

Inter-annual Variability of Planktonic Copepods in a Tropical Bay in Southeastern Brazil

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ABSTRACT

*The aim of this work was to study the structure of the copepod community in relation to hydrographic conditions in Espírito Santo Bay, from 1993 to 1997. Zooplankton samples were obtained in the horizontal tows four times a year, using a 200 µm net. Temperature, salinity and dissolved oxygen were determined in the water samples. The overall mean density of the copepods was 9,085 ind.m⁻³ with the peaks exceeding 15,000 ind.m⁻³ in the summer and autumn during the first three years (1993 - 1995). The PCA analysis was used to relate the environmental conditions with the distribution of the copepods. The increases in the abundant species, namely *Acartia lilljeborgi*, *Oithona hebes*, *Oithona oculata*, *Paracalanus quasimodo*, *Parvocalanus crassirostris* and *Euterpina acutifrons*, were related to the decreases in the diversity. The spatial and temporal variations of the temperature and salinity influenced the abundance of the species during the five years of the sampling and the dominant species alternated in abundance.*

Key words: Copepoda, Crustacea, Spatial-temporal variation, Espírito Santo Bay, Brazil

INTRODUCTION

The Espírito Santo Bay is a coastal system located in the south-eastern Brazil. The bay is economically important because of the location of one of the busiest ports in Brazil (Tubarão) at its entrance. The region is popular for recreation and fishing. However, it is suffering degradation caused by the industry and household wastes. Iron-ore pellets, coal particles and oil are found in the region (Nalesso and Mazzioli, 2000; Pereira et al. 2000; Nassar et al. 2003; Jesus et al. 2004).

The investigations on the coastal plankton of the state of Espírito Santo, mostly on the numerical

distribution of the groups or selected taxa, have been conducted since 1986. Espírito Santo Bay has been the subject of general descriptive studies on the planktonic communities in order to evaluate the environmental quality (Bonecker et al. 1987, 1991). Dias (1994, 1999) reported on the temporal-spatial distribution of the copepods and the occurrence of the morphological abnormalities in *Acartia lilljeborgi*. The determination of the factors driving the inter-annual variability in the marine zooplankton is an important issue (Christou, 1998). In the coastal waters of south-eastern Brazil, long-term studies on zooplankton are only a few (Dias, 1994; Lopes, 1994; Bassani et al. 1999; Dias et al. 1999; Schutze and Ramos,

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1999; Valentin et al. 1999). The south-east coast of Brazil, especially the estuarine areas located near the large urban concentrations and important commercial ports, has been strongly impacted by the human activities (Carmo, 1987; Tommasi, 1987; Carmo et al. 1994).

The aim of this work is to study the occurrence, pattern of abundance, seasonality and temporal distribution of the copepods in the Espírito Santo bay estuary, from the data collected over a five-year period. Several additional questions were also addressed: Was the copepod community different from a previous study in 1986-1987? Did physical and chemical parameters influence the copepod population?

MATERIALS AND METHODS

Espírito Santo Bay (20°15'S - 40°14'W and 20°18'S - 40°17'W) is located in the city of Vitória (Brazil). The bay's area is approximately 20 km²; its depth is less than 10 m and its entrance is 3.5 km wide. The bay's waters are frequently renewed because of the proximity of the open sea (Jesus et al. 2004).

The sampling program was carried out in the summer, fall, winter and spring of 1993 to 1997 at eight stations. Sampling was done at four stations inside (stations 1, 2, 3 and 4) and four other stations outside (5, 6, 7 and 8) the bay. The zooplankton samples were collected during the day at high tide, by sub-surface horizontal hauls with a conical net of mesh size 200 µm and mouth diameter 60 cm. A calibrated flow-meter was mounted centrally in the mouth of the net. The samples were preserved in 4% buffered formalin.

The temperature and salinity were measured using a Beckman thermosalinometer (0.1 °C). Pluviometric data were provided by Mr. Luis Carlos Austin (6° DISME – National Institute of Meteorology of Rio de Janeiro). Dissolved oxygen was measured according to APHA (1985).

The samples were divided into fractions with a Folsom splitter (McEwen et al. 1957), and replicated subsamples containing at least 100 individuals were taken for the analysis (Frontier, 1981). The taxon abundance per cubic meter and species composition were determined for all the samples. The copepods were identified to the species level whenever possible, according to

Björnberg (1981) and Bradford-Grieve et al. (1999). The total density of each species was estimated from the adults and copepodites. Shannon's diversity index (Shannon, 1948) was calculated to evaluate the degree of organization of the copepod community.

The analysis of variance (ANOVA) was used at a significance level of $p=0.05$ to identify the statistical differences among the sampling stations. All the data were evaluated for the normality and homogeneity prior to the analysis. A Principal Component Analysis (PCA) was performed to assess the main trends of the variability in the data. The PCA included the biotic and abiotic variables averaged for all the stations in the same cruise (copepod density; diversity; density of the species which, combined, represented 80% of total copepod abundance; temperature; salinity and dissolved oxygen). The data were log-transformed [$\log(x+1)$] to obtain a homoscedastic data distribution (Legendre and Legendre, 1983). The correlation between the biotic and abiotic variables was estimated using the *r*-Pearson index ($p=0.05$).

