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Short and long-term temporal variation of the zooplankton in a tropical estuary (Amazon region, Brazil)

Variação temporal do zooplâncton em um estuário tropical (região amazônica, Brasil)

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Abstract: Nyctemeral and seasonal distribution of the zooplankton of the Taperaçu estuary and the effect of the hydrological parameters on the dynamics of these organisms were studied in March (rainy season) and September 2005 (dry season). Zooplankton samplings were carried out during spring tides at 2-hours intervals during a 24 h period. Samples were collected with a plankton net of 120 μm mesh size. Simultaneous temperature, salinity, pH and dissolved oxygen concentration measurements were accomplished at subsurface. The estuary presented a high seasonal variation in salinity (9.1-40.0) with regimes oscillating from mesohaline to polihaline/marine during the rainy and dry season, respectively. Temperature, pH and salinity were significantly higher during the dry season. A total of 50 taxa were identified, belonging to the following groups: Arthropoda, Sarcomastigophora, Cnidaria, Mollusca, Nematoda, Platyhelminthes, Bryozoa, Chordata, Annelida and Chaetognatha. Copepods dominated quantitatively the local zooplankton with 50% of the total organisms. Total zooplankton densities oscillated from 16,491 to 397,476 ind.m^{-3} during the dry and rainy season, respectively. Rainfall was the principal responsible for the hydrological parameters oscillations, mainly salinity, which influenced directly the population dynamics of the zooplankton of the Taperaçu estuary.

Keywords: Zooplankton. Tropical Coastal Zone. Amazon littoral. North Brazil.

Resumo: A distribuição nictemeral e sazonal do zooplâncton do estuário do Taperaçu e o efeito dos parâmetros hidrológicos na dinâmica desses organismos foram estudadas nos meses de março (período chuvoso) e setembro (período seco) de 2005. As amostragens do zooplâncton foram obtidas nas marés de sizígia em intervalos de duas horas durante um período de 24 h, coletadas com rede de plâncton de 120 μm. Simultaneamente às amostragens, foram medidas, na superfície da água, temperatura, salinidade, pH e oxigênio dissolvido com auxílio de um multi-analisador. O estuário apresentou uma elevada variação sazonal de salinidade (9,1-40,0) com regimes oscilando de mesohalino a polihalino/marinho durante os períodos chuvoso e seco, respectivamente. Os valores de temperatura, pH e salinidade foram significativamente mais elevados durante o período seco. Foram identificados 50 táxons incluídos nos seguintes grupos: Arthropoda, Sarcomastigophora, Cnidaria, Mollusca, Nematoda, Platyhelminthes, Bryozoa, Chordata, Annelida e Chaetognatha. Os copépodos dominaram quantitativamente o zooplâncton local com 50% dos organismos. A densidade total do zooplâncton variou de 16.491 a 397.476 ind.m^{-3} durante os períodos seco e chuvoso, respectivamente. A pluviometria local mostrou ser a principal responsável pela oscilação dos parâmetros hidrológicos, principalmente a salinidade, que influenciou diretamente a dinâmica populacional do zooplâncton do estuário do Taperaçu.

Palavras-chave: Plâncton. Zona Costeira Tropical. Litoral Amazônico. Norte do Brasil.

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INTRODUCTION

Estuaries are located at the interface between the continental and marine domains (Lam-Hoai *et al.*, 2006) and represent one of the most productive ecosystems worldwide (Day *et al.*, 1989). This productivity is associated with peculiar characteristics, such as the constant environmental fluctuations to which these ecosystems are subjected which are resultant from the marine and freshwater influxes, retaining nutrient and other substances that stimulate its productivity (Elliott & Mclusky, 2002).

In these ecosystems, spatial and temporal variations of zooplankton are driven by environmental factors (rainfall, tidal currents, amongst others), food availability and the interaction of these factors (Li *et al.*, 2000; Li *et al.*, 2006). Zooplankton population size appears to be controlled by tidal exchanges (Grindley, 1984) and distribution patterns seem to be related to the strength of freshwater output. For estuarine mangrove ecosystems that are not subject to high salinity variation (i.e. estuaries with restricted freshwater discharge), tides have a major influence on the structure and density of the zooplankton communities present within the estuary (Rodriguez, 1975; Robertson *et al.*, 1988).

The Amazon estuaries are characterized by semidiurnal macrotides and harbour the second largest continuous mangroves area on earth (Herz, 1991; Kjerfve *et al.*, 2002). Rainfall regimen and tidal circulation in these ecosystems appears to be among the principal factors underlying its productivity. Perhaps surprisingly, detailed studies on the estuarine zooplanktonic communities from the Amazon littoral are scant and essentially focused on copepods specific composition (Wright, 1936 a,b; Calef & Grice, 1967; Krumme & Liang, 2004), copepods biomass (Magalhães *et al.*, 2006) and on ichthyoplankton structure and dynamics (Barletta-Bergan *et al.*, 2002). Thus, the purpose of this study was to determine the nyctemeral and seasonal variation in the zooplankton composition of Taperaçu estuary and to evaluate the effect of the hydrological parameters on the distribution patterns of these organisms.

MATERIALS AND METHODS

Study area

The northern region of Brazil presents an extremely irregular and jagged coastline (Souza Filho & Paradella, 2001), consisting of numerous highly active estuaries extending from São Marcos Bay, in Maranhão State, until Oiapoque River mouth, in extreme north of Amapá State (Barthem, 1995). The Bragantine peninsula is located in this region, on the Northeast coast of Pará, and extends from Maiaú to Caeté River bay (00°46’00”-1°00’00”S and 46°36’00”-46°44’00”W), comprising 166 km^2 of mangrove area (Cohen *et al.*, 2005).

The Taperaçu estuary is situated on this peninsula and presents a semidiurnal macrotide regimen with tide heights varying from 4 to 6 meters during spring tides (Cohen *et al.*, 1999; DHN, 2007). Its margins are covered by different vegetation and dominated by mangrove species (*Rhizophora mangle* Linnaeus, 1753, *Avicennia germinans* (L.) Stearn, 1958 and *Laguncularia racemosa* (L.) Gaertn f. 1805), salt marshes, grasses and Ciperaceae.

It is located inside the Extractive Marine Reserve of Caeté-Taperaçu, which is used by riverine traditional extractive populations. Climate is equatorial hot and humid (Martorano *et al.*, 1993) with annual average temperature and rainfall of 25.50°C and 2,500 mm, respectively. This region shows two marked seasons: the rainy season (from December to May) and dry season (from June to November) (Souza-Filho & Paradella, 2001).

