Anais da Academia Brasileira de Ciências (2009) 81(2): 187-197
(Annals of the Brazilian Academy of Sciences)
ISSN 0001-3765
www.scielo.br/aabc

# Seasonal variation in the copepod community structure from a tropical Amazon estuary, Northern Brazil

**ANDRÉ MAGALHÃES[1], NATÁLIA DA R. LEITE[1], JOÃO G.S. SILVA[1], LUCI C.C. PEREIRA[2] and RAUQUÍRIO M. DA COSTA[1]**

[1]Laboratório de Plâncton e Cultivo de Microalgas, Universidade Federal do Pará, Instituto de Estudos Costeiros, Alameda Leandro Ribeiro s/n, Aldeia, 68600-000 Bragança, PA, Brasil
[2]Laboratório de Oceanografia Costeira e Estuarina, Universidade Federal do Pará, Instituto de Estudos Costeiros, Alameda Leandro Ribeiro s/n, Aldeia, 68600-000 Bragança, PA, Brasil

*Manuscript received on August 1, 2008; accepted for publication on October 7, 2008; presented by* ALEXANDER W.A. KELLNER

**ABSTRACT**

The main purpose of this study was to investigate the seasonal variation of copepod community structure during t months of July, September and November 2003 (dry season) and January, March and May 2004 (rainy season) in t Curuçá estuary, northern Brazil. Samples were collected during neap tides via gentle 200$\mu$m mesh net tows from a sm powerboat. Measurements of surface water conductivity were accomplished *in situ* using an electronic conductivimet and salinity was later obtained through the transformation of the conductivity values. Salinity varied seasonally fro $7.2 \pm 0.1$ to $39.2 \pm 1.8$ (mean $\pm$ standard deviation) and was influenced mainly by differences in the amount of rainf between the studied sampling seasons. In total, 30 Copepoda taxa were identified and *Acartia tonsa* comprised the mo representative species throughout the entire studied period followed by *Acartia lilljeborgii*, *Subeucalanus pileatus* a *Paracalanus quasimodo*. In the present study, the density values, ecological indexes and copepod species dominan presented a clear seasonal pattern, showing that the studied area may be considered seasonally heterogeneous in relatio to the investigated parameters.

**Key words:** copepod, salinity, ecological indexes, seasonal changes, Brazil.

## INTRODUCTION

Mangrove estuaries are located in tropical and subtropical regions and in these ecosystems phytoplankton and zooplankton productivity are sustained by the input of organic and inorganic nutrients originated from adjacent mangrove forests (Yáñez Arancibia et al. 1993, Schwamborn et al. 1999). In these environments copepods are usually the dominant zooplanktonic component comprising 60 to 80% of the total biomass (López-Ibarra and Palomares-García 2006) and playing an important role as prey for many juvenile and adult zooplanktophage fish key factor in the control of fish stock sizes (Pay Rippingale 2001, Evjemo et al. 2003). As part pelagic food webs, copepods also contribute trans energy and organic matter from the primary produ the higher trophic levels of the aquatic system ( et al. 1984). More recently, studies have also high the role of copepods in the consumption of carb duced by the microbial loop (Champalbert and 2002, Sommer and Stibor 2002).

The seasonal and spatial variability observe occurrence and distribution of copepods are dire lated to abiotic (e.g. salinity, turbidity and tempe

(Escribano and Hidalgo 2000, Beyst et al. 2001). The relationship between distribution of copepods and environmental variables have been studied in several estuaries (e.g. Hassel 1986, Soetaert and Rijswijk van 1993, Sarkar and Choudhury 1998, Lawrence et al. 2004, David et al. 2007) and salinity has been shown to be (Ara 2004, Froneman 2004, Uriarte and Villate 2005, Li et al. 2006) one of the main factors controlling species development and seasonal distribution of copepods in estuarine and marine environments because the organism's capacity to osmoregulate affects ecological tolerances (Rippingale and Hodgkin 1977, Cervetto et al. 1999).

According to Islam et al. (2006), estuaries are of great interest for studying copepod population dynamics, because they are extremely dynamic and heterogeneous ecosystems, subject to strong fluctuations in environmental parameters. In the Amazon estuaries of Brazil, knowledge about copepod communities is relatively scarce. There is little information published on the community structure of these organisms (Krumme and Liang 2004, Magalhães et al. 2006). Therefore, the purpose of the present study was to assess the copepod composition and characterize seasonal density and dominance patterns as well as ecological indexes of their populations related to salinity variations in the Curuçá estuary, northern Brazil.

## STUDY AREA

The Curuçá estuary is located on the Amazon littoral, north-eastern Pará State, near the city of Curuçá (00°43′48″S and 47°51′06″W) and is part of the second largest contiguous mangrove unit of the world (Kjerfve and Lacerda 1993). The predominant coastal vegetation along the margins of the Curuçá estuary is represented by three genders of mangroves: *Avicennia*, *Rhizophora* and *Laguncularia*. The main hydrodynamic feature is a maximum tidal height of 5 m in a semi-diurnal cycle, although this range can reach 6 m during the equinoctial spring tides (DHN 2008). The region is characterized by a tropical hot and humid climate, which presents a pronounced seasonality with the dry season lasting

## MATERIALS AND METHODS

### Sampling Strategy and Laboratory Methods

To assess spatial and temporal patterns of the copepods, samples were collected at four stations in the inner part of the Curuçá estuary (Fig. 1) in the neap tides of July, November and December 2003 (dry season) and January, March and May 2004 (rainy season). The plankton tows were accomplished at sub-surface water level, using a conical-cylindrical net (200$\mu$m mesh size, 50 cm diameter and 1.8 m in length) fitted with a flowmeter to estimate the volume of water filtered through the net. All samples collected were immediately conditioned in plastic bottles and preserved in 5% formalin, buffered with sodium tetra-borate. Only one tow was made at each station, performed with a boat for approximately 3 min at a speed of 1.5 knots, producing a total of 24 plankton samples. Measurements of sub-surface water conductivity were accomplished *in situ* using an electronic conductivimeter (Orion, Model 105). Salinity was later obtained through the transformation of conductivity values.

