et al.* (1978). Water samples were filtered on GF-C filters, which were used for suspended matter and chlorophyll-*a* determinations. Aliquots of non-filtered and filtered water samples were frozen for subsequent analyses. Total and dissolved Kjeldahl nitrogen (TkN and DkN) followed Mackereth *et al.* (1978); nitrate plus nitrite ($\text{NO}_3^- + \text{NO}_2^-$) were determined by flow injection using the cadmium reduction method described in Zagatto *et al.* (1981). Ammonium (NH_4^+) was determined according to Koroleff (1976). Total phosphorus and total dissolved phosphorus (TP and TDP), orthophosphate (PO_4^{3-}), and soluble reactive silica (Si) were measured according to methods described in Golterman *et al.* (1978). Dissolved organic carbon (DOC) was quantified in a Total Organic Carbon Analyser (Shimadzu TOC-5000).

Samples of the entire water column were also obtained for enumerating bacterio- and phytoplankton. Samples for bacterial analysis were preserved with 2% buffered and filtered formaldehyde and estimated using a flow cytometer (FAC Sort, Becton Dickison) according to the protocol

described in del Giorgio *et al.* (1996). Phytoplankton samples from the initial and final sampling days were preserved with a lugol solution and counted in sedimentation chambers under an inverted microscope. Chlorophyll-*a* content was determined spectrophotometrically after extraction with 80% ethanol (Nusch & Palme, 1975).

Zooplankton samples were obtained from the entire water column with the use of a pump, filtered through a 68 μm plankton net, and preserved with a 4% buffered sucrose formaldehyde solution. Small-bodied organisms (rotifers, naupliar forms, and larvae of some meroplanktonic organisms) were counted in Sedgewick-Rafter cells under an optic microscope. Larger organisms (cladocerans, and juvenile and adult forms of copepods) were enumerated in open chambers under a stereoscopic microscope.

Data analysis

Individual Contrast Multivariate Analysis of Variance (MANOVA; Wilks' λ statistics) (von Ende, 1993) was used to test alterations in the values of the response variables (abiotic and biotic) as a function of nutrient additions and time (C x E and T in Table 1). In the case of a significant result, variance analyses (ANOVA; F statistics) were done for successive sampling dates separately (von Ende, 1993). These statistical analyses were conducted with log ($x + 1$) transformed data. Spearman rank correlation was used to detect relations among variables in the enriched treatment.

RESULTS

There was no significant difference (MANOVA, $p > 0.05$) between control and enriched enclosures or any time effect for the following abiotic variables: pH, ammonium, nitrate + nitrite, soluble reactive silica, total dissolved and total phosphorus, total Kjeldahl nitrogen, dissolved organic carbon, and TN:TP (Table 1).

It was not possible to test statistical differences in water transparency, salinity, and orthophosphate, as there was no variance in the values within and/or between groups. In the case of orthophosphate, some of the values fell beneath the detection limit of the analytical method used.

There was no overall statistical difference between treatments for ammonium and orthophosphate concentrations, even though higher values were obtained for the enriched enclosures than for the controls, especially on the first day after nutrient addition (data not shown), and on the second and fourth sampling dates (Fig. 1). The average ammonium and orthophosphate concentrations measured after nutrient addition were 27.21 μM and 0.15 μM , respectively. The concentration of ammonium corresponded to approximately the aimed-at value (28 μM), whereas that of orthophosphate was 3.5 times inferior to the expected value.

Even though the average value of dissolved Kjeldahl nitrogen was higher for the enriched enclosures than for the controls (MANOVA, $p < 0.000$, Table 1), analysis of variance conducted on successive sampling dates was not able to detect significant differences (ANOVA, $p > 0.05$).

The highest mean value of the bacterial density was detected on the fourth day for the enriched enclosures (Fig. 2). No statistical difference was, however, observed between treatments or among sampling dates (MANOVA, $p > 0.05$). For the enriched enclosure, in which the highest bacteria number occurred, we simultaneously observed the highest chlorophyll-*a* and dissolved oxygen values. Overall bacterioplankton density showed a positive correlation with dissolved oxygen ($r = 0.69$, $p < 0.02$) and a negative correlation with TN:TP values ($r = -0.70$, $p < 0.02$).