Sample collection and laboratory procedures

Zooplankton subsurface samples were collected each two hours in a fixed station (00°55’06.8”S and 46°44’00”W) (Figure 1) during a nyctemeral cycle through horizontal plankton hauls of 3 minutes performed with a 120 μm mesh size plankton net equipped with a mechanical flowmeter to estimate the filtered water volume. Collections were carried out in the spring tides of March/2005 (dry period) and September/2005 (rainy period). Retained

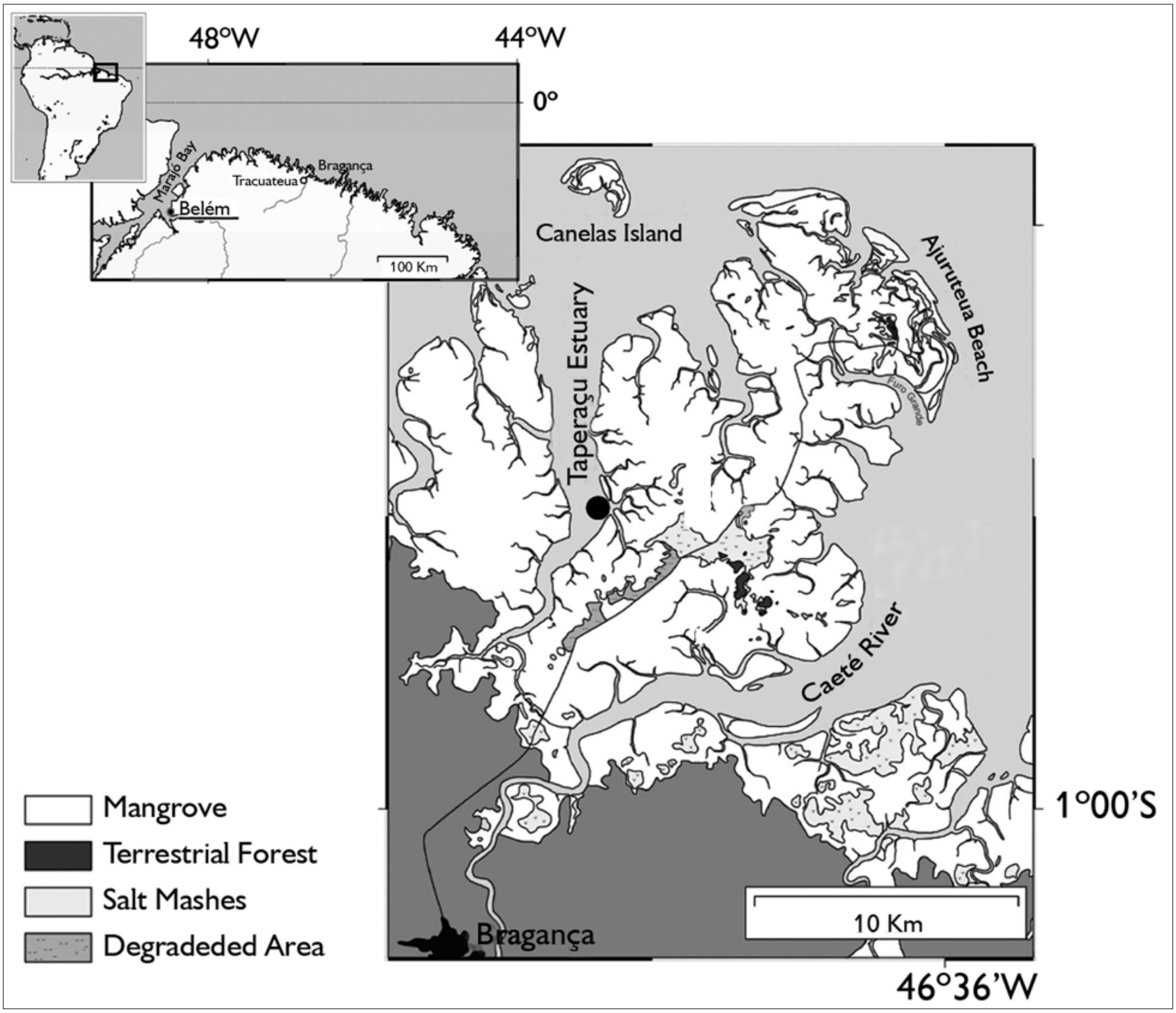

Figure 1. Location of the study area and sampled station (black arrow) in Taperaçu estuary (Bragança, Pará, Brazil) (Modified of MADAM Project).

organisms were immediately fixed in 4% neutral formalin (Sodium tetraborate – borax). Subsurface water samples were collected and analysed *in situ* to determine conductivity (salinity), temperature, dissolved oxygen and pH using a multiparameter analyser. Rainfall data from the meteorological station of Tracuateua (01°05'S and 47°10'W), located 17 km far from the county of Bragança, were obtained from the 'Instituto Nacional de Meteorologia' - INMET.

Samples were identified to the lowest taxonomic level possible under an stereoscopic microscopy using specific literature (Trégouboff & Rose, 1957; Boltovskoy, 1981; Boltovskoy, 1999). To compensate for uncertainty in identification procedures, genera and more extended groups were also considered. Prior to sorting and identifying the organisms, samples were fractioned with a Folsom Plankton Sample Splitter (McEwen *et al*., 1957) owing to the high abundance of organisms or detritus.

Frequency of occurrence was calculated and different taxa were grouped according to the criteria established by Matteucci & Colma (1982).

To evaluate the ecological patterns of zooplankton species from Taperaçu estuary, Shannon-Wiener specific diversity (H') and Pielou's equitability (J') were also calculated using the following equations:

$$H' = -\sum p_i . \log_2 p_i$$
$$J' = H' / \log_2 S$$

where *pi* is the number of individuals from species *i* divided by the number of individuals from all combined species (*ni/N*) and *S* corresponds to the total number of species in the sample.