Due to the great amount of organisms present in the samples, aliquots were taken using a Folsom Plankton Sample Splitter according to the degree of organism concentration. Under a stereoscopic microscope the copepod individuals were identified to the lowest possible taxonomic level and counted, using appropriate identification keys (Trégouboff and Rose 1957, Boltovskoy 1981, Bradford-Grieve et al. 1999).

### Ecological Indexes and Statistical Analyses

The quantitative data obtained for each sample was used to calculate absolute and relative density, as well as ecological indexes (diversity and evenness). The copepod diversity was calculated using the Shannon-Wiener's index ($H'$, as log to the base 2) and evenness was calculated through Pielou's index ($J$, as log to the base 2).

Additionally, to visualize and compare diversity profiles in different seasonal periods and between sampling months, K-dominance curves (Lambshead et al. 1983) were plotted. For this, species were ranked from 1 to x, with species 1 representing the largest percentage of total individuals, species 2 the second largest, etc.

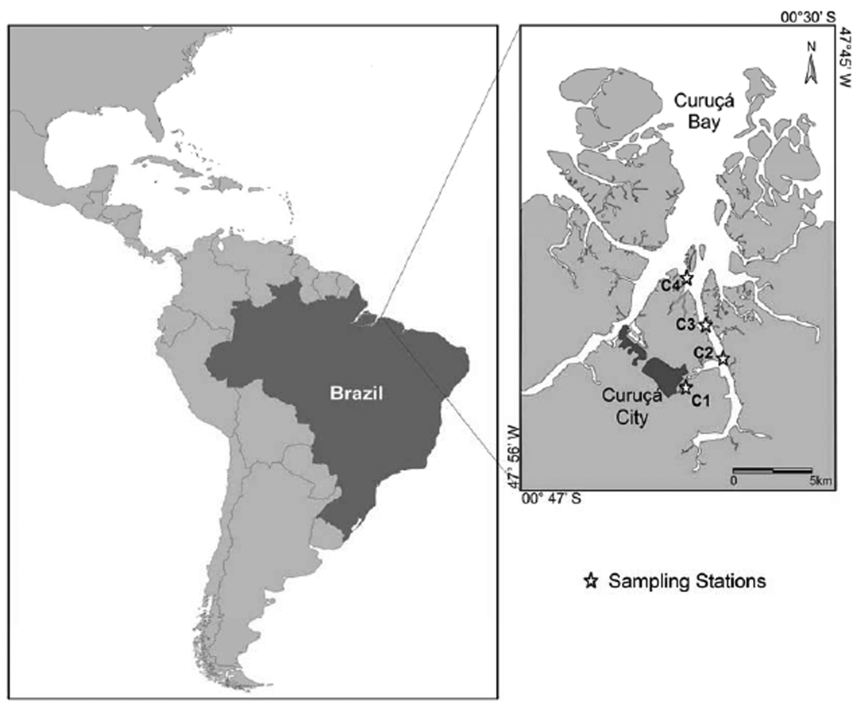


Fig. 1 – Geographical localization showing the study area with the four sampling stations (C1, C2, C3 and C4) in the Curuçá estuary (Pará
(Modified from Hercos and Giarrizzo 2007).

ical indexes, were $\log(x+1)$-transformed so that their distributions approached normality. The assumption of homogeneity of variance was tested using Bartlett’s Chi-square test. Where the variances were homogeneous, one-way ANOVA with a 5% significance level was used to determine possible seasonal and spatial differences in density, diversity and evenness of copepods. However, when variances were heterogeneous, the non-parametric Mann-Whitney $U$-test was applied (Zar 1999).

Spearman’s correlation coefficient was calculated to characterize the relationships between salinity, copepod density and ecological indexes. All these statistical analyses were conducted employing the program STATISTICA, version 5, computer software package.

To investigate similarities among sampling months, hierarchical agglomerative cluster analysis and non-metric multidimensional scaling (MDS) ordination were computed using the Bray-Curtis similarity index and $\log(x+1)$-transformed density data, performed through

## RESULTS

### Salinity and Rainfall

In the present study, salinity, as well as density a
logical indexes, did not show spatially significa
ferences ($p > 0.05$) among the four sampled s
Thus, reported values for each sampling mont
pooled and have been evaluated on seasonal scal
rainy seasons).

