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Zooplankton (Cladocera and Rotifera) variations along a horizontal salinity gradient and during two seasons (dry and rainy) in a tropical inverse estuary (Northeast Brazil)

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Abstract. The present study investigated the influence of environmental variables on the spatial and temporal composition of the most abundant zooplankton groups (Cladocera and Rotifera) in a tropical inverse estuary located in a salt pond-dominated area. Zooplankton and twelve environmental variables were sampled at nine permanent stations throughout a two-year period (Sep 2005 to Sep 2007). A total of nineteen species, mostly freshwater dwellers, was detected throughout the study and ten species accounted for 97% of all individuals. Mean species richness and abundance were significantly higher at the uppermost stations, but only during the rainy seasons, when salinity drastically decreased due to freshwater input. According to multiple regression and canonical correspondence analyses salinity, nutrients, pluviometry, pH, Chlorophyll-*a* and transparency were the most important predictors of zooplankton community structure. The low community diversity and strong dominance of the pollution-tolerant *Brachionus* genus (80% of all individuals) support the idea that only plastic species are able to cope with harsh spatial and seasonal variations such as the ones observed during our observations in the estuary.

Key words: Brazil, community, estuary, salinity gradient, zooplankton.

Resumo. Variações do zooplâncton (Cladocera e Rotifera) ao longo de um gradiente horizintal de salinidade e durante duas estações (seca e chuvosa) em um estuário tropical inverso (Nordeste do Brasil). O presente estudo avaliou a influência de variáveis ambientais na composição espacial e temporal dos grupos zooplanctônicos mais abundantes (Cladocera e Rotifera) em um estuário tropical inverso localizado numa área dominada por salinas. O zooplâncton e doze variáveis ambientais foram amostrados em nove pontos permanentes ao longo de um período de dois anos (Set 2005 a Set 2007). Um total de dezenove espécies, a maioria habitante da água doce, foi observado durante o estudo e dez espécies representaram 97% de todos os indivíduos. As médias de riqueza de espécies e abundância foram significativamente maiores nos pontos superiores próximos à margem do rio, mas somente durante os períodos chuvosos, quando a salinidade reduziu-se drasticamente devido ao influxo de água doce. De acordo com as análises de regressão múltipla e correspondência canônica, salinidade, nutrientes, pluviometria, pH, Clorofila-*a* e transparência foram os mais importantes preditores da estrutura da comunidade do zooplâncton. A baixa diversidade de comunidade e forte dominância do gênero *Brachionus*, tolerantes a poluição (80% de todos os indivíduos), suporta a idéia de que somente espécies plásticas são capazes de suportar variações espaciais e sazonais adversas como as observadas durante as nossas observações no estuário.

Palavras-chave: Brasil, comunidade, estuário, gradiente de salinidade, zooplâncton.

Introduction

Brackish waters of typical estuarine systems are the result of a mixture in freshwater and salt water inputs (Remane & Schlieper 1971, McLusky & Elliott 2004). Thus, one expects to find a horizontal gradient of salt concentration in these estuaries, with freshwater nearby the river border and salinity increasing seawards to reach typical oceanic levels. However, some estuaries show the opposite pattern, with a horizontal gradient of salt concentration increasing upstream (Hammer 1986, Simier *et al.* 2004).

Salinity is amongst the most important environmental factors with the potential to significantly influence estuarine communities (Savenije 2006). Therefore, fluctuations in salinity and other environmental factors (e.g. temperature, pH, nutrients and pigments) on both spatial and seasonal scales, play major ecological roles promptly controlling the composition and distribution of estuarine species (Prado-Por & Lansac-Tôha 1984, Lansac-Tôha & Lima 1993). This is true, given that only select species are able to cope with major environmental shifts (Hammer 1993).

The Mossoró River Estuary (MRE) is a 24 km inverse system in which salinity decreases from the river border towards the sea, with salt concentrations varying between saline and brackish. Located in a semi-arid region, the high daily evaporation rates (~1 cm/m³), low annual rainfall and consequently low river outflow, are responsible for this inverse pattern. Although inverse estuaries are often considered a synonym for hypersaline estuaries, in some cases such as in the MRE, salt concentrations rarely exceed 50 g/l, which is stated by Hammer (1986) as the minimum concentration for a water body to be classified as hypersaline (see McLusky & Elliott 2004, Simier *et al.* 2004).

The salt industry has been exploiting the MRE for over 300 years and nowadays over 25 ponds for salt extraction are permanently located along the estuary's margin. The gross annual salt production is approximately 2,400,000 tons and the Rio Grande do Norte State (RN) is responsible for up to 90% of Brazil's salt production, with the highest contribution coming from the MRE. As a consequence of the long history of unregulated exploitation, mangrove forests have been submitted to high levels of impact, currently covering a substantially smaller area relative to the original.

Atypical environments like the MRE encompass a very small portion of the inland aquatic environments of the world (Sassi 1991, Hammer 1993), but are of high scientific and economic interest because of their uniqueness (Hammer 1986, McLusky & Elliott 2004) and income prospective (Coetzee *et al.* 1996, Lamberth & Turpie 2003).

Despite the importance of inverse estuaries, many ecological processes which take place therein are still poorly known, and need more thorough investigations, especially at the community-level (Hammer 1986, Sassi 1991, Neumann-Leitão *et al.* 1992, Bos *et al.* 1996, Williams 1998, Derry *et al.* 2003). Furthermore, areas which are subject to high degradation due to human activities are particularly important since species composition can be altered throughout the years (Matsumura-Tundisi & Tundisi 2003).

The present study aimed at evaluating zooplankton community composition spatially (along a salinity gradient) and temporally (encompassing dry and rainy seasons). We focused on Cladocera and Rotifera zooplankton provided those constitute the more diverse and abundant metazooplankton groups in the study area. It was hypothesized that salinity acts as a restraining force on species abundance, whereas freshwater input (and its associated nutrients) has a positive effect on the community.

Material and methods

Study area. The study was carried out at the Mossoró River Estuary (MRE), located in a floodplain with an area of 14,276 km² in Rio Grande do Norte (RN) state, northeastern coast of Brazil (Fig. 1). The inlet extends for about 24 km from the lower reach (salinity: ~ 10), nearby the South Atlantic Ocean, to the uppermost portion (~ 28), delimited by the river border, yet still influenced by tidal fluctuation. Salinity increases, however, from the lower reach of the estuary towards the sea and typical marine regimes are observed in the ocean. It has a maximum depth of 10 m with an average of 6 m. The region is under semi-arid climatic influence, typically receiving low, yet concentrated annual rainfall (rainy season between Feb and Jun). The Caatinga, vegetation region dominated by xeric shrublands and thorn forests, encloses most of the area, albeit Restinga and Atlantic Forest areas are also present. In addition, the estuary is under the influence of constant winds (> 7 km/h during ~ 75% of the year) and high water temperatures (~ 29ºC) yearlong.

*Sampling design.*Monthly samples were collected during two consecutive years (Sep-05 to Sep-07) at 9 permanent sampling stations following a horizontal gradient (~ 24 km) (Fig. 1). Throughout the study span, 225 samples were collected during the day (between 0800 and 1600) and at high tides (for standardizing sampling). Although the vertical profile was not investigated, samplings were standardized and collected within the first 2 m of the water column.

