SPATIAL AND TEMPORAL DISTRIBUTION IN DENSITY AND BIOMASS OF TWO *Pseudodiaptomus* SPECIES (COPEPODA: CALANOIDA) IN THE CAETÉ RIVER ESTUARY (AMAZON REGION - NORTH OF BRAZIL)

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(With 5 figures)

ABSTRACT

Spatial and temporal density and biomass distribution of the planktonic copepods *Pseudodiaptomus richardi* and *P. acutus* along a salinity gradient were investigated in the Caeté River Estuary (North-Brazil) in June and December, 1998 (dry season) and in February and May, 1999 (rainy season). Copepod biomass was estimated using regression parameters based on the relation of dry weight and body length (prosome) of adult organisms. The Caeté River Estuary was characterized by high spatial and temporal variations in salinity (0.8-37.2‰). Exponential length-weight relationships were observed for both *Pseudodiaptomus* species. Density and biomass values oscillated between 0.28-46.18 ind. m^{-3} and 0.0022-0.3507 mg DW. m^{-3} for *P. richardi*; and between 0.01-17.02 ind. m^{-3} and 0.0005-0.7181 mg DW. m^{-3} for *P. acutus*. The results showed that the contribution of *P. richardi* for the secondary production in the Caeté River Estuary is more important in the limnetic zone than in other zones where euhaline-polyhaline regimes were predominant. However, it was not possible to observe a clear pattern of spatial and temporal distribution for *P. acutus*.

Keywords: *Pseudodiaptomus*, Caeté River Estuary, biomass, spatial and temporal distribution, Brazil.

RESUMO

Variação espacial e temporal da densidade e biomassa de duas espécies de *Pseudodiaptomus* (Copepoda, Calanoida) no estuário do rio Caeté (Região Amazônica - Norte do Brasil)

A distribuição espacial e temporal da densidade e biomassa dos copépodos planctônicos *Pseudodiaptomus richardi* e *P. acutus*, ao longo de um gradiente de salinidade, foi estudada no Estuário do Rio Caeté (Norte do Brasil) durante os meses de junho e dezembro de 1998 (estação seca) e fevereiro e maio de 1999 (estação chuvosa). A biomassa dos copépodos foi estimada a partir de parâmetros da regressão baseada na relação entre o peso seco e o comprimento do corpo (prossoma) de organismos adultos. O Estuário do Rio Caeté caracterizou-se por uma grande variação espacial e sazonal na salinidade (0,8-37,2‰). A relação peso-comprimento para ambas as espécies de *Pseudodiaptomus* foi do tipo exponencial. Os valores de densidade e biomassa oscilaram entre 0,28-46,18 ind. m^{-3} e 0,0022-0,3507 mg DW. m^{-3} para *P. richardi*; e entre 0,01-17,02 ind. m^{-3} e 0,0005-0,7181 mg DW. m^{-3} para *P. acutus*. Os resultados revelaram que a contribuição de *P. richardi* para a produção secundária no Estuário do Rio Caeté é mais importante na zona liminética que em outras zonas onde foram dominantes os regimes eurihalino-polihalino. Contudo, para *P. acutus* não foi possível observar de forma clara um padrão de distribuição espacial e temporal para a área estudada.

Palavras-chave: *Pseudodiaptomus*, Estuário do Rio Caeté, biomassa, distribuição espacial e temporal, Brasil.

INTRODUCTION

Among other organisms, copepods are involved in the turnover of nutrients and regulation of phytoplanktonic populations on which they feed. As part of the food chain, they contribute to transferring energy and organic matter from the primary producers to the main consumers of the aquatic system, including various fish species of commercial value (Parsons *et al.*, 1984). Recent studies have also highlighted the role of copepods when using carbon produced by the microbial loop (Pace & Cole, 1996; Champalbert & Pagano, 2002; Osidele & Beck, 2004).

Planktonic copepods of the *Pseudodiaptomus* genus are worldwide distributed and commonly found in estuarine waters (Walter, 1986). Along the Brazilian coastline, four species (*Pseudodiaptomus richardi* Dahl, *Pseudodiaptomus acutus* Dahl, *Pseudodiaptomus marshi* Wright and *Pseudodiaptomus gracilis* Dahl) were recorded (Björnberg, 1981). Among them, *P. richardi* and *P. acutus* were noted to be widely distributed, spreading in many tropical and subtropical Brazilian estuarine waters from the Tocantins River Estuary, Pará (Cipólli & Carvalho, 1973), North of Brazil, to the Patos Lagoon, Rio Grande do Sul (Montú, 1980), South of Brazil.