Results showed a significant seasonal varia
sub-surface water salinity (Mann-Whitney $U$-test
$p < 0.05$). The lowest value ($7.2 \pm 0.1$; ave
standard deviation) was registered in March (rai
son), while the highest value ($39.2 \pm 1.8$) was re
in November (dry season) (Fig. 2). When co
to salinity, an opposite trend was observed for
tal monthly rainfall, with the rainy season present

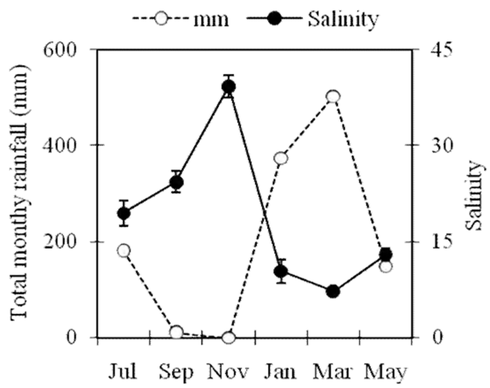


Fig. 2 – Seasonal variation of salinity (means ± SD) in relation to total monthly rainfall (ANA 2006) in the Curuçá estuary.

### Copepod Composition and Density

A total of 30 Copepoda taxa were identified (Table I). Among them, eighteen could be assigned to species level and the others were either not identified to the species level or unidentified. Monthly and seasonal distributions of copepod densities were presented (Figs. 3b, 5c and Table I). *Acartia tonsa* (Dana, 1849) was the taxa most represented throughout the entire study period, reaching up to 91.5% of the total copepod density registered in May, followed by *Acartia lilljeborgii* (Giesbrecht, 1889) with 23.4% in September, *Subeucalanus pileatus* (Giesbrecht, 1888) with 17.4% in November and *Paracalanus quasimodo* (Bowman, 1971) with 14.9% in July.

Among the main taxa, *A. tonsa* (ANOVA, $F = 22.1$, $p < 0.001$) and *S. pileatus* (ANOVA, $F = 17.6$, $p < 0.001$) showed significant seasonal differences in density patterns. Seasonal differences were also observed for total copepod density (ANOVA, $F = 17.6$, $p < 0.05$). Monthly results of the copepod density, diversity and evenness were plotted against salinity (Fig. 3). The Spearman coefficient showed a significant relationship between salinity and densities of *A. tonsa* ($rs = -0.59$, $p < 0.05$) and *S. pileatus* ($rs = 0.54$, $p < 0.05$). On the other hand, there was no significant correlation in the case of *A. lilljeborgii* ($rs = 0.40$, $p > 0.05$), *P. quasimodo* ($rs = 0.30$, $p > 0.05$) and total copepod densities ($rs = 0.37$, $p > 0.05$). In addition

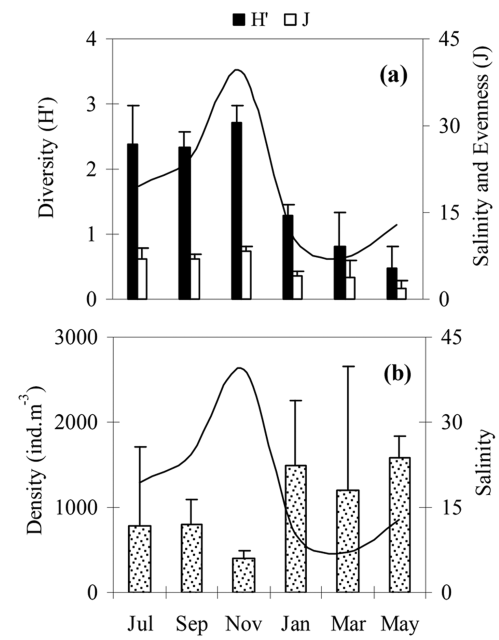


Fig. 3 – Monthly means (± SD) in copepod ecological indexes (a) and total copepod density (b) registered in the Curuçá estuary. These data were plotted against salinity (line).

### Community Structure

Consistent seasonal patterns of diversity and evenness were evident throughout the sampling periods (Fig. 3a), and the lowest values for all of these indexes were recorded in May.

Highly significant statistical differences were found in diversity (ANOVA, $F = 79.4$, $p < 0.00001$) between the two seasons. The values increased during the dry season and decreased in the rainy season, with average values oscillating between $0.47 \pm 0.33$ (May) and $2.72 \pm 0.25$ (November) bits.ind$^{-1}$. The accentuated decrease in diversity during rainy months was accompanied by high total copepod densities. An opposite situation was detected for dry months. Similarly, evenness (ANOVA, $F = 37.2$, $p < 0.00001$) showed significant seasonal difference, with average values ranged from $0.17 \pm 0.11$ (May) to $0.75 \pm 0.05$ (November).

K-dominance curves also revealed a gradual decline in diversity throughout the rainy months (Fig. 4b). The curves for these months exhibited a higher dominance

**TABLE I**
**Taxonomic composition, absolute (means ± SD) and relative densities of copepods collected during dry (July, September and November) and rainy seasons (January, March and May) in the Curuçá estuary.**