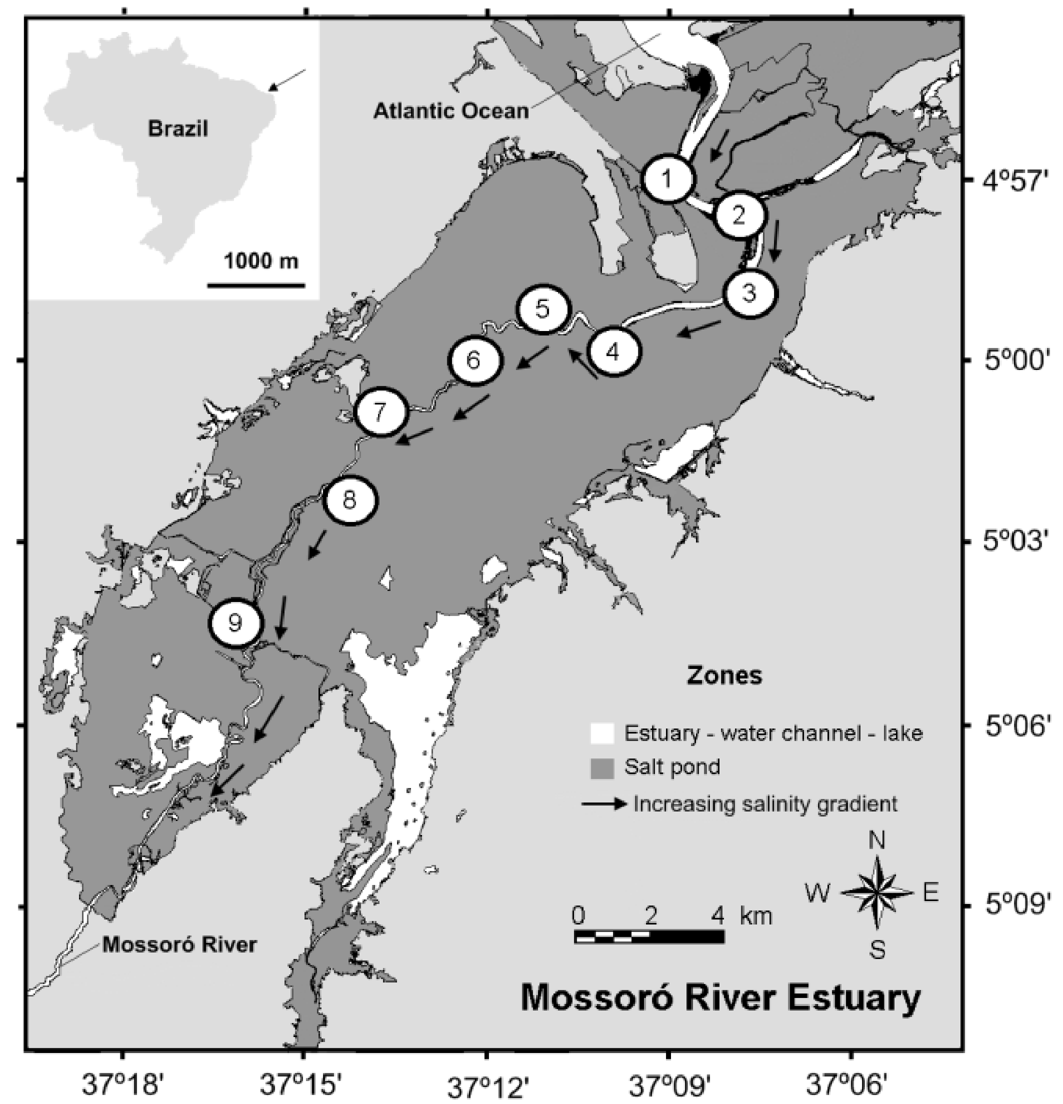

Figure 1. Mossoró River Estuary and associated zones. Sampling stations indicated by numbers and direction of increasing salinity gradient indicated by arrows. Inset: location of the study area in the Northeastern coast of Brazil.

Zooplankton was collected using a 60 μm mesh size plankton net of 25 cm mouth diameter by filtering 70 l of water at each sampling station. Volume filtered was estimated by calculating the horizontal tow distance with regards to diameter of mouth aperture area. The collected individuals were preserved in 5% formaldehyde saturated with sugar (Haney and Hall 1973). Three aliquots (1 ml of volume each) were taken from each sample (between 80 and 140 ml of volume) and counted on a Sedgwick-Rafter chamber. If an aliquot had less than 100 individuals another one was examined and the results combined. The mean number of individuals of the three aliquots represented each sample. Qualitative and quantitative data were calculated simultaneously.

Twelve environmental variables were assessed at the same stations as the zooplankton. Transparency (Secchi disk), temperature (digital thermometer), salinity (Fisher portable refractometer) and pH (Hanna portable membrane pHmeter) were measured *in situ*. Dissolved oxygen was measured following Winkler`s method. Nutrients concentrations (ammonia NH_3, nitrite NO_2, nitrate NO_3 and total phosphorous) were estimated according to the procedures described by Rodier (1975), Mackereth *et al.* (1978) and APHA (1995). Chlorophyll-*a* and Pheophytin concentrations were determined spectrophotometrically based on the procedures described in APHA (1995). Pluviometric rates were provided by LABESA (Laboratory of Semi-Arid

Ecology) at the margin of estuary nearby each sampling station.

Ecological indices and data analysis. Species richness was expressed as the total number of species in each sample. Additionally, log-based Shannon`s index (H') was calculated using Primer 5 software as a measure of community diversity (see Krebs 1989).

Since data departed from normality, spatial and seasonal variations were evaluated by performing, respectively, non-parametric rank-based Kruskal-Wallis one-way ANOVA and Friedman ANOVA tests on Statistica 7 software (Sokal & Rohlf 1995). All comparisons and correlations (below) were considered significant when p values were < 0.05.

Stepwise multiple-regression analyses (MRA) were made using Statistica 7 to determine the proportion of variance in zooplankton numbers which could be attributed to environmental data (Sokal & Rohlf 1995). In the regression models, zooplankton abundances, richness and diversity (separated by season) were entered as dependent variables, and the environmental variables as predictors of their variance. Data from rare species (i.e., those which contributed < 1% of total abundance) were excluded from the individual species correlations, but contributed to total richness, diversity and abundance. Prior to the analyses, data was log-transformed (base 10) and linearity between variables and multicolinearity between independent variables were tested (Sokal & Rohlf 1995), but data proved to be non-linear.

In addition to the MRA, a canonical correspondence analysis (CCA) was performed with log-transformed data (natural) using CANOCO 4.5 software (ter Braak & Smilauer 1998). For this test, all species were included, but the downweighting of rare species option was employed. The Monte-Carlo randomization test (499 permutations under the reduced model) was performed to assess the probability of the observed pattern being due to chance (see ter Braak 1986).