Spatial and temporal studies of copepod biomass, production and distribution, are of major importance to assess copepods 1) contribution in the production and flux of particulate/dissolved organic matter and 2) role in estuary trophodynamics (Froneman, 2001; Perissinotto *et al.*, 2003). Copepods are also known as key factors in controlling fish stock size (Payne & Rippingale, 2001; Evjemo *et al.*, 2003). From the larval to the adult stage, they constitute a major component in the diet of numerous zooplanktophage fish (Nielsen & Munk, 1998; Xie & Yang, 2000).

Most studies on copepods from the North Brazilian coast focused mainly on the specific composition of these organisms (Wright, 1936a,b; Calef & Grice, 1967), providing little data on copepod biomass and production in Amazonian estuaries. The aim of the present work is to study spatial and temporal distribution patterns in terms of density and biomass of two species of planktonic copepods (*P. richardi* and *P. acutus*), regarding the salinity gradient in the Caeté River Estuary.

MATERIAL AND METHODS

Study area

The Caeté River Estuary (0° 45' - 1° 07' S and 46° 50' - 46° 30' W), in the municipality of Bragança (Pará-Brazil), is situated approximately 150 km south of the Amazon River Delta and is a permanently open estuary characterized by high turbidity and shallow waters of approximately 10 m depth (Lara, 2003). It is dominated by a semi-diurnal tidal cycle, with tides ranging between 2.5 and 5.5 m. The Caeté River is 100 km long, with a freshwater catchment basin of 3.000 km^2 (Schwendenmann, 1998) and a flooded area of approximately 110 km^2 (Cohen *et al.*, 1999). The climate is equatorially humid, with a rainy season that usually extends from January to May, while the dry or less rainy season is from June to December. This seasonal pattern is a result of the convergence zone drift above the region. Long-term data from the Tracuateua Meteorological Station located 50 km south-west of Bragança are presented (Fig. 1). Annual average rainfall and temperature are about 2,500 mm and 25.5 °C, respectively, with 75% of the precipitation falling in the rainy season (INMET, 1992). The discharge of the Caeté River ranges from 180 m^3. s^{-1} in the rainy season to 0.3 m^3. s^{-1} in the dry season (Lara & Dittmar, 1999).

Sampling methods

The sampling area was divided into three regions, according to the salinity gradient of the estuary: upper (A), middle (B) and lower estuary (C) (Fig. 2).

Zooplankton samples were collected in June and December, 1998 (dry season) and February and May, 1999 (rainy season). Each sample consisted of a 5 min sub-surface haul towing a conical plankton net (300 μm mesh size, 1 m long and 0.32 m in mouth opening diameter). The actual volume filtered per netting haul was calculated using a digital flowmeter with a standard rotor (Hydrobios-Kiel, Model 438 110) attached to the mouth of the net. After collection, the net samples were preserved in 4% buffered formalin-seawater solution. Surface salinity measurements were registered in all sampling procedures using an optical refractometer (Atago, Model S/Mill-E).
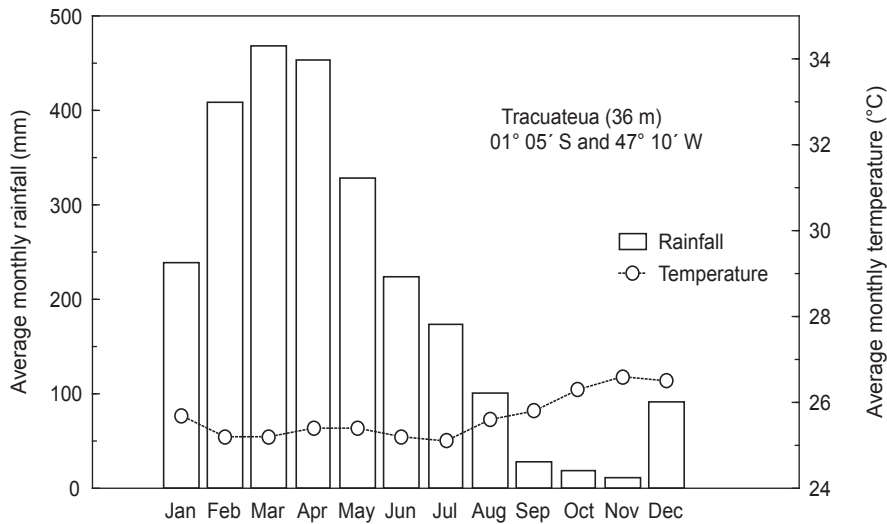
Fig. 1 — Climate diagram of Tracuateua Meteorological Station. (*Source*: INMET, 1992).