| Taxa | Dry | % | Rainy | % |
|---|---|---|---|---|
| *Acartia* (juveniles) | 1.5 ± 2.5 | 0.06 | 0 ± 0 | 0 |
| *Acartia tonsa* Dana, 1849 | 1097.1 ± 729.0 | 41.74 | 4853.8 ± 814.9 | 85.44 |
| *Acartia lilljeborgii* Giesbrecht, 1889 | 435.1 ± 275.6 | 16.55 | 208.7 ± 99.9 | 3.67 |
| *Acartia* sp. | 0.5 ± 0.8 | 0.02 | 0 ± 0 | 0 |
| *Paracalanus quasimodo* Bowman, 1971 | 306.0 ± 132.4 | 11.64 | 217.9 ± 231.4 | 3.84 |
| *Parvocalanus crassirostris* (F. Dahl, 1894) | 10.5 ± 4.4 | 0.40 | 4.1 ± 7.0 | 0.07 |
| *Pseudodiaptomus marshi* Wright, 1936 | 3.6 ± 5.7 | 0.14 | 21.7 ± 12.0 | 0.38 |
| *Pseudodiaptomus richardi* (F. Dahl, 1894) | 0.5 ± 0.8 | 0.02 | 9.0 ± 8.0 | 0.16 |
| *Pseudodiaptomus acutus* (F. Dahl, 1894) | 58.4 ± 31.5 | 2.22 | 50.3 ± 62.9 | 0.89 |
| *Pseudodiaptomus* sp. | 34.5 ± 25.4 | 1.31 | 26.2 ± 14.7 | 0.46 |
| *Labidocera* (juveniles) | 104.4 ± 121.5 | 3.97 | 0 ± 0 | 0 |
| *Labidocera fluviatilis* F. Dahl, 1894 | 25.8 ± 26.9 | 0.98 | 81.8 ± 132.7 | 1.44 |
| *Calanopia americana* F. Dahl, 1894 | 5.0 ± 5.7 | 0.20 | 2.7 ± 4.0 | 0.05 |
| *Subeucalanus pileatus* (Giesbrecht, 1888) | 159.1 ± 104.9 | 6.05 | 28.5 ± 23.6 | 0.50 |
| *Centropages furcatus* (Dana, 1849) | 17.3 ± 3.0 | 0.66 | 17.6 ± 18.1 | 0.31 |
| *Temora longicornis* (Müller, 1792) | 10.0 ± 4.3 | 0.38 | 0 ± 0 | 0 |
| *Candacia* sp. | 0.9 ± 1.5 | 0.03 | 0 ± 0 | 0 |
| *Corycaeus speciosus* Dana, 1849 | 2.3 ± 3.9 | 0.09 | 5.2 ± 9.0 | 0.09 |
| *Corycaeus latus* Dana, 1849 | 0 ± 0 | 0 | 0.7 ± 1.2 | 0.01 |
| *Corycaeus lautus* Brady, 1883 | 7.8 ± 8.7 | 0.30 | 21.2 ± 36.8 | 0.37 |
| *Corycaeus* sp. | 0 ± 0 | 0 | 1.6 ± 2.9 | 0.03 |
| *Oithona* spp. | 23.5 ± 12.8 | 0.90 | 101.2 ± 93.1 | 1.78 |
| *Oncaea* sp. | 4.8 ± 7.8 | 0.18 | 0 ± 0 | 0 |
| *Cymbasoma* sp. | 13.9 ± 23.6 | 0.53 | 0.7 ± 1.2 | 0.01 |
| *Tisbe* sp. | 124.0 ± 67.3 | 4.72 | 8.7 ± 10.1 | 0.15 |
| *Euterpina acutifrons* (Dana, 1847) | 82.2 ± 31.6 | 3.13 | 12.7 ± 12.2 | 0.22 |
| *Clytemnestra scutellata* Dana, 1847 | 0.1 ± 0.1 | [b] | 0 ± 0 | 0 |
| Harpacticoida [a] | 0 ± 0 | 0 | 6.5 ± 9.8 | 0.11 |
| Parasitic Copepoda [a] | 0.3 ± 0.5 | 0.01 | 0 ± 0 | 0 |
| Copepoda [a] (adults and juveniles) | 99.0 ± 47.4 | 3.77 | 0 ± 0 | 0 |

[a]Organisms identified to group level; [b]Less than 0.01%.

density distributions among both dry and rainy seasons (Fig. 4c).

The cluster and MDS analyses performed on monthly density of taxa registered during the present study clearly showed the temporal differences in the copepod community at the Curuçá estuary. The results indicated the presence of two distinct groups at 65% sim-

these three sampling months, a gradual reductio *A. tonsa* densities was verified following an incr salinity. On the other hand, the second group, corresponded to January, March and May (rainy s showed a considerable increase in *A. tonsa* contri on total copepod density, while salinity values dec (Fig. 5c). When comparing density distribution

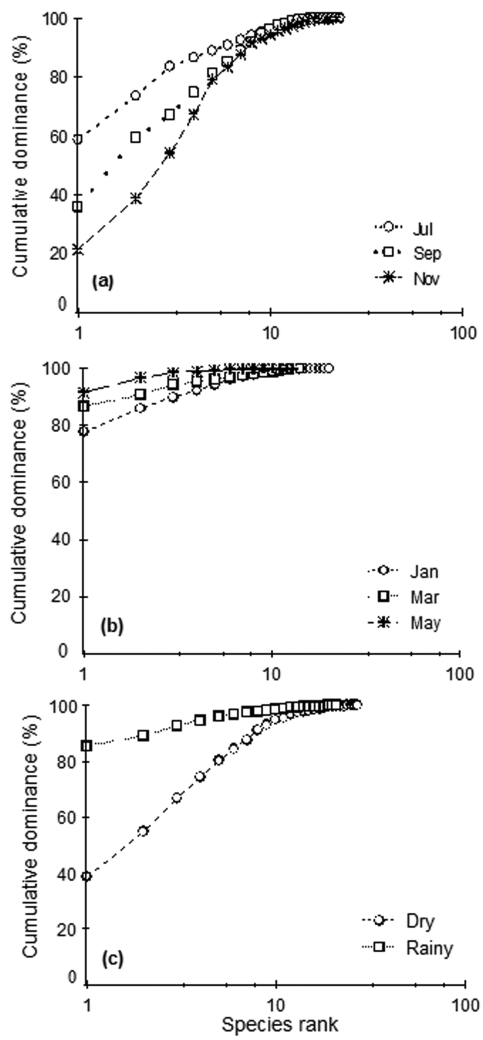


Fig. 4 – Cumulative dominance curves of copepods for dry (a) and rainy (b) sampling months and for the two seasons (c) in the Curuçá estuary.

site situation was verified. For the former, the highest density was reported during the rainy season (group II), while for the last three species these values were greater in the dry season (group I).