Even though there was no significant difference between enriched and control enclosures or any time effect for chlorophyll-*a* (MANOVA, $p > 0.05$, Table 1), a peak concentration of this variable was observed in the enriched treatment on the fourth day (Fig. 2) when the mean chlorophyll-*a* concentration presented a 259% increase when compared to the initial sampling. Chlorophyll-*a* values showed a positive correlation with the concentrations of orthophosphate ($r = 0.59$, $p < 0.05$), total dissolved phosphorus ($r = 0.58$, $p < 0.05$), and total phosphorus ($r = 0.77$, $p < 0.01$). Dissolved oxygen concentration and picoplanktonic cyanobacterial density also presented a positive relation with chlorophyll-*a* values ($r = 0.65$, $p < 0.05$ and $r = 0.89$, $p < 0.05$, respectively), while a negative relation between them and TN:TP was observed ($r = -0.79$; $p < 0.01$).

TABLE 1

Mean values and standard deviations (in parentheses) of the abiotic and biotic variables measured in the open water station in Imboassica Lagoon, in the control (C) and in the enriched (E) enclosures from October to November 1996. SV = source of variation; Wilks' λ is the MANOVA statistics used and p = probability values.

Variable	Lagoon	Control	Enriched	SV	Wilks' λ	p
Temperature (°C)	24.90 (0.35)	25.25 (0.33)	25.12 (0.33)	C x E	0.434	0.575
				T	0.032	0.047
pH	8.24 (0.15)	8.19 (0.15)	8.07 (0.24)	C x E	0.386	0.519
				T	0.300	0.414
Alkalinity (mEq. L ⁻¹)	1.59 (0.11)	1.64 (0.19)	1.62 (0.23)	C x E	0.301	0.416
				T	0.008	0.012
Secchi (m)	1.10 (0.04)	1.02 (0.02)	0.95 (0.10)	C x E	–	–
				T	–	–
Conductivity (mS.cm ⁻¹)	8.93 (0.13)	9.76 (0.18)	9.77 (0.24)	C x E	0.770	0.890
				T	0.010	0.015
Salinity (u.s.)	5.50 (0.58)	5.50 (0.52)	5.58 (0.51)	C x E	–	–
				T	–	–
O ₂ (mg.L ⁻¹)	8.97 (0.85)	8.34 (0.48)	7.89 (1.31)	C x E	0.065	0.110
				T	0.007	0.010
SM (mg.L ⁻¹)	14.60 (1.82)	13.52 (1.22)	14.44 (1.51)	C x E	0.184	0.264
				T	0.013	0.020
NH ₄ ⁺ (μM)	1.45 (0.45)	1.06 (0.96)	24.48 (19.05)	C x E	0.107	0.156
				T	0.069	0.101
NO ₃ ⁻ + NO ₂ ⁻ (μM)	0.71 (0.17)	0.78 (0.18)	0.95 (0.17)	C x E	0.391	0.525
				T	0.221	0.313
Si (μM)	129.23 (9.56)	116.19 (17.42)	124.31 (15.19)	C x E	0.164	0.277
				T	0.117	0.170
PO ₄ ³⁻ (μM)	ND – 0.13 *	ND – 0.10 *	ND – 0.24 *	C x E	–	–
				T	–	–
TDP (μM)	0.17 (0.15)	0.16 (0.10)	0.33 (0.16)	C x E	0.075	0.111
				T	0.206	0.292
TP (μM)	0.46 (0.15)	0.52 (0.25)	0.84 (0.45)	C x E	0.060	0.088
				T	0.063	0.093

TABLE 1 (continued)