RESULTS

Environmental data

The salinity varied over the sampling area. The lowest salinity was found in the inner station of the bay near the mouth of the Passagem River (station 3), one of the entrances of the estuarine system in the rainy season. Higher salinities found in the inner stations of the bay reflected the penetration of the saline wedge (Table 1).

The precipitation followed the normal pattern (rainy summer and dry winter), except during 1994 and 1996, when summer precipitation was below average (206.8 mm annually) (Fig. 1).

The water temperature maxima were recorded during the early autumn of 1995 and 1996, and minima in the winter of 1997. During the survey period, the highest water temperatures were found inside the bay, showing discernible spatial variation (Table I).

The station located near the Passagem River had higher values of dissolved oxygen which could be explained by the frequent renewal of the water because of the proximity of the open sea (Table I).

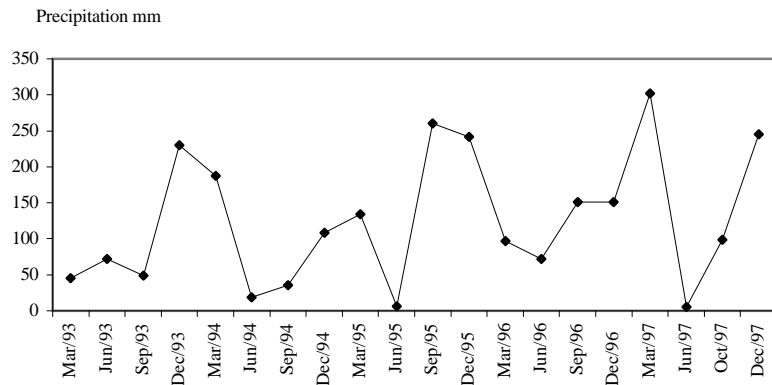


Figure 1- Precipitation measured during the cruises.

Table 1 - Minimum, maximum, mean and standard deviation of the copepod density (ind.m⁻³), temperature (°C), salinity and dissolved oxygen (mg.L⁻¹) in Espírito Santo Bay during a 5-year period (1993-1997).

Parameters	Stations							
	1	2	3	4	5	6	7	8
Salinity								
Min	28.1	28.4	27.5	28.2	30.4	30.1	32.2	32.3
Max	37.1	37.0	37.2	37.2	37.0	37.2	37.5	37.5
Mean	34.5	34.3	33.5	34.6	34.7	35.0	35.6	36.0
S.D.	2.1	2.3	2.5	2.2	1.8	1.8	1.6	1.6
Temperature								
Min	22.2	22.4	22.6	22.3	21.3	21.8	20.9	20.1
Max	26.0	26.0	28.7	26.1	25.7	25.3	25.4	25.8
Mean	23.9	23.9	24.7	23.7	23.3	23.3	23.0	23.1
S.D.	1.1	1.0	1.7	1.2	1.1	1.0	1.0	1.6
Dissolved oxygen								
Min	5.3	5.2	5.8	6.0	6.1	5.3	6.2	5.8
Max	12.8	12.0	11.8	11.4	11.0	10.3	8.8	11.2
Mean	7.3	7.1	7.1	7.0	6.9	6.8	6.8	7.0
S.D.	1.8	1.6	1.3	1.2	1.1	1.0	0.6	1.2
Copepod density								
Min	456.1	119.1	1478.0	658.0	951.7	68.9	68.3	69.7
Max	35994.2	57754.1	70406.0	55123.4	26126.9	26708.2	14559.2	10279.9
Mean	11853.8	15119.2	13041.8	13379.0	7027.1	5522.6	3876.0	2857.9
S.D.	11965.7	15781.7	17731.7	15534.7	6383.4	6660.8	3901.9	2990.7

The copepod community

The copepods were the predominant group, representing more than 85% of the total zooplankton. There was a discernible spatial variation in overall copepod density. Based on the ANOVA, the copepod density was different

among the sampling stations ($p=0.05$). It grouped the inner stations (1, 2, 3 and 4) separated from those located outside the bay (stations 5, 6, 7 and 8). The copepod density inside the bay ranged between 119 and 70,406 ind.m⁻³ (stations 1, 2, 3 and 4) and outside between 68 and 26,708 ind.m⁻³

(stations 5, 6, 7 and 8). Inside the bay, stations 1 (west of Camburi Beach) and 3 (near the Passagem River channel) had the lowest copepod density (lower than $13,050 \text{ ind.m}^{-3}$). The overall mean copepod density was $9,085 \text{ ind.m}^{-3}$, with abundance peaks (up to a mean of $15,000 \text{ ind.m}^{-3}$) occurring in the summer and autumn during the first three years (1993 through 1995), following the periods of highest precipitation. During 1996-1997, the abundance pattern changed. The highest densities were found in the winter (Fig. 2).