Results

Environmental characterization. No significant spatial variation was observed for pluviometry (Fig. 2), but significant seasonal variation was detected (Fig. 3). Salinity values increased significantly upstream (between stations 1 and 9) (Fig. 2) and were significantly lower during the rainy seasons (Fig. 3). Water temperature also increased significantly upstream (Fig. 2), with a trend towards higher values during the second rainy season (Fig. 3). No significant spatial differences were observed for pH values (Fig. 2), but lower values were observed during the second rainy season (Fig. 3). Water transparency values decreased significantly upstream (Fig. 2) and showed significant seasonal variation (Fig. 3). Although spatial and seasonal differences were detected for oxygen, no clear spatial patterns were observed and a small trend towards higher values during the dry season was detected (Figs. 2 and 3). No spatial variation was detected for any of the nutrients (Fig. 2). Between seasons, higher values of NO_2, NO_3 and total phosphorous were observed during the rainy seasons (Fig. 3). Chlorophyll-*a* and Pheophytin values significantly increased upstream (Fig. 2) and a significant trend towards higher values during the first rainy season was observed (Fig. 3). *Species composition and distribution.* A total of 157,464 individuals belonging to 16 rotifer species (*Anuraeopsis fissa* (Gosse), *Brachionus angularis* (Gosse), *Brachionus calyciflorus* Pallas, *Brachionus caudatus* Barrois & Daday, *Brachionus falcatus* Zacharias, *Brachionus leydigi* (Rousselet), *Brachionus patulus* (Müller), *Brachionus plicatilis* Müller, *Brachionus urceolaris* (Müller), *Epiphanes macrourus* (Barrois & Daday), *Filinia longiseta* (Ehrenberg), *Filinia opoliensis* (Zacharias), *Hexarthra mira* (Hudson), *Keratella tropica* (Apstein), *Keratella valga* (Ehrenberg) and *Polyarthra vulgaris* Ehrenberg) and 3 cladoceran species (*Ceriodaphnia cornuta* (Sars), *Diaphanosoma spinulosum* Herbst and *Moina minuta* Hansen) were collected throughout the study span. The ten most abundant species, which accounted for 97% of all collected individuals, were (mean ind.l^{-1}; relative abundance): *B. urceolaris* (245.7; 35.1%), *B. plicatilis* (146.5; 20.9%), *B. calyciflorus* (79.2; 11.3%), *B. leydigi* (73.9; 10.6%), *C. cornuta* (47.2; 6.7%), *E. macrourus* (40.4; 5.7%), *H. mira* (12.6; 1.8%), *K. tropica* (12.4; 1.8%), *F. opoliensis* (10.1; 1.4%) and *B. falcatus* (8.6; 1.2%). Each of the remaining nine species contributed to less than 1% of all collected individuals.

Species richness significantly increased upstream (Fig. 4) and community diversity (Shannon's index) showed a similar significant pattern, albeit less marked (Fig. 4). Significant seasonal fluctuations were observed for species richness and diversity, which showed higher values especially during the second rainy season (Fig. 4).

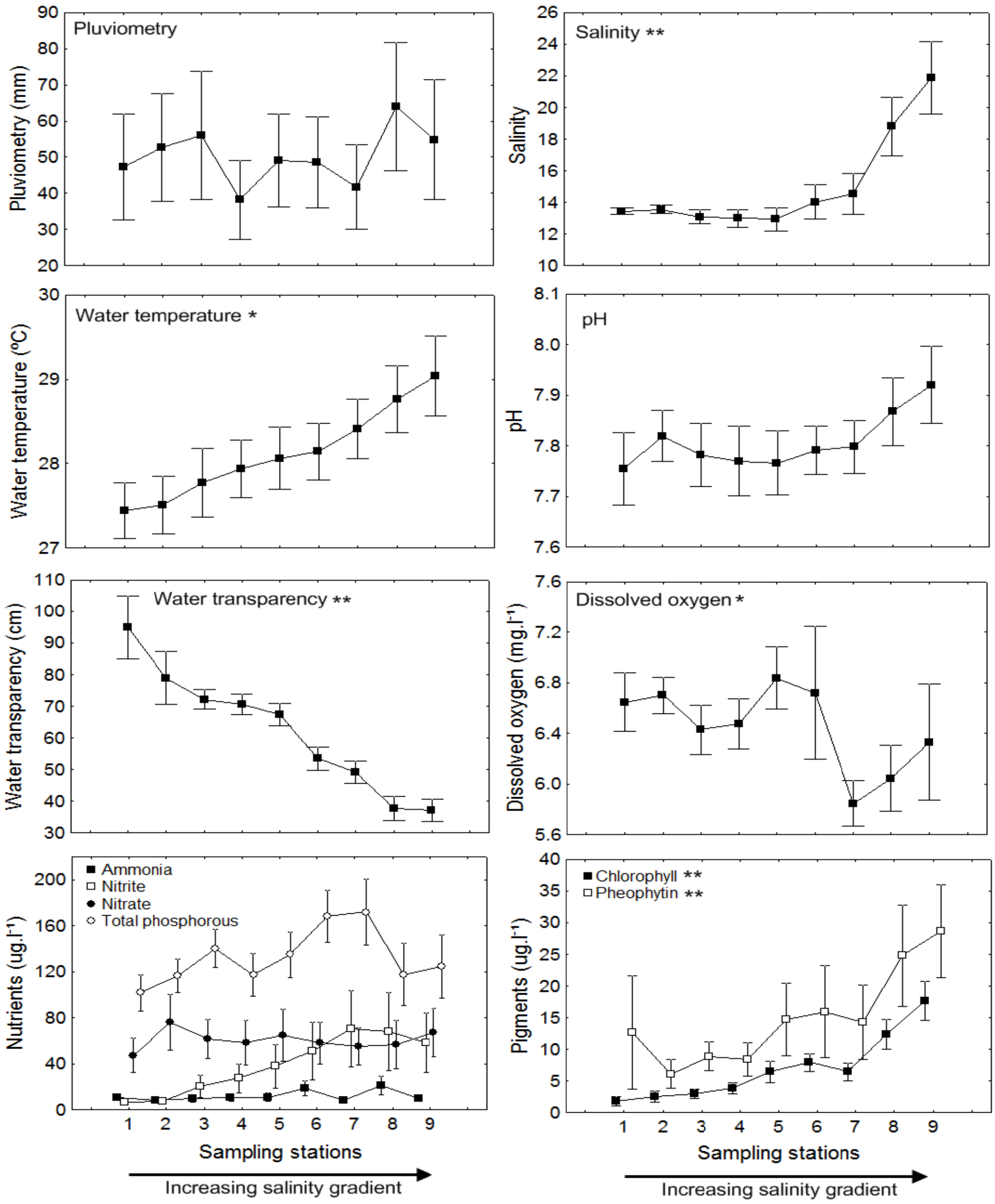

Figure 2. Mean values (± SE) of monthly records of environmental variables sampled during the 2-years observation period at 9 permanent stations at the Mossoró River Estuary. SE variations specify the temporal variances of the data within each sampling station. KW ANOVA results of comparisons among stations indicated: *significant at $p < 0.05$ and **significant at $p < 0.001$.