Statistical analysis

Basic community data (organisms abundance and number of taxa) and community indices (Shannon-Wiener's diversity and Pielou`s equitability, using all taxonomic levels) were tested for differences among samples. The assumption of data normality and homogeneity of variances were tested through Lilliefors (Conover, 1971) and Bartlett's Chi-square test (Sokal & Rohlf, 1969), respectively, using STATISTICA 6.0 package (StatSoft, 2001). When data were not normal, log (x+1) transformations were performed to achieve near normality distributions. One-way ANOVA followed by Fisher LSD post-hoc test were applied to compare hydrological parameters (salinity, dissolved oxygen and temperature), total and most representative zooplankton densities, specific diversity and equitability between different day-night, seasonal and tide periods. However, when the variances were heterogeneous, non-parametric Mann-Whitney *U*-test was applied (Zar, 1999). To investigate similarities among periods, tides and sampling months, hierarchical agglomerative (WPGMA) analyses of similarity were calculated using Bray-Curtis similarity index and log (x+1) transformed total density (ind.m^{-3}) data using the PRIMER (Plymouth Routines Multivariate Ecological Research) statistical package, version 6.1.6. Spearman rank correlation analyses were also used to verify correlations between biotic and abiotic variables employing the computer software package, STATISTICA, version 6.0.

RESULTS

Monthly average rainfall registered between 2000 and 2005 varied from 2.20 mm (November) to 510.60 mm (March), characterizing two seasonal periods: dry period (August-December) and rainy period (January-July), showing a wide range during the annual cycle. In the sampled months, rainfall oscillated between 0.30 mm in September/2005 and 501.60 mm in March/2005, with a total annual amount of 1,820.50 mm, which represented a decrease of 5.1% with relation to the average obtained in the last 5 years (Figure 2).

At the sampling station, salinity varied from 9.10 (March, at 2:00 h) to 40.00 (September, at 20:00 and 22:00 h), presenting a seasonal pattern, with significantly higher values during the dry period (mean=36.66; F=523.57; p=0.0000). Temperature varied between 25.90°C and 30.10°C, in March and September, respectively, evidencing significantly higher values (mean=28.38; F=17.13; p=0.0004) during the dry period. Hidrogenionic potential (pH) revealed slightly acid to alkaline character during the sampled period, varying between 6.15 (March, at 12:00 h) and 7.92 (September, at 22:00 h), with significantly higher values (mean=7.63; U=0.00; p=0.0000) in the dry period. Dissolved oxygen concentrations oscillated between 2.80 mg.L^{-1} (March, at 02:00 h) and 5.90 mg.L^{-1} (September, at 12:00 h), showing lower values during the rainy period (mean=4.25; F=4.13; p=0.054). However, there were no significant differences between the studied parameters along the nyctemeral cycle and flood and ebb tides (Figure 3).

Taperaçu zooplankton community was represented by 38 Arthropod taxa, two taxa each of Cnidaria, Mollusca and Chordata, and one taxon each of Sarcomastigophora, Chaetognatha, Nematoda, Platyhelminthes, Bryozoa and Annelidea. Copepoda was the Subclass comprising

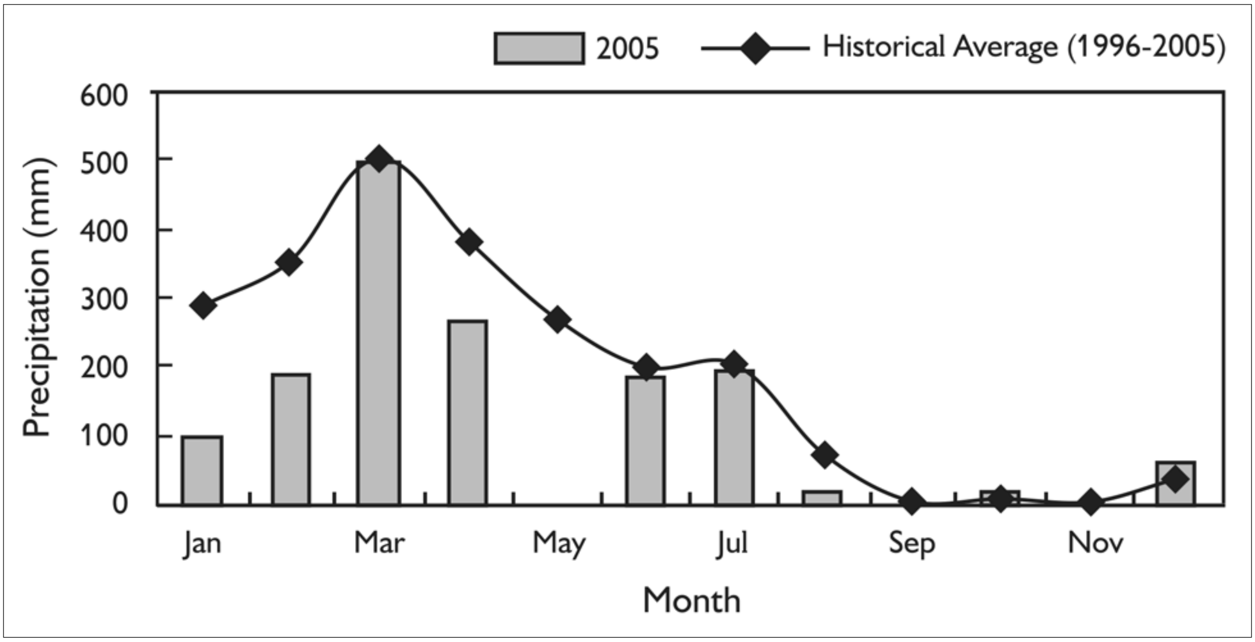

Figure 2. Monthly precipitation of Tracuateua Meteorological Station in 2005 (mm, histogram). Averaged monthly precipitation (mm, ♦-♦) in the last ten years (1996-2005) (Source: INMET, unpublished data).

the higher number of Arthropoda, with 25 taxa (50%) (Table 1), from which six were more representative.

Unidentified copepod nauplii and copepodites and *Oithona oswaldocruzi* were the most representative taxa with relative abundances varying from 4.8% (September, at 14:00 h) to 49.7% (March, at 14:00 h) and from 2.6% (March, at 02:00 h) to 42.1% (September, at 04:00 h), respectively, followed by unidentified Harpacticoida, *Paracalanus quasimodo*, *Pseudodiaptomus marshi,* brachyuran zoea, *Oithona hebes*, *Pseudodiaptomus acutus,* Cirripedia nauplii, Foraminifera, *Oikopleura dioica* and *Euterpina acutifrons*.