## DISCUSSION

Sub-surface water salinity was characterized by pronounced seasonality, with the largest values found in

Lam-Hoai et al. 2006) seasonal changes in salinity are mainly influenced by rainfall distribution between the seasons. In general, decreases in pluviometric precipitation during the dry season caused gradual decreases in river discharges and land run-off. Consequently, it was possible to verify increases in salinity in the inner parts of these estuaries due to the input of a larger volume of coastal and marine waters in those environments.

The distributional pattern observed for total copepod density, with the highest values registered in the rainy season, was in part related to the behavior of *A. tonsa* which was the species most represented as was also reported in many other estuarine systems (Palomares-García and Gómez-Gutiérrez 1996, Hoffmeyer and Torres 2001, Vieira et al. 2003). This calanoid planktonic copepod is a cosmopolitan species, common in estuaries of the Atlantic coast of South and North America (Bradford-Grieve et al. 1999), and is considered an important zooplankton component in most of these estuaries showing a high degree of tolerance for environmental change.

The significant and negative correlation between salinity and density of *A. tonsa*, evidenced the species preference for estuarine waters that show mesohaline characteristics (18.0 > surface salinity > 5.0), according to the Venice system of classification of saline waters (Anonymous 1958). Intraspecific tolerance to low and moderate salinities could explain the higher numerical representativeness of *A. tonsa* during the entire rainy season, when salinities were not accentuated.

Numerous completed studies on estuaries describe the reduction in copepod species density during the rainy season (Lansac-Tôha 1985, Mwaluma et al. 2003, Osore et al. 2004, among others). An opposite trend was verified for *A. tonsa* in the Curuçá estuary. This observation is consistent with the one described by Ara (1998), who studied the temporal variability and production of copepods in the Cananéia Lagoon estuarine system (São Paulo, Brazil) and pointed out that the highest *A. tonsa* densities were registered in February, which represents the rainy season.

For *S. pileatus*, a species of warm coastal and shelf

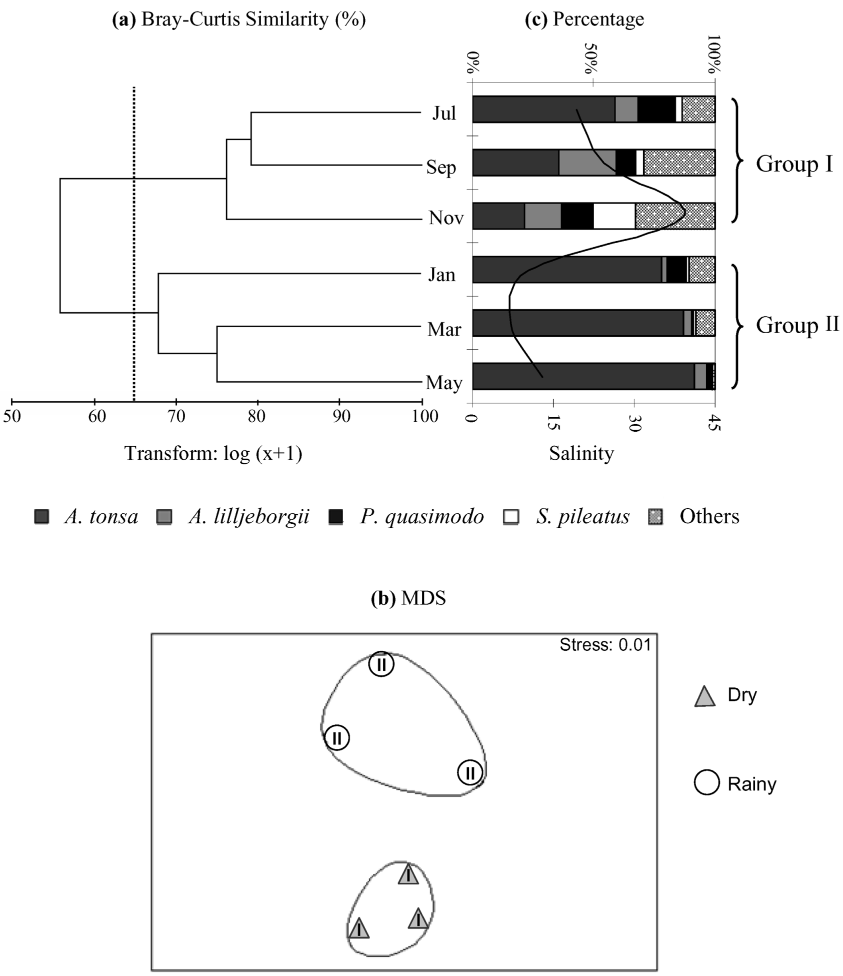


Fig. 5 – Cluster (a) and MDS (b) analyses based on copepod taxa densities during dry (group I) and rainy (group II) sampling months in th
estuary. Percentage of the main taxa density (c). These data were plotted against salinity (line).