Three replicates were taken consecutively in each studied area (upper, middle and lower estuary), in the spring tide and sampled in the downstream direction, producing a total of 36 plankton samples. Plankton hauls were performed using a small powerboat at an average speed of 1.5 Knots.

Laboratory procedures

Subsamples were obtained to determine numerical density and biomass using a Folsom plankton splitter. Copepods were counted and identified under a stereoscopic microscope. In the present study, only the adult stages of *P. richardi* and *P. acutus* were considered, as the use of a 300 μm mesh-size net did not allow for a proper sampling of the juvenile stages (CI-CV).

The length of the specimens (prosome length) was measured using an eyepiece micrometer with the animals placed in a lateral position to avoid possible errors that could be triggered by the body curvature. After being measured, the animals were rinsed with a small amount (0.5-1 mL) of distilled water and placed in small, pre-weighed, aluminum foil dishes (40 mm in diameter). The latter were then dried at 60 °C in an electric oven for 24 h and then cooled in a desiccator with silica gel at room temperature, and their dry weights were measured using an electronic microbalance (Sartorius, Model BP-410S). Weight loss subsequent to formalin use

was not taken into consideration (Chisholm & Roff, 1990).

Individuals were divided into different length classes (15 classes represented by three replicate groups of 100 individuals for *P. richardi* and 14 classes with three replicate groups of 10 individuals for *P. acutus*). The smaller number of individuals used from *P. acutus* was due to their lower density. Class intervals were of 40 μm and different numbers of classes are related to the dimensions of different species.

Biomass was estimated by the product of density (ind. m^{-3}) of each length class and the average dry weight of individuals sampled in each class (DW, μg), which was calculated from prosome length (L, μm), by an exponential length-weight regression equation, shown as:

$$DW = ae^{bL} \qquad (1)$$

Where *a, b* and *e* are constant.