Variable	Lagoon	Control	Enriched	SV	Wilks' λ	p
DkN (μM)	24.75 (4.27)	27.00 (5.29)	44.20 (13.29)	C x E	0.000	0.000
				T	0.000	0.000
TkN (μM)	35.11 (3.75)	32.75 (4.69)	51.80 (15.99)	C x E	0.040	0.059
				T	0.055	0.082
DOC (mM)	0.97 (0.27)	1.00 (0.16)	1.12 (0.08)	C x E	0.352	0.479
				T	0.556	0.704
TN:TP	88.85 (44.78)	84.02 (52.35)	73.44 (29.39)	C x E	0.272	0.378
				T	0.154	0.221
Bacterioplankton (cells.ml ⁻¹)	2.8 x 10 ⁶ (3.5 x 10 ⁵)	3.7 x 10 ⁶ (2.3 x 10 ⁶)	3.9 x 10 ⁶ (1.8 x 10 ⁶)	C x E	0.109	0.159
				T	0.098	0.143
Chlorophyll- <i>a</i> ($\mu\text{g. L}^{-1}$)	3.88 (1.66)	3.35 (1.06)	5.52 (4.11)	C x E	0.280	0.390
				T	0.282	0.391
Phytoplankton (ind.ml ⁻¹)	2.1 x 10 ⁴ (8.1 x 10 ³)	2.0 x 10 ⁴ (5.1 x 10 ³)	2.8 x 10 ⁴ (2.0 x 10 ⁴)	C x E	0.853 #	0.408
				T	5.784 #	0.074
				C x E x T	0.777 #	0.428
Zooplankton (ind.m ⁻³)	1.1 x 10 ⁶ (6.7 x 10 ⁵)	1.4 x 10 ⁶ (7.2 x 10 ⁵)	1.7 x 10 ⁶ (7.3 x 10 ⁵)	C x E	0.087	0.128
				T	0.029	0.044

* Minimum–maximum values; # ANOVA: F values.

Cyanophyceae, Cryptophyceae, Dinophyceae, Chrysophyceae, Bacillariophyceae, Zygnemaphyceae, and Chlorophyceae constituted the phytoplankton community in Imboassica Lagoon. It was numerically dominated by picoplanktonic cyanobacteria of the *Synechocystis* and *Synechococcus* genera, which represented at least 62% of the total phytoplankton density. The lowest (62%) as well the highest (96%) contribution of this group to the

entire phytoplankton community was observed in enriched enclosures. Cyanobacteria were also the dominant group in the control enclosures and open water station.

There was no nutrient or time effect upon the phytoplankton numbers (ANOVA, $p > 0.05$, Table 1). In the enriched enclosures phytoplankton density was positively related to that of the cyanobacteria ($r = 0.89$, $p < 0.02$) and to pH ($r = 0.89$, $p < 0.02$).