Results of spatial distribution of the ten most abundant species revealed somewhat similar patterns, with significant spatial differences in the density of five species, which showed peaks of abundances between stations 6 and 9 (Fig. 5). Also, all species showed highly significant seasonal variation in abundance with clear peaks during the rainy seasons, particularly the second one.

Zooplankton-environmental variables associations. Predictors of zooplankton community were fairly different between the two seasons (Table I). According to the regression models, the most important variables responsible for zooplankton variance were pH, water temperature, NO_2 and Chlorophyll-*a* during the dry seasons, and total phosphorous, water transparency, NO_3, salinity and pH during the rainy seasons.

For the canonical correspondence analysis, the Monte-Carlo test was significant (test of significance of all canonical axes: trace: 0.65; F-ratio: 3.58; $p < 0.01$). Cumulatively, axes 1 and 2 accounted for 63.9% of the total variance, with zooplankton-environmental variables correlations of 0.77 (Axis 1) and 0.53 (Axis 2). Within the biplot, two general, somewhat divergent, groups of species were distinct. The first group comprised 14 species which correlated positively with NO_3, total phosphorous, NH_3, water temperature, Chlorophyll-*a*, or pluviometry; the second group comprised 5 species which correlated positively with water transparency or salinity (Fig. 6).

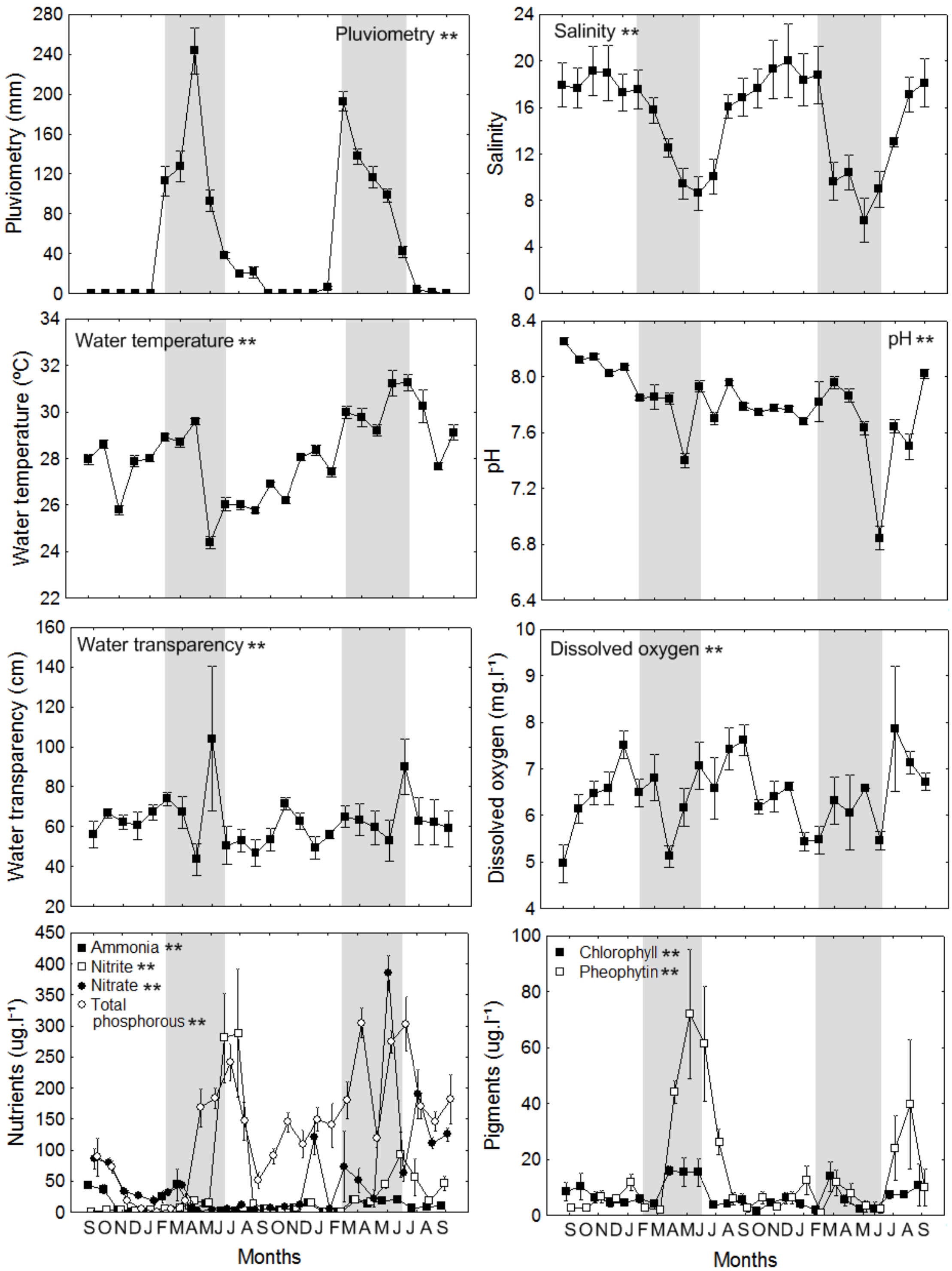

Figure 3. Environmental variables (± SE) sampled throughout a 2-year period at the Mossoró River Estuary averaged for the 9 stations. SE variations specify the spatial variances of the data within each sampled month. Shaded areas indicate the rainy seasons. Friedman ANOVA results of comparisons among months indicated: **significant at p < 0.001.

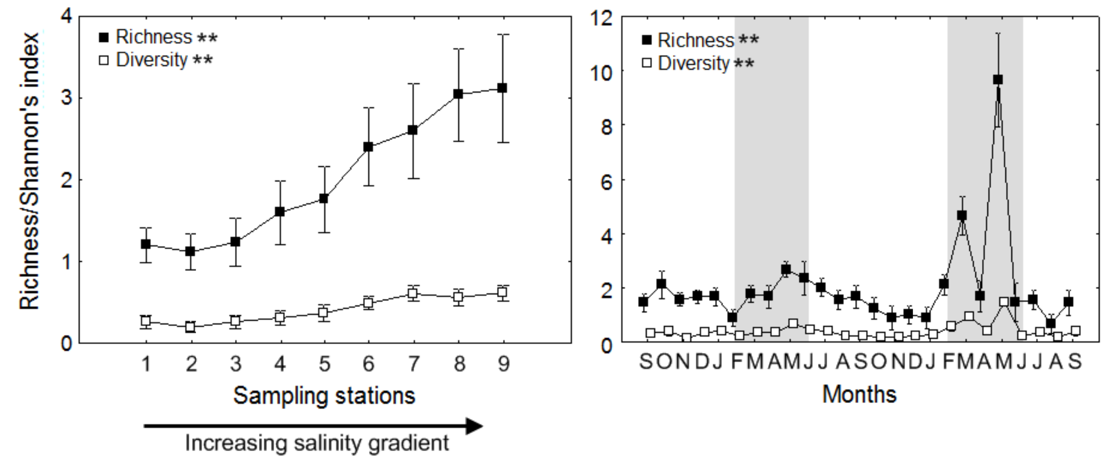

Figure 4. Mean values (± SE) of two ecological indices (richness and Shannon's index of diversity) sampled at 9 permanent stations reflecting an increasing salinity gradient (left panel), and throughout a 2-year period (right panel) at the Mossoró River Estuary. SE variations specify the temporal variances of the data within each sampling station (left) and the spatial variances of the data within each sampled month (right). Shaded areas indicate the rainy seasons. KW ANOVA and Friedman ANOVA results of comparisons spatially and temporally, respectively, indicated: **significant at p < 0.001.