Densities of *P. acutus* varied significantly between seasonal periods (F=6.13; p=0.0214), with higher values registered during the rainy period. The same pattern was observed for brachyuran zoea (F=7.04; p=0.0144). *E. acutifrons* and Cirripedia nauplii showed significantly higher values during the dry period (U=14.5; p=0.0008 and U=34.00; p=0.0282, respectively) (Figure 4).

Only 10% of the identified taxa occurred in all samples (Unidentified copepod nauplii and copepodites, *Paracalanus quasimodo*, unidentified Harpacticoida, *Oithona oswaldocruzi* and Acari). Five (10%) and 2 taxa (4%) were observed exclusively during the dry and rainy periods, respectively, showing significant differences between these samples (F=5.88; p=0.0239). *P. richardi*, Amphipoda, *Calanopia americana*, *Centropages furcatus* and Trematoda were observed only in the dry period, while brachyuran megalopa, fish eggs and larvae were registered only during the rainy period (Table 1).

Total zooplankton density varied from 17,841 ind.m^{-3} to 397,476 ind.m^{-3} (121,037 ± 121,092 ind.m^{-3}) in March 2005. In September, the total density oscillated from 16,491 ind.m^{-3} to 262,570 ind.m^{-3} (mean=88,250 ± 80,202 ind.m^{-3}). Copepoda were dominant in both periods, with densities varying from 14,384 ind.m^{-3} to 287,469 ind.m^{-3} in March and from 11,857 ind.m^{-3} to 185,610 ind.m^{-3} in September. The other groups showed significantly higher densities during ebb tides (F=4.65; p=0.0421), varying from 3,456 ind.m^{-3} (March) to 166,898

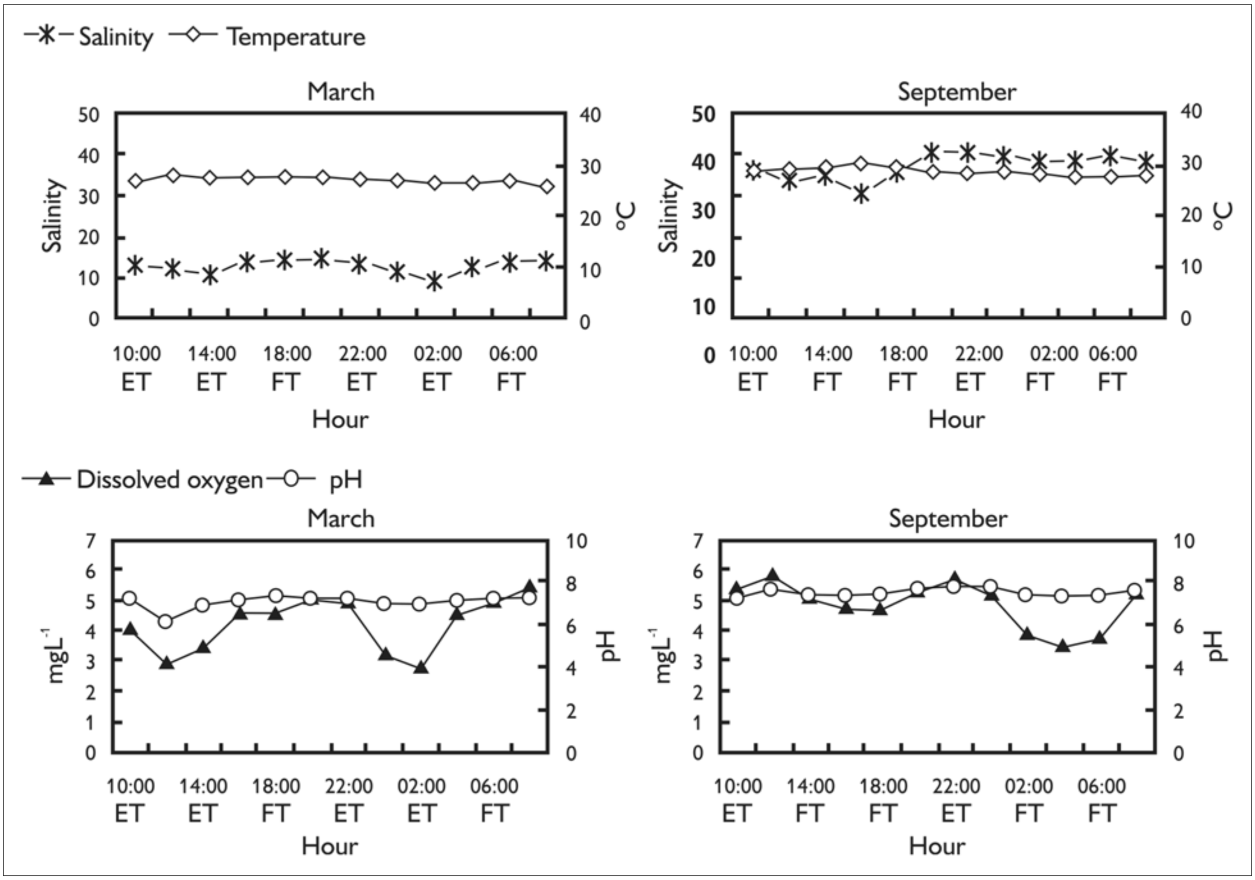

Figure 3. Nyctemeral variation of salinity, temperature, dissolved oxygen and pH in Taperaçu estuary. (ET) ebb tide, (FT) flood tide.

ind.m^{-3} (March) with average values of 22,406 ± 34,636 ind.m^{-3} (Figure 5). However, there were no significant differences between sampling hour or tide period for total zooplankton and Copepoda densities.

Diversity (H') oscillated between 1.29 bits.ind^{-1} (March, at 16:00 h) and 2.95 bits.ind^{-1} (March, at 00:00 h). Diversity indexes were significantly higher during the ebb tides (mean=2.17; F=20.52; p=0.0001). Equitability (J') varied significantly between tidal cycles, with higher values (mean=0.59; F=27.13; p=0.0000) observed during the ebb tides. The lowest and highest values were registered in September at 06:00 h (0.36) and at 08:00 h (0.78) (Figure 6).

Cluster analysis (77% of similarity) based on species density in each sample showed three well defined groups (Figure 7). The first group (1) included samples of both seasonal periods, which presented the highest densities of *Oithona oswaldocruzi* (from 7,353 ind/m^{-3} to 61,869 ind/m^{-3}). However, this group could be divided into two subgroups: 1a, comprised of rainy period samples with the highest observed densities; and 1b, including samples obtained in the dry period. Group 2 comprised samples collected in September (dry period) showing high densities of *Paracalanus quasimodo*. Group 3 was constituted of samples collected in the rainy period, with unidentified copepod nauplii and copepodites presenting the highest densities. Group formation showed a clear seasonal variation concerning to zooplankton composition and abundance.