The highest densities recorded in the dry season suggest that the presence of this species in the studied area depends on the recruitment from the adjacent coastal zone.

*A. lilljeborgii* is the predominant species in various Brazilian estuaries (Nascimento-Vieira and Eskinazi Sant'Anna 1989, Dias 1999, Silva et al. 2003). However, in the present study it's contribution to monthly and seasonal copepod density was not expressive if compared with *A. tonsa*. As observed by Sterza and Fernandes (2006), evaluating the zooplankton community of the Vitória Bay estuarine system (southeastern Brazil),

areas (Lopes et al. 1999, Eskinazi-Sant'Anna and
berg 2006), *P. quasimodo* together with *A. lillj*
were the only main taxa that did not show a
tent seasonal pattern in terms of density. Moreov
oceanic copepods *Corycaeus speciosus* (Dana,
*Corycaeus latus* (Dana, 1849), *Corycaeus lautus* (
1883) and *Cymbasoma* sp. were also recorded, al
they were not numerically representative in the
study.

At the Curuçá estuary, the ecological i
showed significant seasonal variations, which w

pod diversity in rainy months was related to an increase of *A. tonsa* contribution for the total copepod density. *A. tonsa* density was increased with the decrease in salinity. This may have occurred due to the reduced contribution of coastal and marine waters during rainy months. The opposite was detected for dry months. Copepod diversity values obtained in the Curuçá estuary tended to be greater than those observed in other estuaries worldwide (Hsieh and Chiu 1997, Islam et al. 2006).

Evenness presented a similar trend to diversity, with both parameters increasing with salinity values. The decline of these parameters in the rainy season indicated the presence of lower "stability" condition for the estuary, when compared with the dry season. Thus, the situation in the latter is completely different. The copepod community structure is relatively more diverse and the salinity influence on this community is greatest.

Monthly and seasonal changes in the balance of relative density of four main copepod species as visualized in the K-dominance curves, directly affect the behavior of ecological indexes. In particular, changes in *A. tonsa* contribution in the studied period were strongly responsible for alterations in these indexes. The present study has shown a clear seasonal pattern in density, diversity and evenness of copepod community and salinity values, which had been confirmed by plots of cluster and multidimensional scaling (MDS). Therefore, the studied area may be considered spatially uniform and seasonally heterogeneous in relation to these parameters. Nevertheless, further investigations on biomass and copepod community production in the Curuçá estuary should be assessed for providing a better understanding of the trophic structure of this ecosystem.

**ACKNOWLEDGMENTS**

We are grateful to Hector Hernán Martinez Baeza for English improvements to the manuscript. This work was supported by Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) (Processes #23116.000272/2002-88, #552126/05-5 and #563967/2005-6). The authors Luci Cajueiro Carneiro Pereira and

**RESUMO**

O presente estudo teve como objetivo principal avaliar a variação sazonal na estrutura da comunidade dos copépodos durante os meses de julho, setembro e novembro de 2003 (período seco) e janeiro, março e maio de 2004 (período chuvoso) no estuário do Curuçá, Norte do Brasil. As amostras foram coletadas nas marés de quadratura com auxílio de uma rede de plâncton com 200$\mu$m de abertura de malha, rebocada por meio de uma pequena embarcação a motor. As medidas de condutividade da água foram realizadas *in situ* utilizando-se um condutivímetro eletrônico e a salinidade foi posteriormente obtida através da transformação dos valores de condutividade. Os valores de salinidade variaram sazonalmente de $7,2 \pm 0,1$ a $39,2 \pm 1,8$ (média $\pm$ desvio padrão), tendo sido principalmente influenciados pelas diferenças nas taxas de precipitação entre os períodos de amostragem estudados. Foram identificados no total 30 táxons, com *Acartia tonsa* constituindo a espécie mais representativa durante todo o período de estudo, seguida por *Acartia lilljeborgii*, *Subeucalanus pileatus* e *Paracalanus quasimodo*. Durante este trabalho, os valores de densidade, índices ecológicos e dominância das espécies de copépodos apresentaram um padrão sazonal claro, mostrando que a área estudada pode ser considerada sazonalmente heterogênea em relação a estes parâmetros investigados.

**Palavras-chave:** copépodos, salinidade, índices ecológicos, mudanças sazonais, Brasil.

**REFERENCES**

Agência Nacional de Águas (ANA). 2006. Climatological data (1990-2004). Agência Nacional de Águas, Brasília, DF, Brasil.

Anonymous. 1958. Venice system. Supplement to the Symposium on the classification of brackish waters. Arch Oceanogr Limnol 11 (Suppl): 1–248.

Ara K. 1998. Variabilidade temporal e produção dos copépodos no complexo estuarino-lagunar de Cananéia, São Paulo, Brasil. Ph.D. Thesis, Universidade de São Paulo, Brasil. 308 pp.

Ara K. 2004. Temporal variability and production of the planktonic copepod community in the Cananéia Lagoon estuarine system, São Paulo, Brazil. Zool Stud 43: 179–186.

BJÖRNBERG TKS. 1981. Copepoda. In: BOLTOVSKOY D (Eds), Atlas del Zooplancton del Atlantico Sudoccidental y Métodos de Trabajo con el Zooplancton Marino, Mar del Plata: Instituto Nacional de Investigación y Desarrollo Pesquero, p. 587–679.