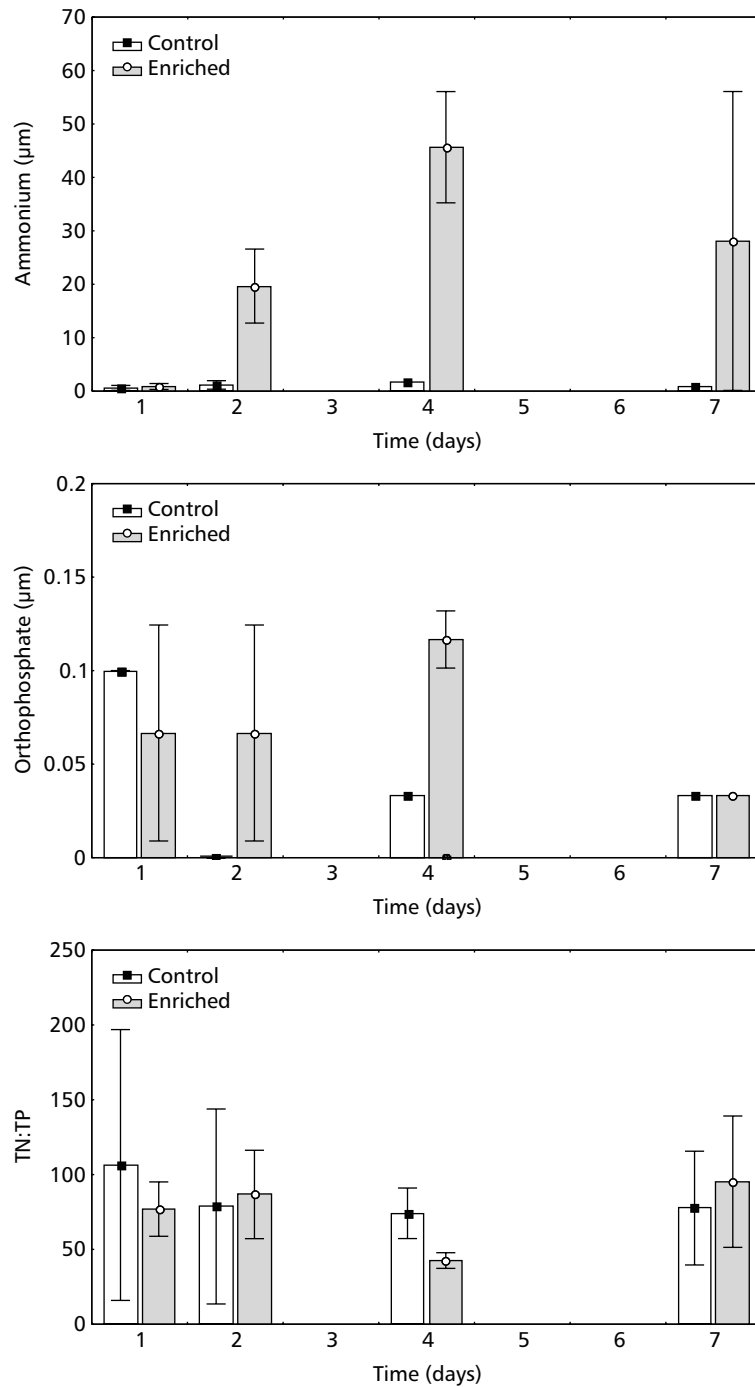


Fig. 1 — Mean (column) and standard deviation ± 1 (bars) of ammonium, orthophosphate concentrations, and TN:TP values in the control (filled squares) and enriched (open circles) enclosures.

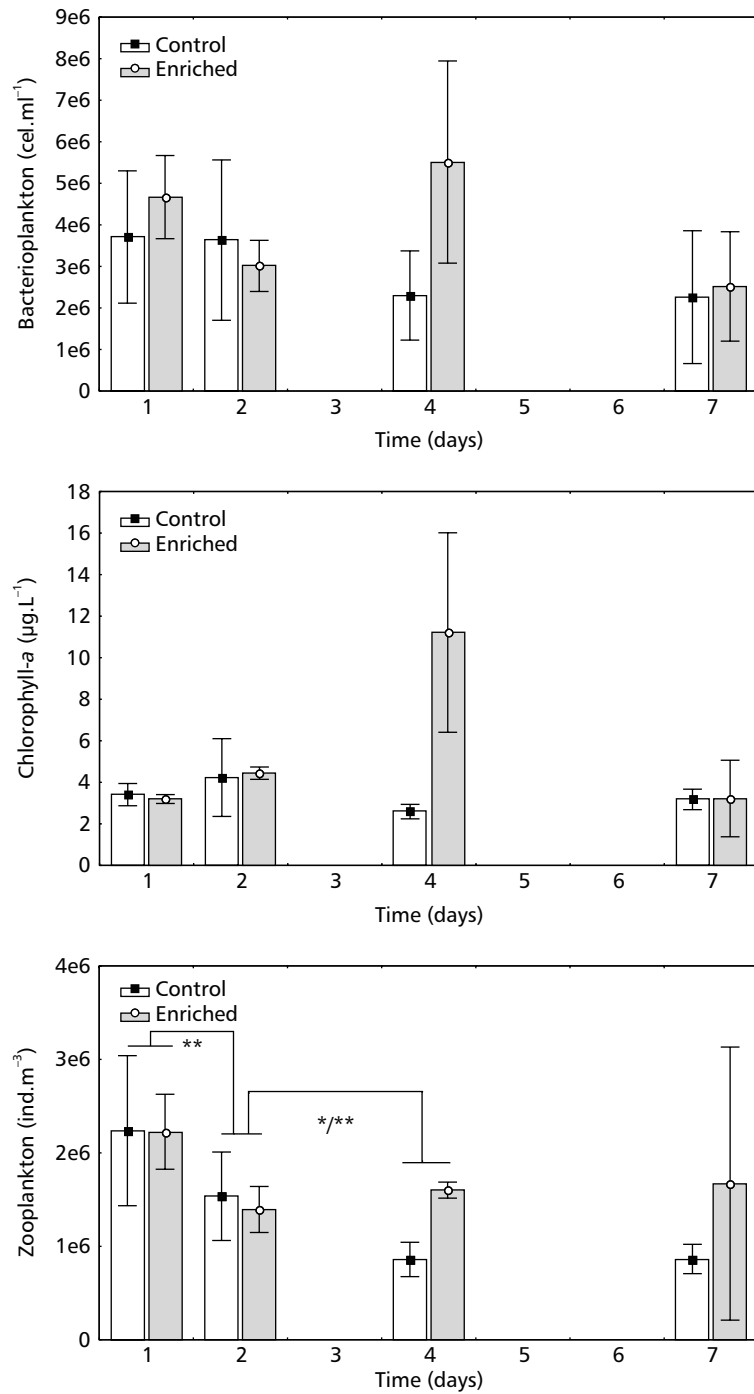


Fig. 2 — Mean (column) and standard deviation ± 1 (bars) of total bacterioplankton density, chlorophyll-*a* concentration, and total zooplankton density in the control (filled squares) and enriched (open circles) enclosures. (*) $p < 0.05$; (**) $p < 0.001$.