Spearman correlation coefficient revealed a significant positive correlation between temperature and Cirripedia

Table 1. Mean density (± SD, ind.m^{-3}) and relative abundance (RA, %) of zooplankton taxa that occurred in the Taperaçu estuary, Pará State, Brazil. (continue)

TAXA	RAINY SEASON		DRY SEASON	
	Mean ± SD	RA	Mean ± SD	RA
Foraminifera	2112 ± 1966	3.32	4265 ± 6953	4.02
Hydromedusae	452 ± 1266	0.25	383 ± 362	0.44
Polyps	49 ± 113	0.02	69 ± 141	0.08
Nematoda	1002 ± 843	1.04	909 ± 1614	0.74
Trematoda	0	0.00	16 ± 44	0.02
Polychaeta larvae	692 ± 1201	0.49	914 ± 886	1.06
Bivalve larvae	813 ± 1781	0.47	1593 ± 2016	1.68
Gastropoda larvae	814 ± 710	0.77	1008 ± 1248	1.17
Acari	1121 ± 738	1.49	934 ± 746	1.34
Unidentified crustacean nauplii and larvae	11 ± 31	0.04	249 ± 492	0.24
Cirripedia nauplii	4511 ± 7512	3.25	5867 ± 4031	8.18
Acartia copepodites	1419 ± 2589	0.91	3810 ± 3735	4.21
Acartia lilljeborgi Giesbrecht, 1892	3664 ± 6246	2.21	3817 ± 4566	3.59
Acartia tonsa Dana, 1848	1656 ± 2115	1.41	2447 ± 3574	2.20
Calanopia americana Dahl, 1894	0	0.00	40 ± 107	0.04
Centropages furcatus Dana, 1849	0	0.00	5 ± 13	0.01
Copepods parasitic	88 ± 305	0.02	2 ± 6	0.01
Euterpina acutifrons Dana, 1847	2261 ± 7557	0.66	3570 ± 3792	3.93
Labidocera copepodites	140 ± 455	0.45	68 ± 217	0.04
Labidocera fluviatilis Dahl, 1894	100 ± 145	0.09	143 ± 374	0.10
Microsetella rosea Dana, 1847	1837 ± 2893	1.86	767 ± 825	1.07
Unidentified copepod nauplii and copepodites	28623 ± 40085	24.13	10327 ± 10773	10.92
Oithona hebes Giesbrecht, 1891	3855 ± 3058	3.87	3823 ± 4640	5.38
Oithona oswaldocruzi Oliveira, 1945	22167 ± 18261	21.92	18886 ± 18559	23.25
Paracalanus quasimodo Bowman, 1971	8033 ± 11291	5.20	10195 ± 11359	11.18
Parvocalanus crassirostris Dahl, 1894	1762 ± 2643	1.32	2697 ± 3115	2.87
Pseudodiaptomus acutus Dahl, 1894	4471 ± 12125	2.45	99 ± 139	0.11
Pseudodiaptomus copepodites	1253 ± 3636	0.61	143 ± 289	0.18
Pseudodiaptomus marshi Wright, 1936	2828 ± 5187	3.20	332 ± 780	0.29
Pseudodiaptomus sp.	364 ± 729	0.56	25 ± 48	0.06
Pseudodiaptomus richardi Dahl, 1894	0	0.00	2 ± 8	0.01
Subeucalanus copepodites	38 ± 131	0.03	105 ± 271	0.09
Subeucalanus crassus Giesbrecht, 1888	38 ± 131	0.01	35 ± 65	0.03
Subeucalanus pileatus Giesbrecht, 1888	289 ± 955	0.08	362 ± 476	0.34
Tisbe sp.	852 ± 1222	0.92	586 ± 1719	0.34

Table 1 (conclusion)

TAXA	RAINY SEASON		DRY SEASON	
	Mean ± SD	RA	Mean ± SD	RA
Unidentified Harpacticoida	11383 ± 10672	10.93	7725 ± 12056	6.05
Ostracoda	197 ± 250	0.26	94 ± 154	0.14
Mysidacea	16 ± 54	0.01	22 ± 47	0.03
Amphipoda	0	0.00	34 ± 81	0.04
Isopoda larvae	3 ± 12	0.01	23 ± 72	0.02
Unidentified Epicaridea	324 ± 515	0.25	78 ± 122	0.11
Brachyuran megalopa	16 ± 54	0.03	0	0.00
Brachyuran zoea	6916 ± 20251	3.16	348 ± 396	0.54
Shrimp larvae	38 ± 131	0.01	16 ± 54	0.01
Shrimp protozoea	19 ± 65	0.00	31 ± 109	0.02
Lucifer faxoni Borradaille, 1915	107 ± 262	0.04	1 ± 5	0.00
Cyphonautes larvae	3 ± 10	0.01	167 ± 287	0.12
Sagitta friderici Ritter-Záhony, 1911	888 ± 1323	0.63	808 ± 777	0.92
Oikopleura dioica Fol, 1872	3798 ± 11297	1.37	3007 ± 3723	2.78
Fish eggs and larvae	74 ± 100	0.11	0	0.00
Total zooplankton	121098 ± 120999	-	90848 ± 86515	-

nauplii density ($r=0.42$; $p<0.05$). *E. acutifrons* densities showed significant and positive correlation with temperature ($r=0.45$; $p<0.05$), salinity ($r=0.67$; $p<0.05$), dissolved oxygen ($r=0.52$; $p<0.05$) and pH ($r=0.71$; $p<0.05$). *O. dioica* was significantly positively correlated with salinity ($r=0.44$; $p<0.05$), dissolved oxygen ($r=0.48$; $p<0.05$) and showed a highly significant positive correlation with pH ($r=0.51$; $p<0.05$). Brachyuran zoea showed a negative significant correlation with salinity ($r=-0.40$; $p<0.05$) and temperature ($r=-0.47$; $p<0.05$). *P. marshi* and *P. acutus* densities were significantly negatively correlated with pH ($r=-0.40$; $p<0.05$ and $r=-0.52$; $p<0.05$, respectively), although this last species showed a highly significant negative correlation with salinity ($r=-0.55$; $p<0.05$).