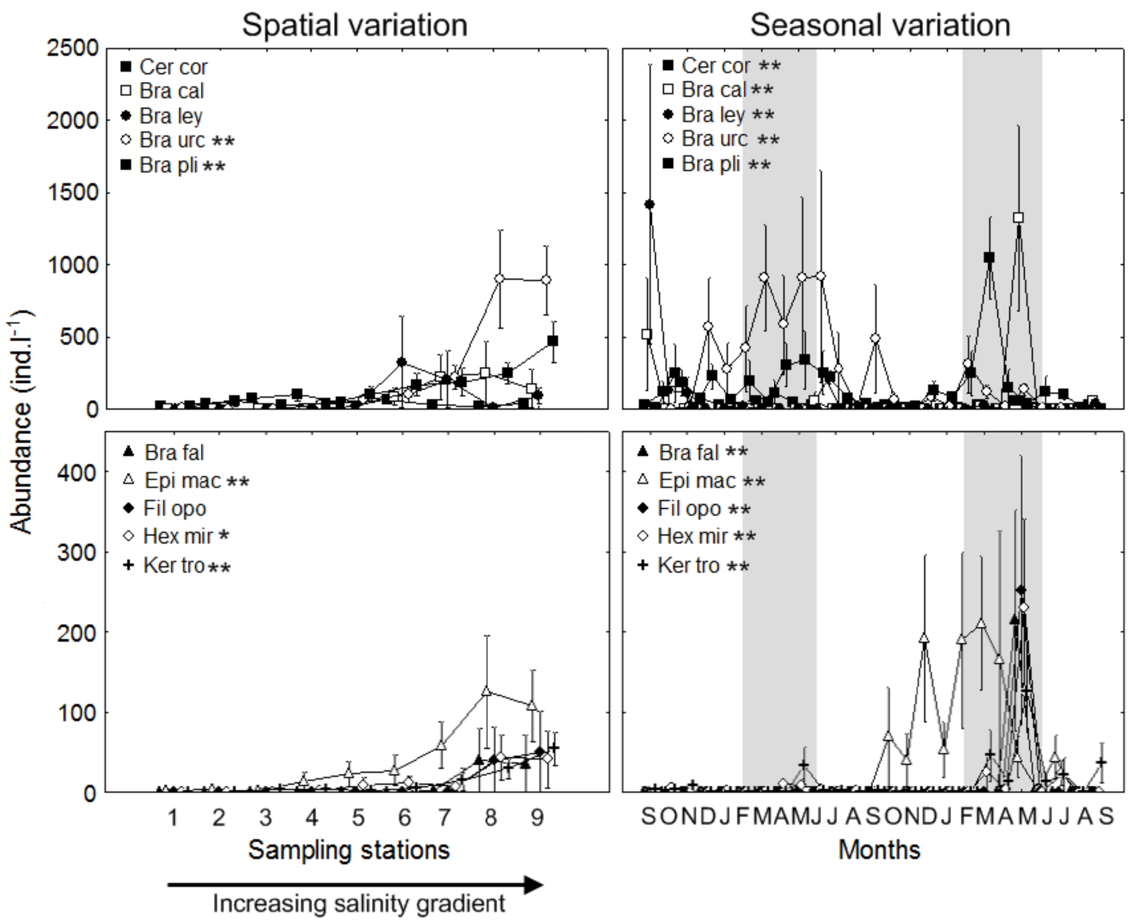

Figure 5. Mean densities (± SE) of ten zooplankton species sampled at 9 permanent stations reflecting an increasing salinity gradient (left panels), and throughout a 2-year period (right panels) at the Mossoró River Estuary. Data from rare species (i.e. those which contributed to less than 1% of total abundance) were excluded from the analyses. SE variations specify the temporal variances of the data within each sampling station (left) and the spatial variances of the data within each sampled month (right). Shaded areas indicate the rainy seasons. KW ANOVA and Friedman ANOVA results of comparisons spatially and temporally, respectively, indicated: *significant at p < 0.05 and **significant at p < 0.001.

Discussion

Zooplankton (Cladocera and Rotifera) in the Mossoró river estuary (MRE) was characterized mostly by freshwater species with a fairly low richness compared to other tropical estuaries (e.g. Rougier *et al.* 2005). Nevertheless, Lansac-Tôha & Lima (1993) made monthly collections throughout a year and detected even lower richness than the present study, suggesting that our results are consistent with some estuary-based investigations, where species richness tend to be lower than freshwater and marine environments (see Hammer 1986, Neumann-Leitão 1994).

The low richness observed in the present study clearly reflected the striking spatial and seasonal fluctuations, particularly of salinity, on freshwater dwellers. This is a common pattern, as acknowledged by many authors (e.g. Prado-Por & Lansac-Tôha 1984, Sassi 1991, Hammer 1993, Lansac-Tôha & Lima 1993, Keller & Conlin 1994, Williams 1998, Herbst 2001, Ara 2002, Derry *et al.* 2003, Toumi *et al.* 2005) suggesting a large-scale occurrence of these relationships. Derry *et al.* (2003) studying temperate saline lakes discerned patterns of community composition along a gradient of salt concentration. In tropical estuaries of Brazil, similar findings have also been observed (see Prado-Por & Lansac-Tôha 1984, Lansac-Tôha & Lima 1993, Lopes 1994, Neumann-Leitão 1994, Magalhães *et al.* 2006).

Further, richness and abundance increased upstream, a seemingly inconsistency with the observed negative relationship between zooplankton and salinity, given that salt concentrations increased likewise. However, species richness and abundance at the more saline stations were only high during the rainy seasons, when salt concentration substantially decreased due to higher freshwater input. This alone explains the seemingly odd higher richness and abundance at the more saline stations, but not the prevailing lower values at the less saline ones. Seasonal salinity fluctuations due to freshwater runoff were high at the more saline stations and a corresponding high fluctuation in species numbers was also observed. Conversely, both salinity and species numbers showed very small seasonal fluctuations at the less saline stations, likely because the area was not significantly affected by the freshwater input and was under higher tidal dynamics. Hence, these stations uphold similar salt concentrations yearlong, and it is reasonable to associate the small variation in community composition at these stations to a lack of seasonal salinity fluctuation. At the higher stations, however, richness and abundance increased as salinity decreased. In fact, the majority of the species identified in our study was exclusively found in the stations nearby the river and during the second rainy season (see below).