There was no difference in Cyanophyceae density between treatments (ANOVA, $p > 0.05$). On the last day of the experiment, in one of the enriched enclosures there was an accentuated reduction in cyanobacteria density, together with an increase in flagellate (*Rhodomonas*) numbers. Besides their positive relation with chlorophyll-*a* and total phytoplankton density, cyanobacteria were also associated with pH ($r = 0.89$, $p < 0.02$).

The zooplankton was composed of 26 taxa (Table 2) represented by holoplanktonic (6 species of rotifers, 4 of cladocerans, and 3 copepod taxa and their naupliar and juvenile forms) and meroplanktonic organisms.

In general, no significant difference in total zooplankton density as a function of the enrichment was observed, (MANOVA, $p > 0.05$, Table 2). A significant time effect was, however, noted (MANOVA, $p < 0.05$, Table 1). A significant decrease was observed from the first to the second day (ANOVA, $p < 0.01$, Fig. 2), although treatments did not differ (ANOVA, $p > 0.05$). From the second to the fourth day, there was a reduction in the average zooplankton density in the controls and, simultaneously, zooplankton density was higher in the enriched treatment (ANOVA, $p < 0.01$, Fig. 2).

No enrichment or time effect was observed on the Calanoida, Cyclopoida and Cirripedia nauplii, Calanoida copepodites, Gastropoda veligers, and Polychaeta larvae (MANOVA, $p > 0.05$).

In the enriched treatment, *Brachionus rotundiformis* (previously known as *Brachionus plicatilis* S type, Segers, 1995) composed 63% to 91% of the total zooplankton community. For this species a time effect (MANOVA, $\lambda = 0.017$, $p < 0.05$) but no nutrient effect was detected (MANOVA, $\lambda = 0.061$, $p > 0.05$). Similarly, as observed for the total zooplankton density, *B. rotundiformis* presented a density decrease from the first to the second day of the experiment (ANOVA, $p < 0.001$, Fig. 3). From the second to the fourth day, this decrease continued in the control treatment (ANOVA, $p < 0.05$, Fig. 3). At this time a higher density of this species was detected in the enriched treatment when compared to the control (ANOVA, $p < 0.001$, Fig. 3). Even though the *B. rotundiformis* density tended to decline over time, its highest number was observed on the last day of the experiment in one of the enriched enclosures.

Hexarthra brandorffi, another rotifer species present on all sampling dates, showed no significant density difference between treatments (MANOVA, $\lambda = 0.152$, $p > 0.05$), but did present changes in time (MANOVA, $\lambda = 0.007$, $p < 0.05$). Contrary to *B. rotundiformis*, this species demonstrated an increase in its density over time, which was considered significant from the second to the fourth day (ANOVA, $p < 0.05$, Fig. 3). However, both rotifer species showed their highest numbers on the last sampling in the same enriched enclosure.

We observed a nutrient effect on the density of *Acartia tonsa* (MANOVA, $\lambda = 0.011$, $p < 0.05$), but there was no effect of time (MANOVA, $\lambda = 0.179$, $p > 0.05$) even though densities of this species tended to be higher in both treatments at the end of the experiment. On the fourth day *Acartia tonsa* density was higher in the controls than in the enriched enclosures (ANOVA, $p < 0.05$, Fig. 3).