DISCUSSION

According to the classification of estuaries (Mouny & Dauvin, 2002; Li *et al.*, 2006 and references therein), Taperaçu estuary can be classified as a system with restricted freshwater influx characterized by a horizontal salinity and temperature gradient throughout the year (unpublished data). However, salinity differences are more accentuated between dry and rainy seasons, varying strongly as a consequence of the high rainfall observed mainly during the rainy period (monthly average values from 202.00 to 510.60 mm). The influence of a semidiurnal macrotide with heights varying from 4 to 6 m (DHN, 2007) to which this estuary is subjected allows the incursion of coastal waters controlled by the river influx and regulate together with rainfall, environmental parameters variation and the structure of plankton communities.

During the field work, the rainfall data obtained from Taracuateua's Metereological Station (40 km from Taperaçu estuary) showed two seasonal periods: the rainy season (from January to July) and the dry season (from August to December). The observed periods are typical for Pará State (Northern Brazil), although they usually occur in most places from December

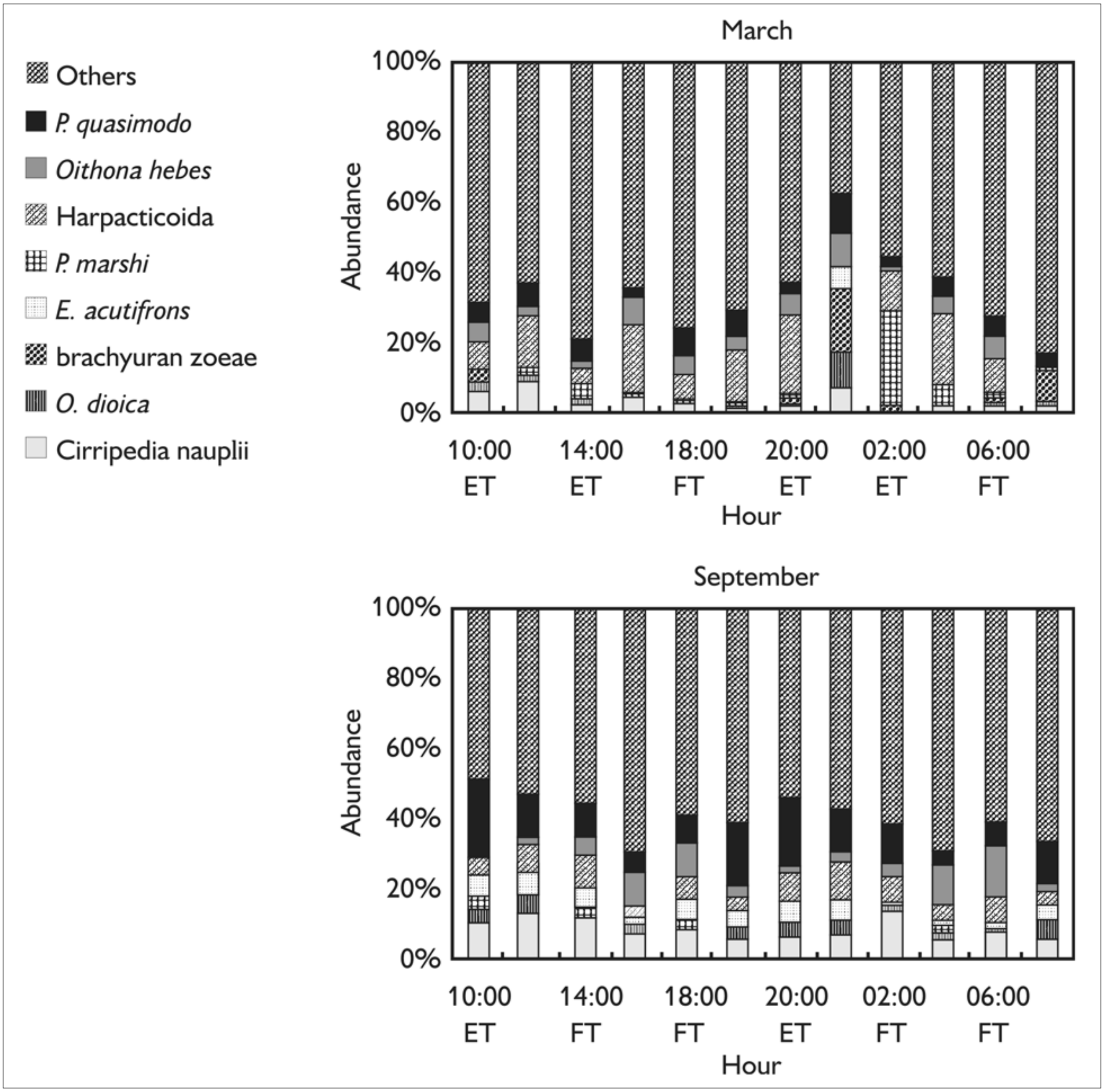

Figure 4. Zooplankton relative abundance in Taperaçu estuary, Pará, Brazil, in two seasonal periods (rainy and dry season). (ET) ebb tide, (FT) flood tide.

to May and from June to November, respectively, with a reported delay for the beginning of the rainy season in the Bragantine zone (Moraes *et al.*, 2005). Salinity and temperature are indicated as crucial factors controlling spatial and vertical distribution of zooplankton (Schumann & Pearce, 1997; Kibirige & Perissinotto, 2003; Telesh, 2004) and their importance in determining the composition and distribution of these organisms are well documented (Beaugrand *et al.*, 2000; Li *et al.*, 2006). In the present study, salinity showed a strongly