The diversity showed the highest values (up to $2.6 \text{ bits.ind}^{-1}$) in the autumn and spring of 1994, and summer of 1995 and 1997. The lowest values were found during the winter of 1997 ($1.2 \text{ bits.ind}^{-1}$) (Fig. 2).

Forty-six taxa of the copepods were recorded, 25 belonging to the order Calanoida, with an overall dominance of the species in the families Acartiidae, Paracalanidae and Temoridae (Table

2). The copepod assemblages were numerically dominated by the estuarine and estuarine/marine copepods, including *Acartia lilljeborgi*, *Paracalanus quasimodo*, *Oithona hebes*, *Temora stylifera* and *Parvocalanus crassirostris*. These species represented 93% of the total density of the copepods collected (Table 2).

The pronounced annual cycles were also apparent for the total density of the copepods, although not for the most copepod species. *A. lilljeborgi* showed the widest seasonal variability (Fig. 3). This species occurred in all the samples, and was usually the most abundant species (up to 48% of the total copepods), except in March 1993, September 1994, June and December 1995, and October and December 1997. In these months, the diversity was highest; *T. stylifera* and *P. quasimodo* were the other relatively common species.

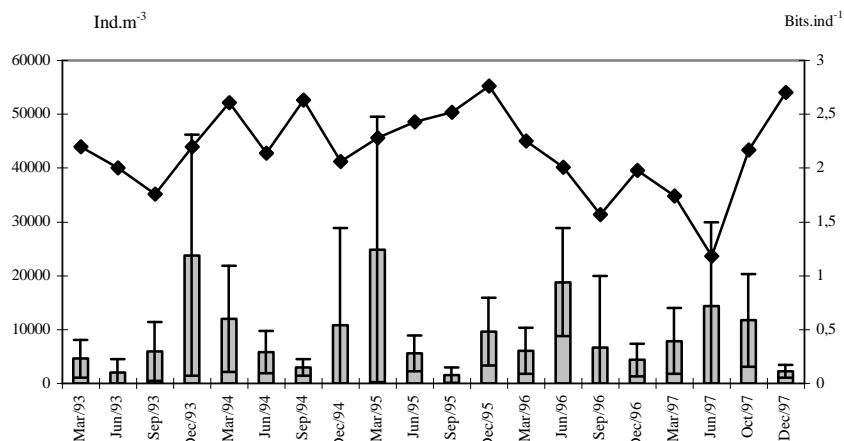


Figure 2 - Mean total copepod abundance (Ind.m^{-3}), and species diversity (Bits.ind^{-1}) values for each cruise (bar=mean; whisker=S.D.).

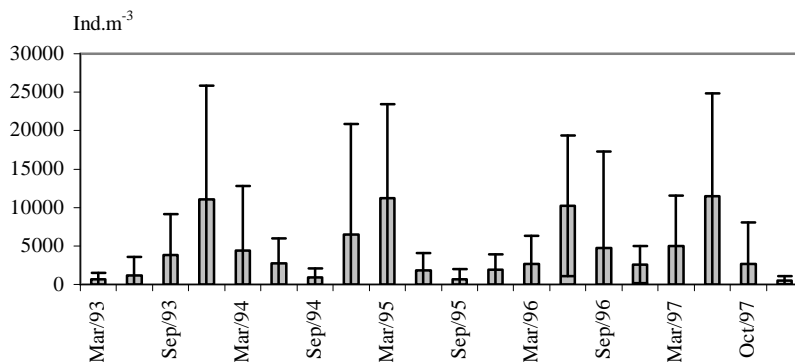


Figure 3 - Abundance of the dominant copepod species *Acartia lilljeborgi* during the sampling period in Espírito Santo Bay, during each cruise (bar=mean; whisker=S.D.).

Table 2 - Minimum, maximum, mean (ind.m⁻³) and percentage occurrence (%) of the copepod taxa sampled in Espírito Santo Bay during a five-year period (1993-1997).