Statistical analysis

Correlation between the density of *Pseudodiaptomus* species and salinity were assessed using the Spearman rank correlation analysis. A Kruskal-Wallis non-parametric ANOVA was used to test differences in density and biomass of *Pseudodiaptomus* on a spatial and temporal scale
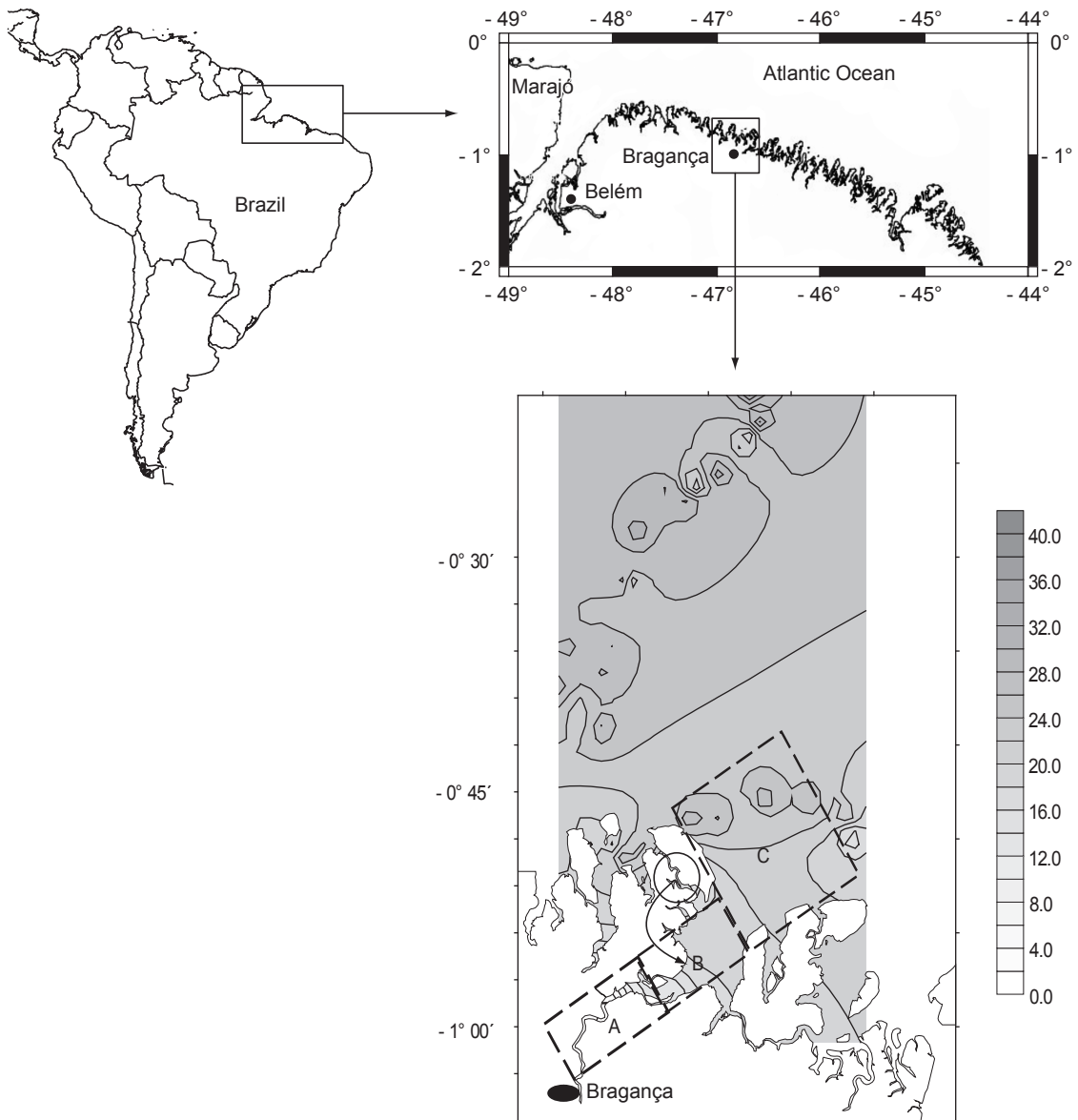
Fig. 2 — Geographical location of the Caeté River Estuary and position of the three sampling areas in relation to the salinity (‰) gradients defining the upper (A); middle (B); and lower (C) estuary.

(Zar, 1999). The analysis was performed with the computer software package STATISTICA 5.0.

RESULTS

The Caeté River Estuary had high temporal and spatial variations of salinity, with increasing values from the upper to the lower estuary (Fig. 3). The lowest average value (0.8‰) was observed in the inner part of the estuary in the rainy season (May).

Conversely, the highest value (37.2‰) was found in the lower estuary in the dry season (December).