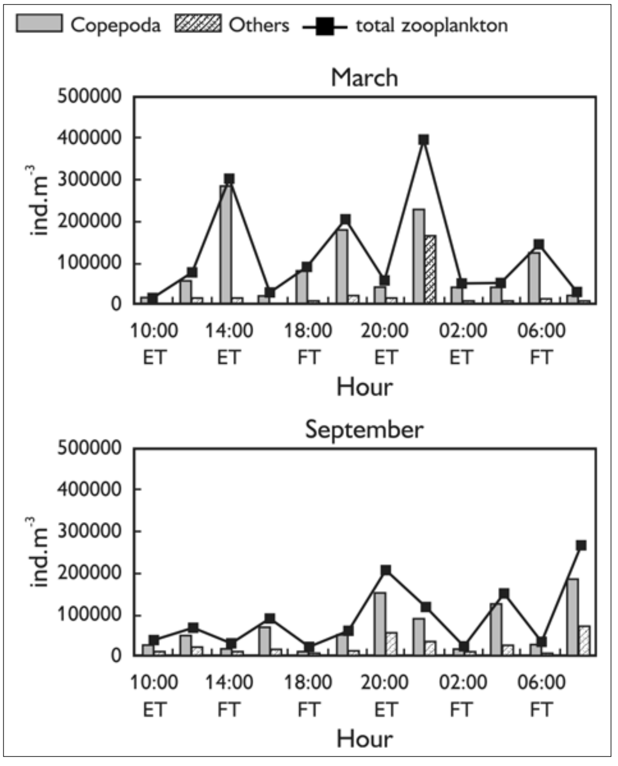

Figure 5. Zooplankton densities (ind.m^{-3}) in Taperaçu estuary, Pará, Brazil, in March 2005 (rainy season) and September 2005 (dry season). (ET) ebb tide, (FT) flood tide.

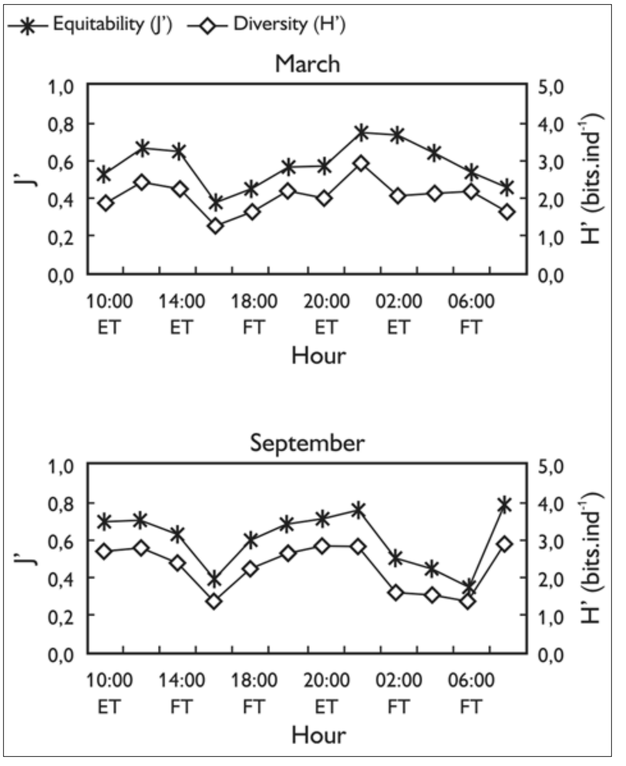

Figure 6. Copepods equitability (J') and diversity (H') in Taperaçu estuary, Pará, Brazil, in March 2005 (rainy season) and September 2005 (dry season). (ET) ebb tide, (FT) flood tide.

seasonal variation, which was related mainly to the observed pluviometric indices that were five hundred times higher during the rainy season. Variation in salinity as a consequence of rainfall regimen has been reported for other Northeastern tropical Brazilian estuaries (Lacerda *et al.*, 2004), but it is more distinct for the estuaries in Northern Brazil, where it may vary from 0 to 39 (Magalhães *et al.*, 2006; Diele & Simith, 2006). In Taperaçu estuary, pluviometric indices and consequently salinity variations influenced the zooplanktonic community structure, which was dominated by copepods and other estuarine, coastal, and oceanic zooplankton species.

Zooplankton composition of Taperaçu estuary was similar to that reported from other Brazilian estuaries, dominated by holoplanktonic organisms (Sterza & Fernandes, 2006). Copepoda, Brachyura, Cirripedia, Foraminifera and Appendicularia were the principal identified groups during the studied period. Unidentified copepod nauplii and copepodites, *Oithona oswaldocruzi*, *O. hebes*, *Pseudodiaptomus marshi*, *P. acutus*, *Paracalanus quasimodo*, unidentified Harpacticoida and *Euterpina acutifrons* were also dominant, with some of them being recorded from previously studied estuaries in the Bragantine Peninsula (Krumme & Liang, 2004; Magalhães *et al.*, 2006).

Pseudodiaptomus richardi, Amphipoda, *Calanopia americana*, *Centropages furcatus* and Trematoda occurred exclusively during the dry period, showing the importance of salinity for the occurrence and population density of the referred taxa in Taperaçu estuary. On the other hand, brachyuran megalopa, fish eggs and larvae were registered only during the rainy period. The occurrence of brachyuran megalopa only in the rainy period agreed