DISCUSSION

In Imboassica Lagoon (open water station), N:P values were higher than 50, suggesting phosphorus limitation. Moreover, orthophosphate concentrations were, except for the initial sampling, below the detectable limit of the analytical method employed. In the enriched treatment, ammonium and orthophosphate showed a reduction from the first day (immediately after nutrient addition, data not shown) to the following day and N:P values presented an increase. This might have happened because the orthophosphate was either preferentially absorbed or precipitated. Chlorophyll-*a* concentrations in the enriched treatment showed a positive relationship with the phosphorus forms, supporting the possibility of phosphorus limitation. The positive correlation between chlorophyll-*a* and particulate phosphorus ($r = 0.78$, $p < 0.01$) may reflect phosphorus incorporation within phytoplankton cells, since organisms tend to absorb and incorporate in to their cells high amounts of the limiting nutrient, and to release into the medium excess nutrient (Sterner, 1989; Urabe *et al.*, 1995). It is worth noting, however, that separate P and N treatments, which could confirm a preferential uptake, were not conducted in this experiment.

TABLE 2
Mean values and standard deviations (in parentheses) or minimum and maximum densities (*) of the zooplankton taxa, expressed in ind./m³, in the open water station in Imboassica Lagoon, in the control and in the enriched enclosures from October to November 1996.

Taxa	Lagoon	Control	Enriched
Rotifera			
<i>Brachionus rotundiformis</i>	8.0 × 10 ⁵ (6.8 × 10 ⁵)	1.0 × 10 ⁶ (6.0 × 10 ⁵)	1.3 × 10 ⁶ (7.1 × 10 ⁵)
<i>Hexarthra brandorffi</i>	3.6 × 10 ³ (2.4 × 10 ³)	1.4 × 10 ⁴ (1.2 × 10 ⁴)	2.2 × 10 ⁴ (3.1 × 10 ⁴)
<i>Keratella cochlearis</i>		0 – 5.0 × 10 ² *	
<i>Lecane bulla</i>			0 – 5.0 × 10 ² *
<i>Lecane stenroosi</i>			0 – 5.0 × 10 ² *
<i>Lepadella patella</i>			0 – 5.0 × 10 ² *
Cladocera			
<i>Alona cf. monacantha</i>	0 – 1.0 × 10 ² *		
<i>Bosmina hagdmani</i>	0 – 5.0 × 10 ¹ *	0 – 5.0 × 10 ¹ *	0 – 5.0 × 10 ¹ *
<i>Ceriodaphnia cornuta</i>	0 – 5.0 × 10 ¹ *		
<i>Diaphanosoma spinulosum</i>		0 – 5.0 × 10 ¹ *	
Copepoda			
Calanoida nauplii	1.8 × 10 ⁵ (4.3 × 10 ⁴)	2.5 × 10 ⁵ (1.5 × 10 ⁵)	2.0 × 10 ⁵ (6.4 × 10 ⁴)
Cyclopoida nauplii	4.5 × 10 ³ (2.9 × 10 ³)	4.2 × 10 ³ (2.3 × 10 ³)	4.4 × 10 ³ (2.4 × 10 ³)
Harpacticoida nauplii	0 – 1.5 × 10 ³ *	0 – 2.0 × 10 ³ *	0 – 1.5 × 10 ³ *
Calanoida copepodids	1.3 × 10 ⁴ (1.7 × 10 ⁴)	1.4 × 10 ⁴ (1.0 × 10 ⁴)	1.1 × 10 ⁴ (5.7 × 10 ³)
Cyclopoida copepodids	0 – 1.5 × 10 ² *	0 – 1.0 × 10 ² *	0 – 1.0 × 10 ² *
Harpacticoida copepodids	0 – 2.5 × 10 ² *	0 – 3.0 × 10 ² *	0 – 1.5 × 10 ³ *
<i>Acartia tonsa</i>	1.6 × 10 ² (1.4 × 10 ²)	8.7 × 10 ² (7.6 × 10 ²)	6.7 × 10 ² (4.4 × 10 ²)
<i>Pseudodiaptomus richardi</i>		0 – 5.0 × 10 ¹ *	
<i>Parasitic copepods</i>	0 – 5.0 × 10 ¹ *	0 – 5.0 × 10 ¹ *	
Cirripedia cipris	0 – 5.0 × 10 ¹ *	0 – 5.0 × 10 ¹ *	0 – 5.0 × 10 ¹ *
Cirripedia nauplii	5.8 × 10 ³ (4.2 × 10 ³)	9.9 × 10 ³ (7.0 × 10 ³)	6.6 × 10 ³ (2.7 × 10 ³)
Chironomidae larvae	0 – 5.0 × 10 ¹ *	0 – 1.0 × 10 ² *	0 – 1.0 × 10 ² *
Polychaeta larvae	2.3 × 10 ⁴ (1.3 × 10 ⁴)	2.6 × 10 ⁴ (1.3 × 10 ⁴)	3.0 × 10 ⁴ (1.5 × 10 ⁴)
Nematoda	0 – 5.0 × 10 ² *	0 – 5.0 × 10 ¹ *	0 – 5.0 × 10 ¹ *
Bivalvia veligers	0 – 1.0 × 10 ³ *	0 – 5.0 × 10 ² *	0 – 1.0 × 10 ³ *
Gastropoda veligers	3.2 × 10 ⁴ (8.0 × 10 ³)	4.3 × 10 ⁴ (2.9 × 10 ⁴)	4.8 × 10 ⁴ (2.8 × 10 ⁴)