It is likely, however, that other factors may have supported the observed higher numbers at these higher stations, since, despite the proximity to the river, salinity still remained higher there than at the lower stations. As detected by some authors (Keller & Conlin 1994, Herbst 2001), in addition to salinity, small-scale differences in factors such as ion composition (Derry *et al.* 2003), food availability (Toumi *et al.* 2005) and predation pressure (Williams 1998) may significantly alter the structure of zooplankton communities in saline environments. These processes need yet to be investigated in the MRE**.** Alternatively, the more conspicuous shifts in community composition at the higher stations may be related to the rapid freshwater discharge which displaced the individuals towards the estuary. Rougier *et al.* (2005) reported a similar finding associating higher rotifer richness in the estuary during the rainy season to a mixing of populations across the estuarine zone due to fluvial hydrodynamics. It is not clear, however, if this was a strictly mechanical passive dislocation or if some active horizontal movement was made by the species, since most individuals were alive when collected, suggesting a tolerance to the conditions. Whatever factor is involved, freshwater input was a highly important determinant of species numbers as previously acknowledged by other authors (e.g. Osore *et al.* 1997, Mwaluma *et al.* 2003, Paranaguá *et al.* 2005, Rougier *et al.* 2005, Magalhães *et al.* 2006). It is likely that richness and abundance were higher during the rainy seasons due to more favorable conditions provided by the rain, particularly, diluting salt concentration, since most species identified are typical freshwater dwellers. The influence of these factors on other groups not evaluated here, such as copepods (albeit not a diverse/abundant group in the MRE; author's personal observations), may divulge additional information.

Further, striking differences of richness and abundance between the two rainy seasons were observed. Since pluviometric rates were similar on both rainy seasons, this suggests that other factors also influenced the species. Higher values of water temperature, NO_3 and total phosphorous and lower values of pH, salinity, NO_2 and Chlorophyll-*a* were observed during the second rainy season.

Table I. Stepwise multiple regression analyses between zooplankton richness and abundance (dependent variables) and environmental variables (predictors) during two seasons (dry and rainy) at the Mossoró River Estuary.

Dependent variables	Regression				Predictors (contribution to total R^2)											
	F	df	P	R^2	S	T	pH	Tr	O_2	NH_3	NO_2	NO_3	TP	Ch-*a*	Ph	P
Ceriodaphnia cornuta DS	4.96	12, 122	<0.001	0.3		-0.2	0.4				0.29					
Brachionus calyciflorus DS	–	–	NS	–												
Brachionus leydigi DS	2.79	12, 122	<0.01	0.2			0.4						0.3			
Brachionus urceolaris DS	3.02	12, 122	<0.001	0.2						-0.4				0.26		
Brachionus plicatilis DS	4.9	12, 122	<0.001	0.3		0.4					-0.2					
Brachionus falcatus DS	–	–	NS	–												
Epiphanes macrourus DS	3.74	12, 122	<0.001	0.3	0.27	0.25							0.2		0.2	
Filinia opoliensis DS	–	–	NS	–												
Hexarthra mira DS	1.86	12, 122	<0.05	0.2					0.3							
Keratella tropica DS	–	–	NS	–												
Richness DS	3.64	12, 122	<0.001	0.3			0.4							0.22		
Diversity DS	2.63	12, 122	<0.01	0.2		0.25	0.3									
Abundance DS	5.48	12, 122	<0.001	0.4			0.4			-0.2	0.19			0.32		
Ceriodaphnia cornuta RS	–	–	NS	–												
Brachionus calyciflorus RS	5.38	12, 77	<0.001	0.5								0.4	0.3			
Brachionus leydigi RS	–	–	NS	–												
Brachionus urceolaris RS	4.82	12, 77	<0.001	0.4				-0.4				0.27				
Brachionus plicatilis RS	3.7	12, 77	<0.001	0.4			0.3			0.25			0.3			
Brachionus falcatus RS	2.58	12, 77	<0.01	0.3				-0.5								
Epiphanes macrourus RS	3.12	12, 77	<0.01	0.3			0.5						0.3			
Filinia opoliensis RS	2.54	12, 77	<0.01	0.3	0.42			-0.4					0.3			
Hexarthra mira RS	4.67	12, 77	<0.001	0.4									0.2			
Keratella tropica RS	7.62	12, 77	<0.001	0.5	-0.33			-0.3	0.2		-0.2	0.23				
Richness RS	4.49	12, 77	<0.001	0.4	-0.3							0.29	0.3			
DiveRSity RS	3.24	12, 77	<0.001	0.3	-0.26		0.3									
Abundance RS	3.29	12, 77	<0.001	0.3				-0.3				0.29				

DS: dry season; RS: rainy season; S: salinity; T: temperature; Tr: water transparency; O_2: dissolved oxygen; NH_3: ammonia; NO_2: nitrite; NO_3: nitrate; TP: total phosphorous; Ch-*a*: Chlorophyll-*a*; Ph: Pheophytin; P: pluviometry; NS: non-significant.

These observations confirm the correlations observed in the CCA, where temperature, NO_3 and total phosphorous were strong predictors of most species. The positive relation between zooplankton, water temperature and high concentrations of nutrients has been detected by many authors (e.g. Montú 1980, Nascimento-Vieira & Sant'-Anna 1989, Neumann-Leitão *et al.* 1992, Lopes 1996; Breitburg *et al*. 1999; Park & Marshall 1999). It is a consensus that an increase in the concentration of nutrients influences the top levels of a food web through a cascade of interactions (e.g. Seip 1991, Forrester *et al.* 1999, Anderson *et al.* 2002). Therefore, zooplankton individuals were likely benefited by this increase during the second rainy season in the present study. It is not clear, however, how the high values of Chlorophyll-*a* during the first rainy season, which is an indicator of high phytoplankton abundance, limited zooplankton abundance.