Species	Min.	Max.	Mean	%
Order Calanoida	0.04	1144.26	161.52	1.78
Family Calanidae	0.56	108.79	12.56	0.14
<i>Calanoides carinatus</i>	0.01	299.60	18.57	0.20
<i>Nannocalanus minor</i>	6.68	6.68	0.33	0.004
<i>Neocalanus robustior</i>	0.15	0.15	0.01	0.0001
<i>Acartia lilljeborgi</i>	505.98	11476.60	4337.27	47.75
<i>Acartia</i> sp.	6.77	6.77	0.34	0.004
<i>Paracalanus quasimodo</i>	0.00	6294.35	1482.22	19.58
<i>Parvocalanus crassirostris</i>	126.25	3150.62	729.63	8.03
<i>Paracalanus aculeatus</i>	1.52	13.55	0.89	0.01
<i>Paracalanus parvus</i>	3.75	3.75	0.19	0.002
<i>Calocalanus</i> sp.	2.09	2.09	0.10	0.001
<i>Clausocalanus furcatus</i>	4.90	6.77	0.58	0.01
<i>Ctenocalanus citer</i>	0.29	0.29	0.01	0.0002
<i>Temora stylifera</i>	21.57	3962.65	734.81	8.09
<i>Pseudodiaptomus acutus</i>	0.26	200.75	23.11	0.25
<i>Subeucalanus pileatus</i>	1.05	72.16	14.91	0.16
<i>Subeucalanus subtenuis</i>	9.20	9.80	0.95	0.01
<i>Subeucalanus</i> sp.	0.65	63.83	10.71	0.12
<i>Centropages velificatus</i>	0.34	318.25	23.79	0.26
<i>Calanopia americana</i>	0.37	38.39	7.32	0.08
Family Pontellidae	2.09	8.72	0.97	0.01
<i>Labidocera fluviatilis</i>	0.01	0.10	0.01	0.0001
Nauplii	0.37	45.07	9.65	0.11
Damaged animals	0.67	9.99	1.86	0.02
Order Cyclopoida				
<i>Oithona hebes</i>	78.15	4558.81	827.83	9.11
<i>Oithona oculata</i>	2.29	188.97	27.14	0.30
<i>Oithona plumifera</i>	0.15	27.82	4.07	0.04
<i>Oithona similis</i>	2.78	2.78	0.14	0.002
<i>Oithona setigera</i>	2.84	12.14	0.75	0.01
<i>Oithona</i> sp.	0.57	8.13	1.13	0.01
Nauplii	0.47	870.87	58.09	0.64
Order Poecilostomatoida				
<i>Corycaeus giesbrechti</i>	12.87	984.50	166.25	1.83
<i>Corycaeus speciosus</i>	4.01	13.59	0.88	0.01
<i>Farranula gracilis</i>	0.06	40.89	5.74	0.06
<i>Oncaea venusta</i>	0.31	8.91	0.61	0.01
<i>Oncaea media</i>	3.03	3.03	0.15	0.002
<i>Oncaea curta</i>	0.29	0.29	0.01	0.0002
<i>Copilia mirabilis</i>	0.05	5.10	0.43	0.005
Family Clausidiidae	0.81	0.81	0.04	0.0004
<i>Hemicyclops thalassius</i>	0.04	27.92	1.77	0.02
<i>Sapphirina nigromaculata</i>	4.00	8.77	0.64	0.01
Order Harpacticoida				
<i>Euterpina acutifrons</i>	5.81	485.21	111.86	1.23
<i>Macrosetella gracilis</i>	4.86	4.86	0.24	0.003
Parasitic Copepoda	0.01	22.32	3.98	0.04
Order Monstrilloida	0.01	0.01	0.002	0.00002

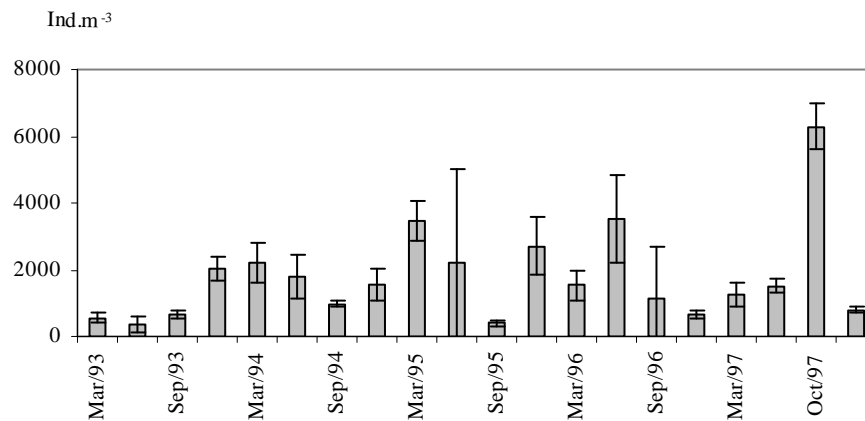


Figure 4 - Abundance of the dominant copepod species *Paracalanus quasimodo* during the sampling period in Espirito Santo Bay, during each cruise (bar=mean; whisker=S.D.).