The Spearman coefficient (rs) between salinity and average density of *P. richardi* showed a significant negative correlation between these two parameters (rs = - 0.78; p < 0.05). On the other
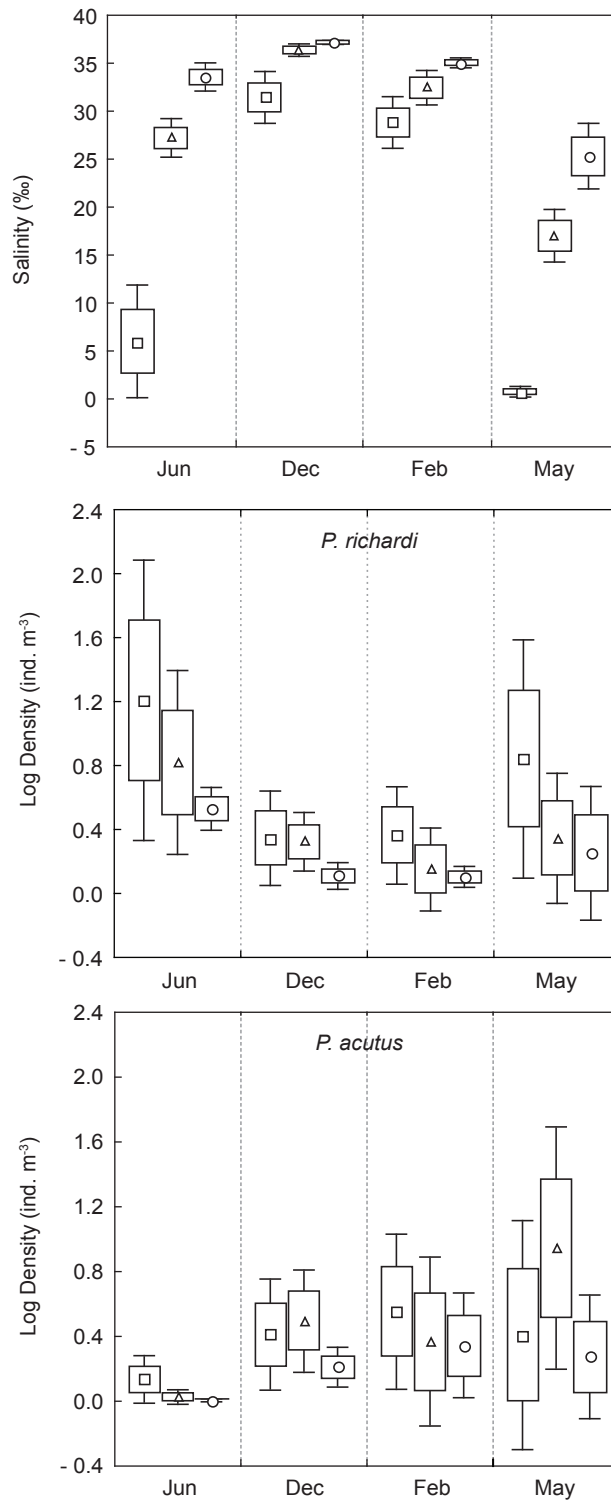
Fig. 3 — Spatial and temporal variation in salinity and density of *P. richardi* and *P. acutus* in the Caeté River Estuary (□ Upper, Δ Midle and O   Lower estuary). Values are shown as means ± standard deviations (vertical bars) and standard errors (box). Densities are in logarithimic scale.

hand, this correlation was not significant in the case of *P. acutus* (rs = - 0.27; p > 0.05).

Among the thirty-six samples collected, 91.7% of them contained specimens of *P. richardi*, while *P. acutus* was present in 77.8% of the cases. *P. richardi* mean density values varied between 0.28 and 46.18 ind. m⁻³, in the lower (February) and upper estuary (June), respectively. In the case of *P. acutus*, these values were 0.01 and 17.02 ind. m⁻³, recorded in the lower (june) and middle (May) estuary, respectively (Fig. 3).

Copepod's dry weight increased concomitantly to the prosome length, following an exponential relationship (Fig. 4). The length-weight relationships were significant for both *P. richardi* and *P. acutus*, and shown respectively, by the following equations:

$$DW = 67.137e^{0.0033L} \, (r = 0.79; \, p < 0.05) \qquad (2)$$

$$DW = 3.581e^{0.0054L} \, (r = 0.76; \, p < 0.05) \qquad (3)$$

Biomass values for both species showed spatial and temporal fluctuations (Fig. 5 and Tables 1 and 2). *P. richardi* biomass varied between 0.0022 mg DW. m⁻³ (lower estuary - February) and 0.3507 mg DW. m⁻³ (upper estuary - June). Values recorded for *P. acutus* were between 0.0005 mg DW. m⁻³ (lower estuary - June) and 0.7181 mg DW. m⁻³ (middle estuary - May).