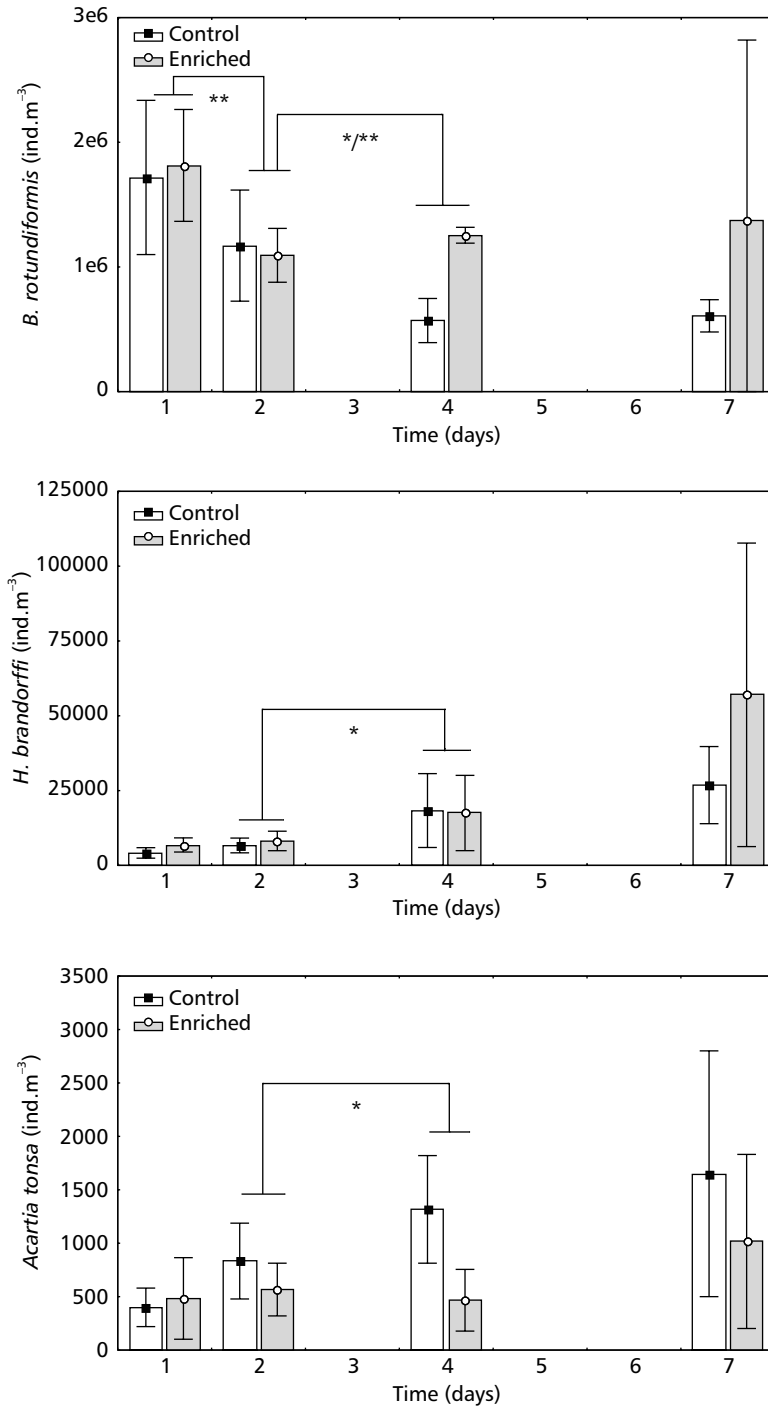


Fig. 3 — Mean (column) and standard deviation ± 1 (bars) of *Brachionus rotundiformis*, *Hexarthra brandorffi* and *Acartia tonsa* densities in the control (filled squares) and enriched (open circles) enclosures. (*) $p < 0.05$; (**) $p < 0.001$.