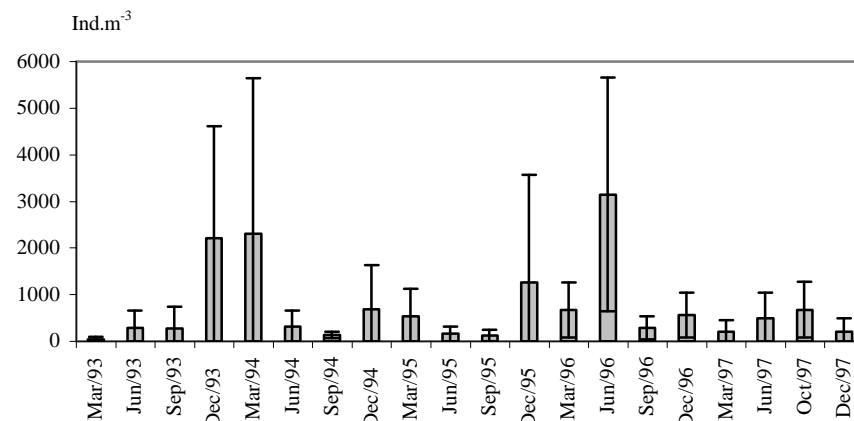
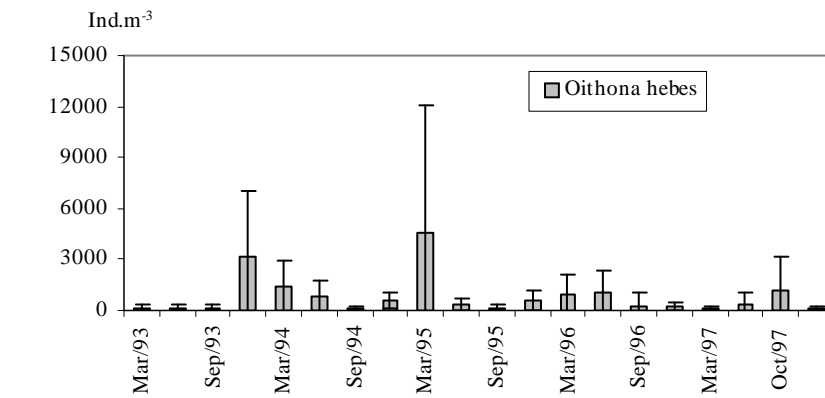


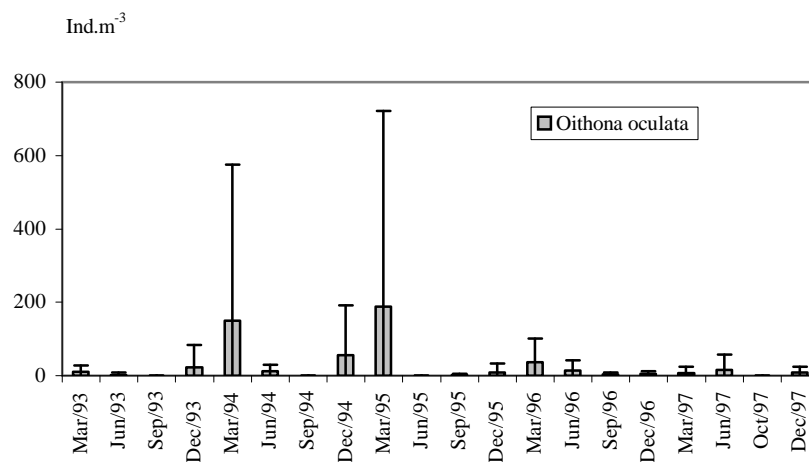
Figure 5 - Abundance of the dominant copepod species *Parvocalanus crassirostris*, during the sampling period in Espirito Santo Bay, during each cruise (bar=mean; whisker=S.D.).

Two species of the family Paracalanidae (*P. quasimodo*, up to 20% and *P. crassirostris*, up to 8% of the total copepods) were very abundant (Table 2). *P. quasimodo* reached peak numbers in March 1995, June 1996 and October 1997 (Fig. 4). This species was more abundant than *A. lilljeborgi* in September 1994, June and December 1995, and October and December 1997. *P. crassirostris* occurred in relatively low densities, with the exception of March 1994 and June 1996 when it reached the densities of more than 2000 ind.m⁻³ (Fig. 5).

The family Oithonidae was represented by five species, *Oithona hebes* and *O. oculata* being the most numerous. The estuarine-marine copepod *O. hebes* comprised up to 9% of the total copepod abundance and reached peak numbers in December 1993, March 1995, March and June 1996, and October 1997 (Fig. 6a and 6b). *Temora stylifera* reached peaks in March and December 1993 and March 1995 (Fig. 7). This species comprised up to 8% of the total copepod abundance, and dominated the copepod population in March 1993, when the mean temperature was 23.7 °C and the salinity was 34.6.



a)



b)

Figure 6a and 6b - Abundances of the dominant copepod species (a) *Oithona hebes* and (b) *Oithona oculata*, during the sampling period in Espírito Santo Bay, during each cruise (bar=mean; whisker=S.D.).