Monthly differences in biomass between sampling areas (spatial study) were never significant, either for *P. richardi* or for *P. acutus*. Similarly, there were no significant differences between biomasses registered within a same
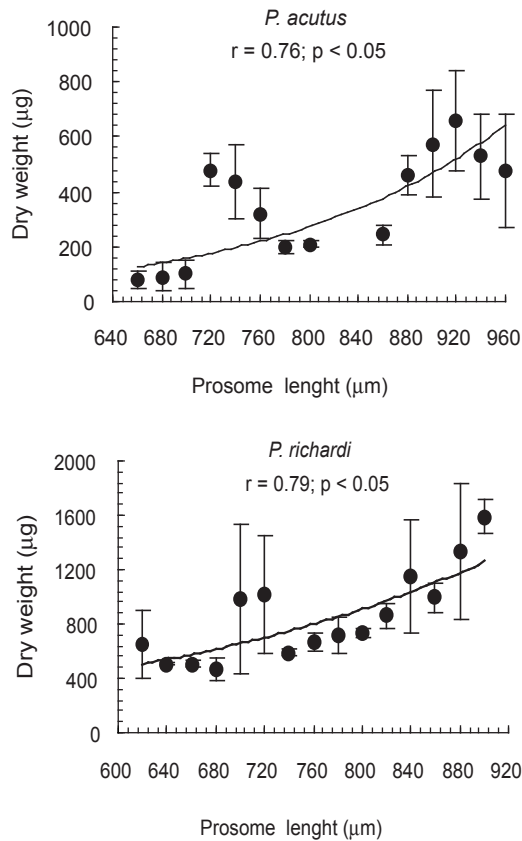

Fig. 4 — Length-weight relationships for two copepod species from the Caeté River Estuary. Dry weights are shown as means (•) ± standard deviations (vertical bars).
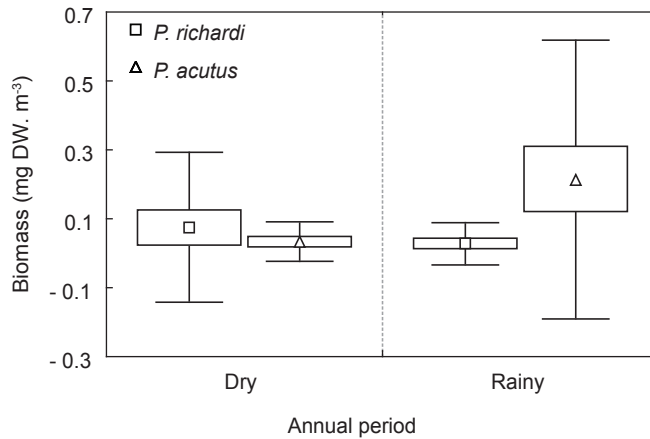
Fig. 5 — Biomasses of *P. richardi* and *P. acutus* in the Caeté River Estuary. Values are shown as means ± standard deviations (vertical bars) and standard errors (box).

TABLE 1

Spatial and temporal variation of *P. richardi* average biomass (mg DW. m^{-3}) along the three sampling areas in the Caeté River Estuary.

Season	Dry		Rainy	
Months/Areas	Jun/98	Dec/98	Feb/99	May/99
Upper	0.3507	0.0198	0.0134	0.1137
Middle	0.0530	0.0120	0.0049	0.0201
Lower	0.0133	0.0036	0.0022	0.0103

TABLE 2

Spatial and temporal variation of *P. acutus* average biomass (mg DW. m^{-3}) along the three sampling areas in the Caeté River Estuary.

Season	Dry		Rainy	
Months/Areas	Jun/98	Dec/98	Feb/99	May/99
Upper	0.0191	0.0922	0.1136	0.2577
Middle	0.0029	0.0617	0.0692	0.7181
Lower	0.0005	0.0267	0.0667	0.0579

area, but in different months (temporal study). Mathematical analyses conducted on density data led to the same conclusion as the biomass study.

DISCUSSION

The Caeté River Estuary has a dynamic horizontal gradient of salinity. Values increased gradually from the inner to the lower estuary, as already observed by Barletta-Bergan *et al.* (2002).

The relatively high value of 28.8‰, registered in the upper estuary during the rainy season (February), is probably related to the inundation of areas which have remained exposed during the dry season. In this mentioned period, salt crystal formations can be observed. During months of relatively high precipitation, the strong river flow leads to flooding in these areas, resulting in an increase of salinity in punctual areas of the estuary.

Temporal variation in salinity can be clearly observed in this study, especially when comparing data recorded in the upper estuary in December (dry season) with those recorded in May (rainy season). This observation was probably triggered by differences in the amount of rainfall between the two seasons. During the study period, such seasonal differences were even higher by the large-scale atmospheric phenomenon, El Niño and La Niña (Magalhães, 2003). Authors, such as Golley & Medina (1975), Porto & Fonteles-Filho (1986), Barletta (1999) and Blaber (2002) also attributed salinity seasonal differences in tropical estuaries to the precipitation rate.