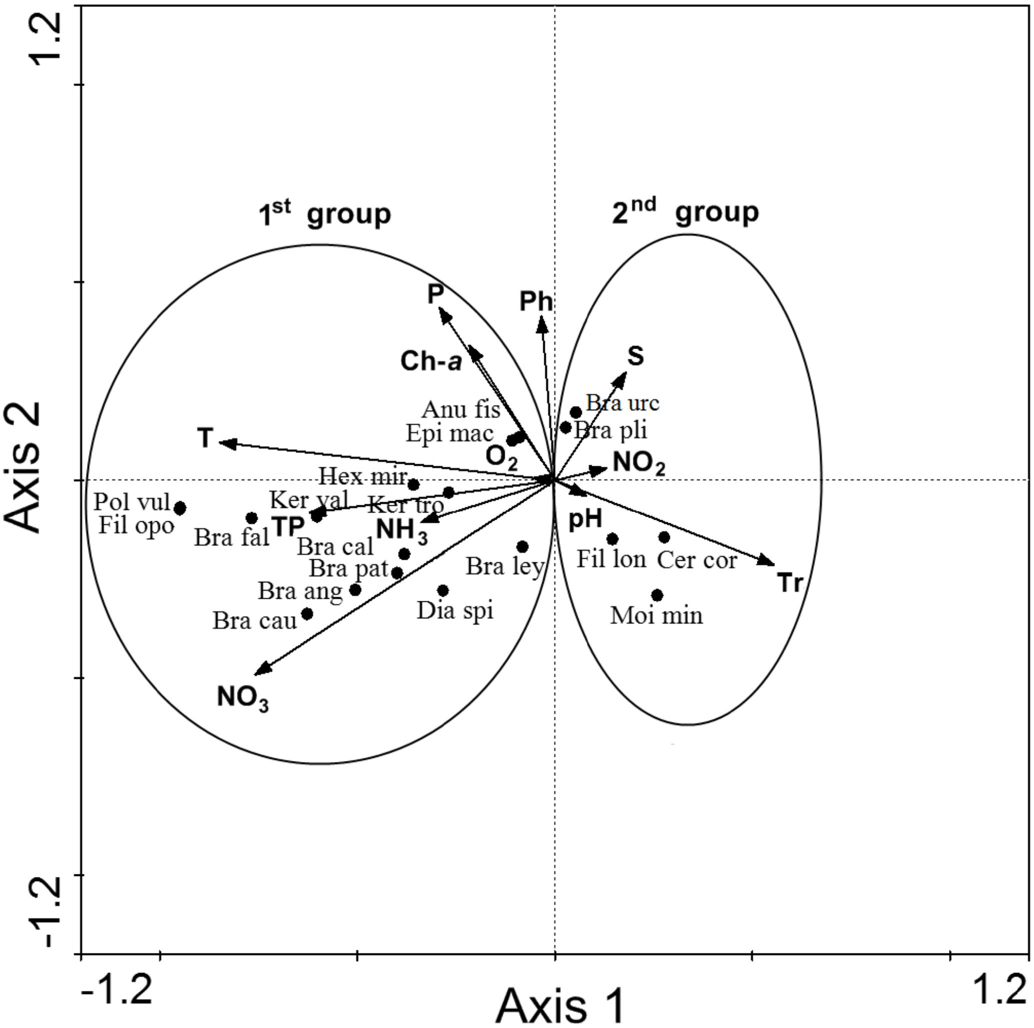

Figure 6. Ordination biplot of 19 zooplankton species (points) and 12 environmental variables (arrows) sampled at 9 permanent stations throughout a two-year period sampling effort at the Mossoró River Estuary. Cer cor: *Ceriodaphnia cornuta*; Bra cal: *Brachionus calyciflorus*; Bra ley: *B. leydigi*; Bra urc: *B. urceolaris*; Bra pli: *B. plicatilis*; Epi Mac: *Epiphanes macrourus*; Moi min: *Moina minuta*; Bra fal: *B. falcatus*; Bra cau: *B. caudatus*; Fil opo: *Filinia opoliensis*; Hex mir: *Hexarthra mira*; Ker tro: *Keratella tropica*; Dia spi: *Diaphanosoma spinulosum*; Bra pat: *B. patulus*; Bra ang: *B. angularis*; Anu fis: *Anuraeopsis fissa*; Fil lon: *F. longiseta*; Ker val: *Keratella valga*; Pol vul: *Polyarthra vulgaris*. S: salinity; T: temperature; Tr: water transparency; O_2: dissolved oxygen; NH_3: ammonia; NO_2: nitrite; NO_3: nitrate; TP: total phosphorous; Ch-*a*: Chlorophyll-*a*; Ph: Pheophytin; P: pluviometry.

According to mean total phosphorous values, the estuary was characterized as eutrophic during the dry seasons and hypereutrophic during the rainy seasons. Also, according to mean Chlorophyll-*a* values, the estuary was characterized as mesotrophic during the dry seasons and eutrophic during the rainy seasons (Carlson 1977).

Two species (*Epiphanes macrourus* and *Brachionus plicatilis*) showed positive relationships with salinity. The latter species has demonstrated great resistance to salinity fluctuations (Madhupratap 1986, Derry *et al.* 2003) and this may have also been the case for *E. macrourus*. In addition, the genus *Brachionus,* which is renowned to tolerate polluted waters (Sampaio *et al.* 2002, Dulic *et al.* 2006, Sousa *et al.* 2008), accounted for 80% of all individuals collected throughout the study span, suggesting an ecological plasticity for the species of this genus and further supporting the notion that only tolerant species are able to survive in highly dynamic environments. In extreme conditions predation and competition pressures could be reduced, and tolerant species may benefit by residing at these areas (Madhupratap 1986, Neumann-Leitão 1994, Herbst 2001).

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References

Anderson, D. M.; Gilbert, P. M.; Burkholder, J. M. 2002. Harmful algal blooms and eutrophication: nutrient sources, composition, and consequences. **Estuaries**, 25: 704-726.

APHA. 1995. **Standard methods for the examination of water and waste water**. American Public Health Association, Washington, 1524 p.

Ara, K. 2002. Temporal variability and production of *Temora turbinata* (Copepoda: Calanoida) in the Cananéia Lagoon estuarine system, São Paulo, Brazil. **Scientia Marina,** 66: 399-406.

Bos, D. G., Cumming, B. F., Watters, C. E. & Smol, J. P. 1996. The relationship between zooplankton, conductivity and lakewater ionic composition in 111 lakes from the Interior Plateau of British Columbia, Canada. **International Journal of Salt Lake Research**, 5: 1-15.

Breitburg, D. L., Sanders, J. G. & Gilmour, C. C. 1999. Variability in responses to nutrients and trace elements, and transmission of stressor effects through an estuarine food web. **Limnology and Oceanography**, 44: 837-863.

Carlson, R. E. 1977. A trophic state index for lakes. **Limnology and Oceanography**, 22: 361-380.

Coetzee, J. C., Adams, J. B. & Bate, G. C. 1996. A botanical importance rating system for estuaries. **Journal of Coastal Conservation**, 2: 131-138.

Derry, A. M., Prepas, E. E. & Hebert, P. D. N. 2003. A comparison of zooplankton communities in saline lakewater with variable anion composition. **Hydrobiologia**, 505: 199-215.

Dulic, Z. Mitrovic-Tutundzic, V., Markovic, Z. & Zivic, I. 2006. Monitoring water quality using zooplankton organisms as bioindicators at the Dubica fish farm, Serbia. **Archives of Biological Sciences**, 58: 245-248.

Forrester, G. E.; Dudley, T. L., Grimm, N. B. 1999. Trophic interactions in open systems: effects of predator and nutrients on stream food chains. **Limnology and Oceanography**, 44: 1187-1197.

Hammer, U. T. 1986. **Saline Ecosystems of the World**. Junk Publishers, Dordrecht, 632 p.

Hammer, U. T. 1993. Zooplankton distribution and abundance in saline lakes of Alberta and Saskatchewan, Canada. **International Journal of Salt Lake Research**, 2: 111-132.

Haney, J. F. & Hall, D. J. 1973. Sugar-coated *Daphnia*: A preservation technique for Cladocera. **Limnology and Oceanography**, 18: 331-333.

Herbst, D. B. 2001. Gradients of salinity stress, environmental stability and water chemistry as a templet for defining habitat types and physiological strategies in inland salt waters. **Hydrobiologia**, 466: 209-219.