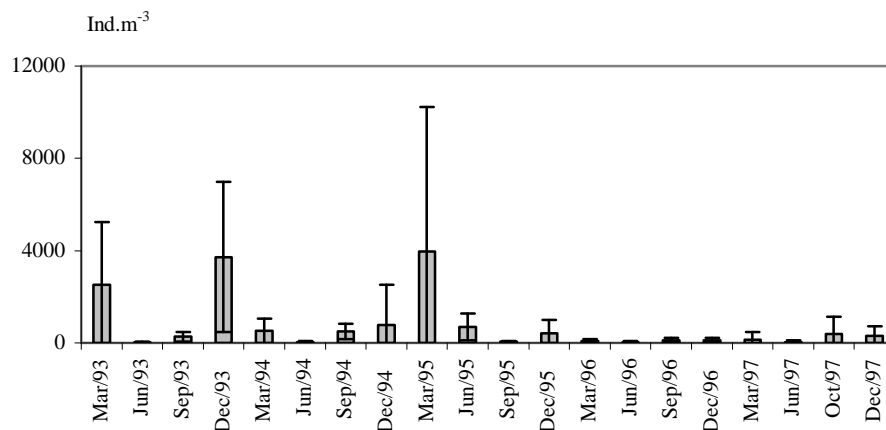


Figure 7 - Abundance of the dominant copepod species *Temora stylifera*, during the sampling period in Espírito Santo Bay, during each cruise (bar=mean; whisker=S.D.).

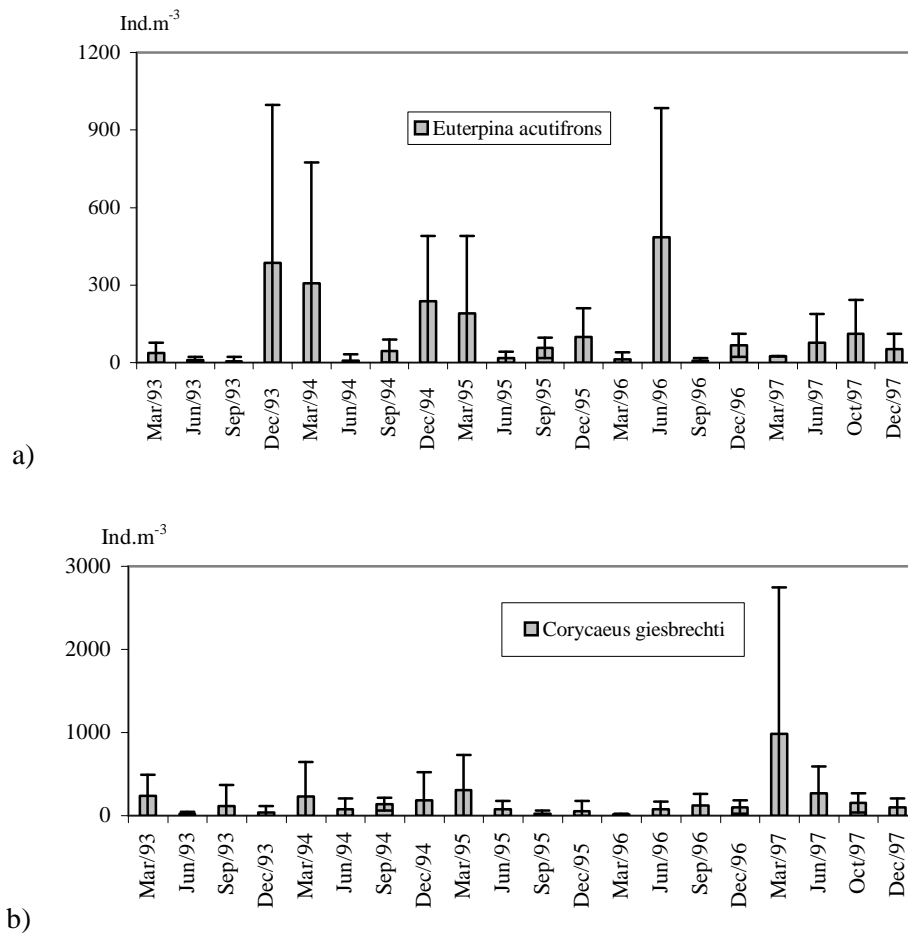


Figure 8a and 8b - Abundances of the dominant copepod species (a) *Euterpina acutifrons* and (b) *Corycaeus giesbrechti*, during the sampling period in Espírito Santo Bay, during each cruise (bar=mean; whisker=S.D.).

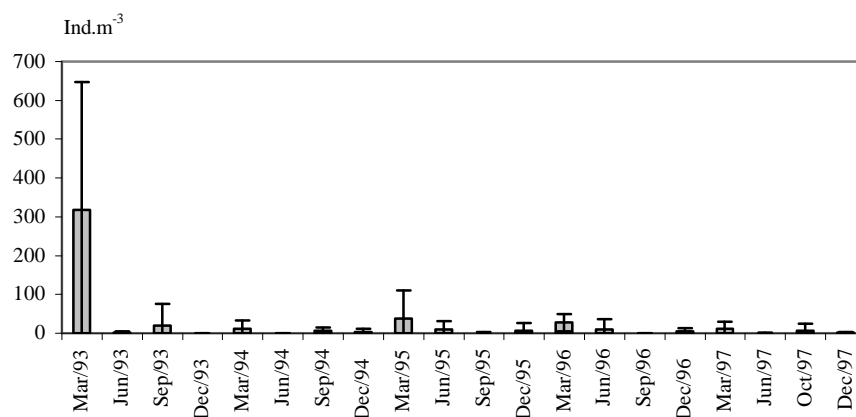


Figure 9 - Abundance of the dominant copepod species *Centropages furcatus*, during the sampling period in Espírito Santo Bay, during each cruise (bar=mean; whisker=S.D.).