Salinity is an important factor when regulating the composition, density and distribution of *Pseudodiaptomus* species in estuaries (Collins & Williams, 1981; Mitra & Patra, 1990; Sarkar & Choudhury, 1998). Similar observations were made in the Caeté River estuarine ecosystem. In this environment, the analyzed species were encountered along a salinity gradient, as already reported in other estuaries of the Brazilian coast (*e.g.* Prado-Por & Lansac-Tôha, 1984; Lansac-Tôha & Lima, 1993).

The Spearman correlation coefficient (rs) showed a significant negative correlation (rs = - 0.78; p < 0.05) between salinity and density of *P. richardi*, indicating the species preference for water of low salinity. Lopes (1994), who studied the structure and seasonal variation of zooplankton in the Guaraú River Estuary (São Paulo, Brazil), pointed out that the salinity longitudinal gradient was (partly) responsible for the spatial segregation of *P. richardi*. The presence of this species in all samples collected in the Caeté River Estuary, where euhaline-polyhaline regimes were predominant, could be related to its transport by currents as all the samples were collected in the ebb tide. Based on the increase of rainfalls noted in February a subsequent increase in density of *P. richardi* was expected in the upper estuary. However, low values were observed, probably as a result of the high salinity, as discussed above.

In the case of *P. acutus*, the correlation between salinity and density was negative but not significant (rs = - 0.27; p > 0.05). Conversely, Tundisi & Matsumura-Tundisi (1968) and Araujo (1996) reported a positive and significant correlation between the same species and salinity. Moreover, the dominance of *P. acutus* in terms of density in areas of high salinity in the vicinity of river mouths (Medeiros, 1983; Santana-Barreto *et al.*, 1991) was described as typical for mangrove areas, bays and estuaries (Montú & Cordeiro, 1998). Nevertheless, in the Caeté River Estuary, a clear pattern of spatial and temporal distribution for *P. acutus* was not observed.

The separation of copepods for biomass determination in terms of dry weight is unlikely due to the presence of other material such as detritus or phytoplankton. Additionally, when material is insufficient to determine the accurate weight, biomass in terms of dry weight can not be directly measured (Ara, 1998). In such a case, it was decided to assess the dry weight using length-weight regression equations. For the study species, this latter method was established based on measurements obtained from individuals captured during the entire study period. For our data, it is believed that seasonal variations in the length-weight relationship were buffered by the temporal heterogeneity of the samples. Nevertheless, according to Ara (2001), such variations can not be significant as variations in temperature and food availability in tropical and sub-tropical regions are much less significant than in temperate and boreal areas. In the present study, dry weight standard deviations were high for some of the regression values. This could be due to the proportion of individuals present in the corresponding stations during the rainy and dry seasons.

Biomass assessment is a strategic approach to have a better understanding of an aquatic ecosystem trophic structure and it is used in studies of rates of production and in assessing population demands or impacts on the environment (Mauchline, 1998). In the present study, biomass estimations were only performed for the adult stages. Prevalence of adults was already reported for various copepod species, although more specifically for Calanoida, from numerous estuaries, lagunes and neritic zones located worldwide (Heinle, 1966; Burkill & Kendall, 1982). In the case of species of the *Pseudodiaptomus* genus, dominance of adult individuals in the populations was confirmed by Uye *et al.* (1983) and Uye & Sano (1995). However, the data obtained in terms of abundance and biomass could underestimate the ecological role of the populations studied in the Caeté River

Estuary. Because of the typically large size of adult copepods, reductions in this group result in the overall zooplankton biomass decreasing (Kreutzweiser *et al.*, 2004).

Biomass values for *Pseudodiaptomus* species in the studied area were lower than those reported in other regions (Liang & Uye, 1997; Eskinazi-Sant'Ánna, 2000). The relatively low values registered in the Caeté River Estuary could be explained by the large mesh size (300 µm) of the plankton net used in this study that should have captured predominant individuals of relatively large sizes. Due to this, juveniles and naupliar stages that could have influenced the overall population biomass were not taken into consideration.

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