BLABER SJM. 2002. Fish in hot water: the challenges facing fish and fisheries research in tropical estuaries. J Fish Biol 61: 1–20.

BOLTOVSKOY D. 1981. Atlas del zooplancton del Atlántico Sudoocidental y métodos de trabajos con el zooplancton marino, Mar del Plata: Instituto Nacional de Investigación y Desarrollo Pesquero, 936 p.

BRADFORD-GRIEVE JM, MARKHASEVA EL, ROCHA CEF AND ABIAHY B. 1999. Copepoda. In: BOLTOVSKOY D (Eds), South Atlantic Zooplankton, Netherlands: Backhuys, p. 869–1098.

CAPO S, SOTTOLICHIO A, BRENON I, CASTAING P AND FERRY L. 2006. Morphology, hydrography and sediment dynamics in a mangrove estuary: the Konkoure Estuary, Guinea. Mar Geol 230: 199–215.

CERVETTO G, GAUDY R AND PAGANO M. 1999. Influence of salinity on the distribution of *Acartia tonsa* (Copepoda, Calanoida). J Exp Mar Biol Ecol 239: 33–45.

CHAMPALBERT G AND PAGANO M. 2002. Copepod feeding in a tuna fishery area of the tropical Atlantic Ocean. CR Biol 325: 171–177.

CLARKE KR AND WARWICK RM. 1994. Changes in marine communities: an approach to statistical analysis and interpretation, United Kingdom: Plymouth Marine Laboratory, 144 p.

COORDENADORIA DE COMUNICAÇÃO SOCIAL DO GOVERNO DO ESTADO DO PARÁ (CCS). 2006. Município de Curuçá. Produced by Start Comunicação e Informática. Available at http://www.governodopara.pa.gov.br/conhecaopara/curucal.asp.

DAVID V, SAUTOUR B AND CHARDY P. 2007. Successful colonization of the calanoid copepod *Acartia tonsa* in the oligo-mesohaline area of the Gironde estuary (SW France) – Natural or anthropogenic forcing? Est Coast Shelf Sci 71: 429–442.

DIAS CO. 1999. Morphological abnormalities of *Acartia lilljeborgi* (Copepoda, Crustacea) in the Espírito Santo Bay (ES, Brazil). Hydrobiologia 394: 249–251.

DIRETORIA DE HIDROGRAFIA E NAVEGAÇÃO (DHN).

ESCRIBANO R AND HIDALGO P. 2000. Spatial dist
of copepods in the North of the Humboldt Curren
off Chile during coastal upwelling. J Mar Biol As
80: 283–290.

ESKINAZI-SANT'ANNA EM AND BJÖRNBERG TKS
Seasonal dynamics of mesozooplankton in B
coastal waters. Hydrobiologia 563: 253–268.

EVJEMO JO, KJELL IR AND OLSEN Y. 2003. Cope
live food organisms in the larval rearing of halibu
(*Hippoglossus hippoglossus* L.) with special emp
the nutritional value. Aquaculture 227: 191–210.

FRONEMAN PW. 2004. Zooplankton community s
and biomass in a southern African temporarily ope
estuary. Est Coast Shelf Sci 60: 125–132.

HASSEL A. 1986. Seasonal changes in zooplankton c
tion in the Barents Sea, with special attention to
spp. (Copepoda). J Plankton Res 8: 329–339.

HERCOS AP AND GIARRIZZO T. 2007. Pisces, Sy
dae, *Hippocampus reidi*: filling distribution gaps
List 3: 287–290.

HOFFMEYER MS AND TORRES ER. 2001. Morph
variables and individual volume of *Eurytemora*
*cana* and *Acartia tonsa* females (Copepoda, Ca
from the Bahía Blanca estuary, Argentina. Hydro
459: 73–82.

HSIEH C-H AND CHIU T-S. 1997. Copepod abunda
species composition of Tanshui River Estuary and
waters. Acat Zool Taiwan 8: 75–83.

ISLAM MDS, UEDA H AND TANAKA M. 2006.
and seasonal variations in copepod communities
to turbidity maximum along the Chikugo estuari
ent in the upper Ariake Bay, Japan. Est Coast S
68: 113–126.

KJERFVE B AND LACERDA LD. 1993. Mangroves o
In: LACERDA LD (Eds), Conservation and Sus
Utilization of Mangrove Forest in Latin Amer
Africa Regions. Part I – Latin America. Mangro
system Technical Report No. 2, Okinawa: Inter
Tropical Timber Organization/International Soc
Mangrove Ecosystems, p. 245–272.

KRUMME U AND LIANG T-H. 2004. Tidal-induced
in a copepod-dominated zooplankton communi
macrotidal mangrove channel in Northern Brazi
Stud 43: 404–414.

LAMBSHEAD PJD, PLATT HM AND SHAW KM. 19

LAM-HOAI T, GUIRAL D AND ROUGIER C. 2006. Seasonal change of community structure and size spectra of zooplankton in the Kaw River estuary (French Guiana). Est Coast Shelf Sci 68: 47–61.

LANSAC-TÔHA FA. 1985. Ecologia do zooplâncton do estuário do Rio Una do Prelado (São Paulo, Brasil). Ph.D. Thesis, Universidade de São Paulo, Brazil. 195 p.

LAWRENCE D, VALIELA I AND TOMASKY G. 2004. Estuarine calanoid copepod abundance in relation to season, salinity, and land-derived nitrogen loading, Waquoit Bay, MA. Est Coast Shelf Sci 61: 547–557.