Keller, W. & Conlin, M. 1994. Crustacean zooplankton communities and lake morphometry in Precambrian Shield lakes. **Canadian Journal of Fisheries and Aquatic Sciences**, 51: 2424-2434.

Krebs, C. J. 1989. **Ecological methodology**. HarpeCollins Publishers, New York, 654 p.

Lamberth, S. J. & Turpie, J. K. 2003. The role of estuaries in South African fisheries: economic importance and management implications. **African Journal of Marine Science**, 25: 131-157.

Lansac-Tôha, F. A. & Lima, A. F. 1993. Ecologia do zooplâncton do estuário do rio Una do Prelado (São Paulo, Brasil). **Acta Limnologica Brasiliensia**, 6: 82-96.

Lopes, R. M. 1994. Zooplankton distribution in the Guarau River Estuary (South-eastern Brazil). **Estuarine, Coastal and Shelf Science**, 39: 287-302.

Lopes, R. M. 1996. Hydrography and zooplankton community structure: a comparative study among estuaries of the Juréia-Itatins ecological station (Southeastern Brazil). **Revista Nerítica**, 10: 27-40.

Mackereth, F. J. H., Heron, J., Talling, J. F. 1978. Water analysis: some revised methods for limnologists. **Freshwater Biological Association Scientific Publication**, 36: 121.

Madhupratap, M. 1986. Zooplankton standing stock and diversity along an oceanic track in the western Indian Ocean. **Bulletin of the National Institute of Oceanography**, 16: 463-467.

Magalhães, A., Costa, R. M., Liang, T. H., Pereira, L. C. C. & Ribeiro, M. J. S. 2006. Spatial and temporal distribution in density and biomass of two *Pseudodiaptomus* species (Copepoda: Calanoida) in the Caeté River Estuary (Amazon region – North of Brazil). **Brazilian Journal of Biology**, 66: 421-430.

Matsumura-Tundisi, T. & Tundisi, J. G. 2003. Calanoida (Copepoda) species composition changes in the reservoirs of São Paulo State (Brazil) in the last twenty years. **Hydrobiologia**, 504: 215-222.

McLusky, D. S. & Eliott, M. 2004. **The estuarine ecosystem: ecology, threats and management**. Oxford University Press, London, 214 p.

Montú, M. 1980. Zooplâncton do estuário da Lagoa dos Patos. I. Estrutura e variações temporais e espaciais da comunidade. **Revista Atlântica**, 4: 53-72.

Mwaluma, J., Osore, M., Kamau, J. & Wawiye, P. 2003. Composition, abundance and seasonality of zooplankton in Mida Creek, Kenya. **Western Indian Ocean Journal of Marine Science**, 2: 147-155.

Nascimento-Vieira, D. A. & Sant'-Anna, E. M. E. 1989. Composition of zooplankton in the Timbó River estuary (Pernambuco-Brazil). **Trabalhos do Instituto Oceanográfico da Universidade Federal de Pernambuco**, 20: 77-97.

Neumann-Leitão, S., Paranaguá, M. N. & Valentim, J. L. 1992. The planktonic rotifers of the estuarine lagunar complex of Suape (Pernambuco, Brazil). **Hydrobiologia**, 232: 133-143.

Neumann-Leitão, S. 1994. Resenha literária sobre o zooplâncton estuarino no Brasil. **Trabalhos Oceanográficos**, 23: 25-53.

Osore, M. K., Tackx, M. I. M. & Daro, M. H. 1997. The effect of rainfall and tidal rhythm on the community structure and abundance of the zooplankton of Gazi Bay, Kenya. **Hydrobiologia**, 356: 117-126.

Paranaguá, M. N., Neumann-Leitão, S., Nogueira-Paranhos, J. D., Silva, T. A. & Matsumura-Tundisi, T. 2005. Cladocerans (Branchiopoda) of a tropical estuary in Brazil. **Brazilian Journal of Biology**, 65: 107-115.

Park, G. S. & Marshall, H. G. 2000. Estuarine relationships between zooplankton community structure and trophic gradients. **Journal of Plankton Research**, 1: 121-135.

Prado-Por, A. M. S. & Lansac-Tôha, F. A. 1984. The distribution of brackish water Calanoida (Copepoda) along the coasts of Brazil. **Hydrobiologia**, 113: 147-150.

Remane, A., Schlieper, C. 1971. **The biology of brackish waters**. Wiley Interscience, New York, 372 p.

Rodier, J. L., 1975. **Analyse de l'eau: Eaux naturelles, eaux residuals, eaux de mer**. Dunod, Paris, 692 p.

Rougier, C., Pourriot, R., Lam-Hoai, T. & Guiral, D. 2005. Ecological patterns of the rotifer communities in the Kaw River estuary (French Guiana). **Estuarine, Coastal and Shelf Science**, 63: 83-91.

Sampaio, E. V., Rocha, O., Matsumura-Tundisi, T. & Tundisi, J. G. 2002. Composition and abundance of zooplankton in the limnetic zone of seven reservoirs of the Paranapanema River, Brazil. **Brazilian Journal of Biology**, 62: 525-545.

Sassi, R. 1991. Phytoplankton and environmental factors in the Paraíba do Norte River estuary, northeastern Brazil: composition, distribution and quantitative remarks. **Boletim do Instituto Oceanográfico**, 39: 93-15.

Savenije, H. H. G., 2006. **Salinity and tides in alluvial estuaries**. Elsevier Science, Amsterdam, 208 p.

Seip, K. L. 1991. Phosphorus and nitrogen limitation of algal biomass across trophic gradients. **Aquatic Sciences - Research Across Boundaries**, 56: 1015-1621.

Simier, M., Blanc, L., Aliaume, C., Diouf, P. S. & Albaret, J. L. 2004. Spatial and temporal structure of fish assemblages in an "inverse estuary", the Sine Saloum system (Senegal). **Estuarine, Coastal and Shelf Science**, 59: 69-86.

Sokal, R. R. & Rohlf, F. J. 1995. **Biometry - the principles and practice of statistics in biological research**. W. H. Freeman & Company, New York, 887 p.

Sousa, W., Attayde, J. L., Rocha, E. S. & Anna, E. M. E. 2008. The response of zooplankton assemblages to variations in the water quality of four man-made lakes in semi-arid northeastern Brazil. **Journal of Plankton Research**, 30: 699-708.

ter Braak, C. J. F. 1986. Canonical correspondence analysis: a new eigenvector technique for multivariate direct gradient analysis. **Ecology**, 67: 1167-1179.

ter Braak, C. J. F. & Smilauer, P. 1998. **CANOCO Reference Manual and User's Guide to Canoco for Windows: Software for Canonical Community Ordination (version 4)**. Microcomputer Power, Ithaca, 332 p.

Toumi, N., Ayadi, H., Abid, O., Carrias, J. F., Sirne-Ngando, S., Boukhris, M. & Bouain, A. 2005. Zooplankton distribution in four ponds of different salinity: a seasonal study in the solar salterns of Sfax (Tunisia). **Hydrobiologia**, 534: 1-9.

Williams, W. D. 1998. Salinity as a determinant of the structure of biological communities in salt lakes. **Hydrobiologia**, 381: 191-201.

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