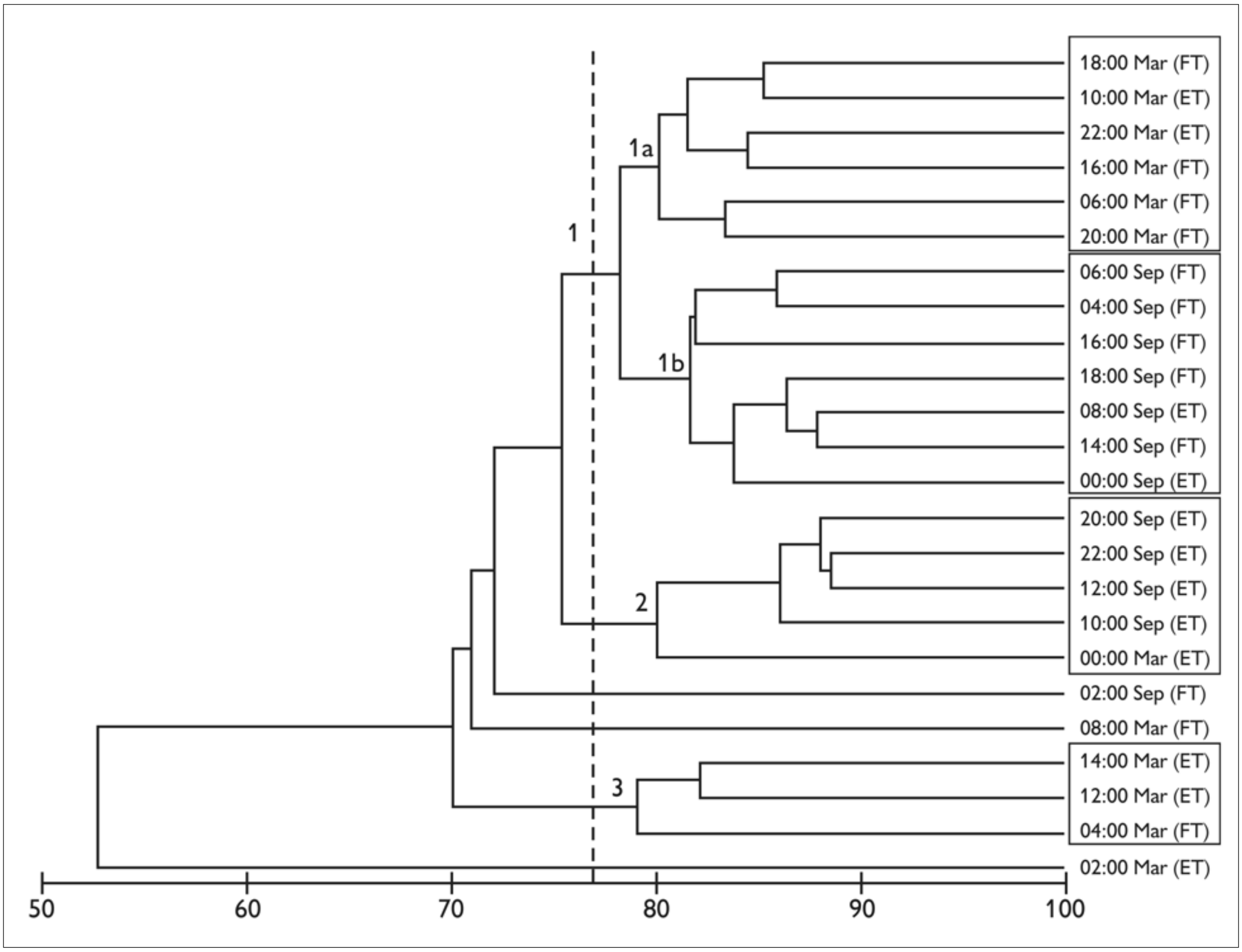

Figure 7. Dendrogram resulting from Bray & Curtis analysis of 24 zooplankton samples at Taperaçu estuary, Pará, Brazil, in March 2005 (rainy season) and September 2005 (dry season). (ET) ebb tide, (FT) flood tide.

well with data obtained by Diele (2000), who reported that the reproductive period of *Ucides cordatus* Linnaeus, 1763 (main Brachyura species of Amazon mangroves) in the Bragantine Peninsula is seasonal, occurring only in the rainy season (March to April).

Zooplankton total densities showed a markedly seasonal variation, with the highest values observed during the rainy season. The pluviometric regimen influenced not only hydrological parameters, but also the number of identified species which presented the highest values with the increase in salinity. At Vitoria Bay estuarine system (Southeastern Brazil), Sterza & Fernandes (2006) registered the highest zooplankton densities and diversity at the stations where the highest salinities were observed. In the present study, the contribution of coastal species increases diversity by the recruitment of coastal adjacent areas. This behavior was also described by other authors for tropical estuaries (French Guiana: Lam-Hoai *et al.*, 2006) with similar characteristics as those recorded in Taperaçu estuary.

Diel vertical migration of the zooplankton organisms was not observed due to absence of stratification in the studied station sector as a consequence of both strong local hydrodynamic (e.g. equinoctial spring tide/ September and March, strong winds/September and high precipitation rates/March) and low local depth (up to 6.0 m). Different results can be found in environments of lower energy level, such as lakes or stratified estuary (Cardoso, 2000; Perticarrari *et al.*, 2004).

Cluster analyses separate samples of March and September, confirming the seasonal variation of zooplankton species composition and abundance (Figure 7). *Oithona oswaldocruzi* was observed in 100% of the collected samples, showing the estuarine character of this species, just as it was observed for other estuarine systems (Ara, 2004). *Paracalanus quasimodo* shows a euhaline-marine behavior, preferring areas with high salinities (Lopes *et al.*, 1998), which explains its high abundances during the dry period in the studied station in Taperaçu estuary.

Spearman correlation coefficient showed a significant positive correlation between temperature and Cirripedia nauplii. Thus, it suggests that high densities of these organisms could be partly attributed to the highest water temperatures observed in the dry period. Also, the increased salinity during this period appears to corroborate the increase in nauplii densities, although the obtained data disagree with previous studies performed in the Caeté estuary (Bragantine region), which showed the dominance of settled *Fistulobalanus citerosum* Henry, 1973 (February and March) on artificial substrates during the rainy period (Marques-Silva, 2002). Probably, these observed differences could be attributed to environmental peculiarities or the breading period of a different species in Taperaçu estuary.

Euterpina acutifrons showed a significant positive correlation with temperature, salinity, dissolved oxygen and pH. This species is well represented in estuarine eutrophic ecosystems (Boltovskoy, 1981) and has been reported as one of the most abundant copepod species in South Atlantic coastal zones, occurring mainly during the dry period (Pereira *et al.*, 2005; Sterza & Fernandes, 2006).

Oikopleura dioica, a typical marine species also found in estuarine polyhaline zones (Mouny & Dauvin, 2002), showed a significant positive correlation with salinity, dissolved oxygen and pH, presenting the highest densities during the dry period.

Although Silva *et al.* (2003) reported that larvae abundance of principal zooplankton taxa, mainly Decapoda larvae, was higher during the dry season in a Northeastern tropical Brazilian estuary, the present work showed a significant negative correlation between brachyuran zoea density and salinity and temperature. The obtained results, as explained before for megalopa larvae, were directly related to the breading period of *Ucides cordatus* which is reported to occur in this area during the rainy season (Diele, 2000).

A significant negative correlation was observed between *Pseudodiaptomus marshi* density and pH. The highest abundances recorded during the rainy period agreed well with data reported in Caeté estuary (Bragantine zone) by Magalhães (2003), who described the preference of this species for less saline estuarine zones. *Pseudodiaptomus acutus* density presented a highly significant negative correlation with pH and salinity, respectively. These results do not agree with those reported for Brazilian subtropical estuaries (Tundisi & Matsumura-Tundisi, 1968; Montú & Cordeiro, 1998), and neither with those recorded by Magalhães *et al.* (2006) in the Caeté estuary (Northern Brazil), which did not observe a clear distribution pattern for this copepod species.

CONCLUSION

The present results indicate that rainfall is the principal factor responsible for the oscillations of hydrological parameters oscillations, mainly salinity, which strongly influenced the zooplankton community temporal variation in the Taperaçu estuary.

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