LI KZ, YIN JQ, HUANG LM AND TAN YH. 2006. Spatial and temporal variations of mesozooplankton in the Pearl River estuary, China. Est Coast Shelf Sci 67: 543–552.

LOPES RM, BRANDINI FP AND GAETA SA. 1999. Distribution patterns of epipelagic copepods off Rio de Janeiro (SE, Brazil) in summer 1991/1992 and winter 1992. Hydrobiologia 411: 161–174.

LÓPEZ-IBARRA GA AND PALOMARES-GARCÍA R. 2006. Estructura de la comunidad de copépodos en Bahía Magdalena, México, durante El Niño 1997-1998. Rev Biol Mar Oceanogr 411: 63–76.

MAGALHÃES A, COSTA RM, LIANG T-H, PEREIRA LCC AND RIBEIRO MJS. 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). Braz J Biol 66: 421–430.

MWALUMA J, OSORE M, KAMAU J AND WAWIYE P. 2003. Composition, abundance and seasonality of zooplankton in Mida Creek, Kenya. Western Indian Ocean J Mar Sci 2: 147–155.

NASCIMENTO-VIEIRA DA AND ESKINAZI SANT'ANNA EM. 1989. Composição do zooplâncton no estuário do Rio Timbó (Pernambuco – Brasil). Trabhs Oceanogr Univ Fed Pernambuco 20: 77–98.

OSORE MKW, MWALUMA JM, FIERS F AND DARO MH. 2004. Zooplankton composition and abundance in Mida Creek, Kenya. Zool Stud 43: 415–424.

PALOMARES-GARCÍA R AND GÓMEZ-GUTIÉRREZ J. 1996. Copepod community structure at Bahia Magdalena, Mexico during El Niño 1983-84. Est Coast Shelf Sci 43: 583–595.

PARSONS TR, TAKAHASHI M AND HARGRAVE B. 1984.

PAYNE MF AND RIPPINGALE RJ. 2001. Effects of salinity, cold storage and enrichment on the calanoid copepod *Gladioferens imparipes*. Aquaculture 201: 251–262.

PORTO HLR AND FONTELES-FILHO AA. 1986. Estudo de densidade e biomassa de camarões do gênero *Penaeus*, na ilha de São Luiz, Estado do Maranhão. Bol Lab Hidrobiol São Luís 7: 42–70.

RIPPINGALE RJ AND HODGKIN EP. 1977. Food availability and salinity tolerance in a brackish water copepod. Aust J Mar Freshw Res 28: 1–7.

SARKAR SK AND CHOUDHURY A. 1998. Distribution of inshore copepod of the Bay of Bengal off Sagar Island: A multivariate analysis. Trop Ecol 29: 146–158.

SCHIPP GR, BOSMANS JMP AND MARSHALL AJ. 1999. A method for hatchery culture of tropical calanoid copepods, *Acartia* spp. Aquaculture 174: 81–88.

SCHWAMBORN R, VOSS M, EKAU W AND SAINT-PAUL U. 1999. Stable isotope composition of particulate organic matter and zooplankton in North-East Brazilian shelf water. Arch Fish Mar Res 47: 201–210.

SILVA TA, NEUMANN-LEITÃO S, SCHWAMBORN R, GUSMÃO LMO AND NASCIMENTO-VIEIRA DA. 2003. Diel and seasonal changes in the macrozooplankton community of a tropical estuary in Northeastern Brazil. Rev Bras Zool 20: 439–446.

SOETAERT K AND RIJSWIJK VAN P. 1993. Spatial and temporal patterns of the zooplankton in the Westerschelde estuary. Mar Ecol Prog Ser 97: 47–59.

SOMMER U AND STIBOR H. 2002. Copepoda – Cladocera – Tunicata: the role of three major mesozooplankton groups in pelagic food webs. Ecol Res 17: 161–174.

SOMMER U, STIBOR H, KATECHAKIS A, SOMMER F AND HANSEN T. 2002. Pelagic food web configurations at different levels of nutrient richness and their implications for the ratio fish production: primary production. Hydrobiologia 484: 11–20.

STERZA JM AND FERNANDES LL. 2006. Zooplankton community of the Vitória Bay estuarine system (Southeastern Brazil). Characterization during a three-year study. Braz J Oceanogr 54: 95–105.

THÜLLEN N AND BERGER U. 2000. A comparative examination of environmental factors at patchy mangrove seedling stands on the peninsula of Bragança, Northern Brazil. Ecotropica 6: 1–12.

TRÉGOUBOFF G AND ROSE M. 1957. Manuel de Planctono-

Uriarte I and Villate F. 2005. Differences in the abundance and distribution of copepods in two estuaries of the Basque coast (Bay of Biscay) in relation to pollution. J Plankton Res 27: 863–874.

Vieira L, Azeiteiro U, Ré P, Pastorinho R, Marques JC and Morgado F. 2003. Zooplankton distribution in a temperate estuary (Mondego estuary southern arm: Western Portugal). Acta Oecol 24: 163–173.

Yáñez Arancibia A, Lara-Dominguez AL an JW. 1993. Interactions between mangrove and s habitats mediated by estuarine nekton assemblag pling of primary and secondary production. Hyd gia 264: 1–13.

Zar JH. 1999. Biostatistical Analysis, 4th ed., Uppe River: Prentice Hall, 663 p.