The marine euryhaline copepods *Euterpina acutifrons*, *Corycaeus giesbrechti* (Figs 8a and 8b) and the coastal-marine *Centropages furcatus* (Fig. 9) occurred in almost all the samples, but in low densities.

The copepod population of Espírito Santo Bay showed the coastal and estuarine characteristics, e.g., with the occurrence of such species as *H. thalassius*, *O. oculata*, *Pseudodiaptomus acutus* and *Labidocera fluviatilis*. The occurrence of the inner- and coastal-water species was chiefly associated with the lower salinities found inside the bay.

The presence of the tropical species such as *Oncaea venusta*, *Clausocalanus furcatus*, *Subeucalanus subtenius*, *O. plumifera* and

Macrosetella gracilis could be associated with the marine influence in the area. These species occurred outside the bay, and were carried into it with the entrance of the water, which caused increased salinity and temperature.

Two cold-water species (*Ctenocalanus citer* and *Calanoides carinatus*) were found outside the bay. *Ctenocalanus citer* and *Calanoides carinatus* occurred in the spring 1993 and in summer from 1994 to 1997, and both were collected in the water of temperatures from 22.4 to 24.8°C.

The relationship between the copepod assemblage and the environmental variables was obtained through the PCA analysis, which disclosed two factors (Fig. 10) that together explained 51% of the variation in the copepod assemblage.

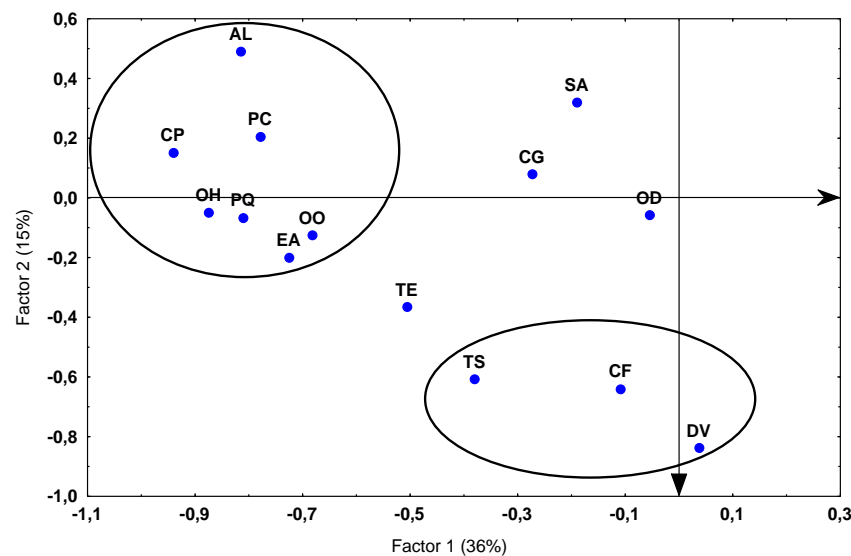


Figure 10 - Scatter plot of variables related to Factors I x II over the five-year sampling period. Symbols for the copepod taxa and environmental parameters included in the multivariate analysis: CP – Copepods, AL - *Acartia lilljeborgi*, PQ - *Paracalanus quasimodo*, PC - *Parvocalanus crassirostris*, TS - *Temora stylifera*, OH - *Oithona hebes*, OO - *Oithona oculata*, CG - *Corycaeus giesbrechti*, EA - *Euterpina acutifrons*, CF - *Centropages furcatus*, DV – Diversity, TE – Temperature, SA – Salinity and OD – Dissolved oxygen.

Factor I (36%) was the temporal factor generated by the variation in the copepod community during the five years of the sampling. The maximum copepod abundance occurred in the summer 1993/94, autumn 1994/95 and winter 1996, associated with the higher mean temperatures and salinity (up to 25.6 °C and 36.7 in autumn 1995). The variations were related to the abundances of

A. lilljeborgi, *O. hebes*, *P. quasimodo*, *P. crassirostris*, *O. oculata*, and *E. acutifrons*. These species were associated ($r > 0.40$), and the abundance of *A. lilljeborgi* acted to decrease the community diversity. Factor II (15%) reflected the influence of the water masses on the copepod assemblage, relating the specimens to the temporal variations in temperature and salinity. These

parameters were especially related to the abundances of *P. crassirostris* and *A. lilljeborgi*. These species showed an affinity to high salinity in the spring 1996, and low temperature in winter 1997. *C. furcatus* and *T. stylifera* were associated with the inverse conditions in the autumn 1993. The diversity ratio (up to 2.2 bits.ind⁻¹) could be associated with the presence of a more-structured copepod assemblage in the region. In these months, the reduction of the *Acartia lilljeborgi* density acted to increase the community diversity ($r = -0.54$).