The phytoplankton community of Imboassica Lagoon was dominated during this study by picoplanktonic cyanobacteria of the genera *Synechocystis* and *Synechococcus*. In the enriched treatment, total cyanobacteria density showed a positive correlation with chlorophyll-*a* content ($r = 0.89$, $p < 0.05$). This indicates that the increase in numbers of these organisms was, at least in part, responsible for the increase in chlorophyll-*a* values.

On the fourth day, higher *Brachionus rotundiformis* and lower *Acartia tonsa* densities in the enriched enclosures than in the controls, concomitant with an increase in chlorophyll-*a* concentration and bacterial density, indicate a positive effect of the enrichment on the first species and a negative one on the second. Higher relative importance of microzooplankton in relation to macrozooplankton is commonly observed under higher trophic conditions, especially in sub-tropical systems (Bays & Crisman, 1983; Beaver & Crisman, 1990). Within the microzooplankton, the rotifer contribution can be important in such conditions, while calanoids are generally the most affected in the macrozooplankton. Blancher (1984) observed that rotifers numerically predominated in eutrophic lakes in Florida, whereas copepods predominated in less rich ones.

Acartia tonsa seemed to experience released predation pressure, since it showed an increase in numbers both in the control and enriched enclosures when compared to the open water station (data not shown). This might suggest that predation is an important structuring factor for the zooplankton community in Imboassica Lagoon. Abreu *et al.* (1994) observed a reduction in copepodit and adult *A. tonsa* densities when juvenile *Xenomelaniris brasiliensis* were present in an enclosure study in Patos Lagoon (Rio Grande do Sul). This fish species also occurs in Imboassica Lagoon (Aguiaro, 1994) and its absence inside the enclosures might have favored *A. tonsa*.

On the last day of the experiment, some variables in the enriched treatment showed differential behaviour. For instance, in two enclosures a considerable reduction in nutrient concentrations, bacterial density, and chlorophyll-*a* values was observed, which had not been

expected since nutrients were added daily. Reduction or stabilization of the nutrient concentrations could have happened as a result of uptake by phyto- and/or bacterioplankton, neither of which was observed. Therefore, some dilution may have occurred within these enclosures as a result of water influx. During the period in which the experiment was conducted, a 15 cm increase in the water level took place due to high rain precipitation, and even though the enclosures apparently suffered no water influx during samplings, this is not certain.

The third enriched enclosure showed signs of environmental stress. It had the highest ammonium and lowest pH and dissolved oxygen levels. Bacterial and cyanobacterial densities and chlorophyll-*a* concentrations were very low, while *Brachionus rotundiformis* and *Hexarthra brandorffi* had their highest densities. Dominance in the zooplankton community was the highest and diversity the lowest observed for all enclosures.

These results suggest that zooplankton, mainly the rotifers, were capable of regulating or even suppressing bacterial and cyanobacterial densities since rotifer species of the genera found in this study can effectively use particles of the picoplankton size range (Pourriot, 1977; Vadstein *et al.*, 1993; Heerkloß & Hlawa, 1995). Arcifa *et al.* (1994), observed a significant negative correlation between *B. plicatilis* and cyanobacteria (*Synechococcus elongatus* and *Synechocystis aquatilis* f. *salina*) in Barra Lagoon. Vadstein *et al.* (1993) demonstrated that *Brachionus plicatilis* presented maximum filtration rate in the presence of 2 µm diameter particles, being able to ingest 0.3 µm particles as well. These authors concluded that in high densities, such those observed under cultivation conditions, *B. plicatilis* can effectively remove bacteria. This rotifer species can use several food items, including bacteria, *Enteromorpha* debris and some algae species, showing positive selectivity to smaller particle size (2 µm) (Heerkloß & Hlawa, 1995).

Overall, our results suggest that both nutrient availability (bottom-up control) and herbivory pressure (top-down control) were important in the regulation of bacterio- and phytoplankton in Imboassica Lagoon.

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