DISCUSSION

Espírito Santo Bay is a typical estuarine system, dominated by the coastal waters. The spatial and temporal variations of the environmental variables (salinity, temperature and dissolved oxygen) are typical for the region (Dias, 1994; Pereira et al. 2000; Jesus et al. 2004) and other estuarine systems of southeastern Brazil (Fernandes et al. 2002; Gomes et al. 2004).

The mean copepod abundance during the present study period was slightly lower than that estimated for an earlier period (1986-1987) by Dias (1994), who found a mean of 9,248 ind.m⁻³. Dias used the same sampling methodology to study the copepod composition in stations located inside the bay. The distribution of the density the values found inside the bay in the present study were similar to that found by Dias (1994). Inside the bay, the stations west of Camburi Beach and near the Passagem River channel showed the lowest copepod density. The results reflected the environmental conditions of these areas, impacted by the human activities such as the industrial, port and household wastes (Nalesso and Mazioli, 2000; Nassar et al. 2003; Jesus et al. 2004). Despite the reduction in the copepod density and the maintenance of the lowest density in the station located near these degraded areas (Camburi Beach and Passagem River channel), the copepod population of the Espírito Santo Bay maintained its characteristics. The copepod assemblage was composed of the estuarine and estuarine/marine species, with the occurrence of the inner- and coastal-water species and the presence of the tropical species.

The temporal variations of the environmental variables could be related to the abundance of almost all the species, during the five years of

sampling, with the dominant species alternating. *A. lilljeborgi* was the most abundant species except in the dry months (when precipitation was lower than 99 mm) and in the months where the salinity values were the lowest of the period. *A. lilljeborgi* has been the most abundant *Acartia* species in Brazilian estuaries. *Acartia* species are indicators of the coastal waters, and are often dominant among the copepods in the warm coastal and estuarine waters of higher salinity (Björnberg, 1981; Lopes, 1994; Ramaiah and Nair, 1997). In the months when the density of *A. lilljeborgi* decreased, *T. stylifera* and *P. quasimodo* were the dominant species. The family Paracalanidae generally occurs in the coastal waters, and *Temora stylifera* is associated with the coastal and shelf waters off Brazilian coasts (Björnberg, 1981; Bradford-Grieve et al. 1999). These abundances levels were similar to other findings for the species along the southeastern Brazilian coast (Lopes, 1994; Wandeness et al. 1997; Silva et al. 2004). The presence of the cold-water species in the rainy months has not been reported in previous studies, e.g., Bonecker et al. (1987, 1991) and Dias (1994). *C. carinatus* was a typical member of the zooplankton upwelling communities, reaching higher abundances in the summer.

The qualitative composition of the copepod fauna studied here was different from that reported by Dias (1994), who found only 22 copepod species, of which *A. lilljeborgi*, *P. quasimodo* and *O. hebes* represented 93% of the total number. The observed relationships of the salinity with the fluctuations in the copepod abundance reflected the changes in the proportions of different water masses, such as the penetration of more saline water into the inner bay. Consequently, there was a small difference in the densities and diversity in comparison with the values found during 1986 and 1987.

Espírito Santo Bay and its surroundings, like other urbanized and industrialized coastal areas, have suffered inputs of the industrial and urban waste. The effects of the degradation caused by the human activities on the marine ecosystems normally are a decrease in the biological diversity and loss of some species (Silva et al. 2004). These effects were not observed in the present study in the areas affected by the industry and household wastes. Although the copepod density decreased, the values of the diversity increased in the present study.

In this five-year data, the variability observed in relation to the abundance, diversity and species composition did not affect the dominant species, which were the same as those found in 1986-1987 by Dias (1994). The difference in the qualitative composition of the copepod fauna in relation to the previous study done in the same region could be associated with the environmental micro-variations (temperature and salinity) that were characteristic of the coastal regions, and the movements of the saline waters into the bay.

ACKNOWLEDGEMENTS

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RESUMO

Este trabalho descreve a estrutura da comunidade de copépodes em relação às condições hidrográficas da baía do Espírito Santo, no período de 1993 a 1997. As amostras do zooplâncton foram obtidas através de arrastos horizontais, quatro vezes ao ano, com uma rede de 200µm. A temperatura, a salinidade e o oxigênio dissolvido foram determinados nas amostras de água. A densidade média dos copépodes foi de 9.085 ind.m⁻³, com picos superiores a 15.000 ind.m⁻³, durante o verão e o outono de 1993 a 1995. Utilizou-se a PCA para relacionar as variáveis ambientais à distribuição dos copépodes. A comunidade dos copépodes, principalmente as altas densidades das espécies *Acartia lilljeborgi*, *Oithona hebes*, *Oithona oculata*, *Paracalanus quasimodo*, *Parvocalanus crassirostris* e *Euterpina acutifrons* foram relacionados à diminuição da diversidade. As variações espaço-temporais da temperatura e da salinidade influenciaram a abundância das espécies durante os cinco anos de coleta, com a alternância das espécies dominantes.

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