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Vertical Copepod Assemblages (0-2300 m) off Southern Brazil

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Cristina de Oliveira Dias, Adriana Valente de Araujo, Rodolfo Paranhos, and Sérgio Luiz Costa Bonecker (2010) Vertical copepod assemblages (0-2300 m) off southern Brazil. *Zoological Studies* **49**(2): 230-242. The structure of copepod assemblages in the region of the Campos Basin was studied for a 1 yr period. Zooplankton samples were obtained in the 2002 wet season and 2003 dry season, by stratified vertical hauls in 4 previously identified water masses: tropical water (TW), South Atlantic central water (SACW), intermediate Antarctica water (IAW), and North Atlantic deep water (NADW). Temperature and salinity were determined. The copepod mean density did not significantly differ ($p < 0.05$) between the northern and southern stations in the 2 seasons, but significantly differed among the water masses, and in each water mass in the 2 seasons, except for the SACW. The highest mean density was found in the TW, and the lowest in the NADW. Eighty-nine taxa of copepods, with 70 generally distributed species and 19 species exclusive to 1 or another water mass were recorded in the 4 water masses. The copepod assemblages of the Campos Basin showed tropical characteristics, and were numerically dominated by epipelagic species: *Clausocalanus furcatus*, *Farranula gracilis*, and *Oncaea venusta* in TW; *Pleuromamma abdominalis*, *Macrosetella gracilis*, *Oncaea venusta*, and *Clausocalanus furcatus* in the SACW; *Clausocalanus furcatus*, *Oncaea venusta*, *Triconia conifera*, and *Calanoides carinatus* in the IAW; and *Oncaea venusta*, *Oithona similis*, *Clausocalanus furcatus*, *Farranula gracilis*, and *Mecynocera clausi* in the NADW. Differences in the copepod community along the water column were found. Differences in copepod compositions and abundances were possibly a consequence of the influences of oceanic and shelf waters, with contributions of deep-water species to the upper-level water masses. Despite the oligotrophic nature of the Brazil Current, the densities found were higher than those observed along the Brazilian coast and in other tropical regions. http://zoolstud.sinica.edu.tw/Journals/49.2/230.pdf

Key words: Zooplankton, Seasonal variations, Tropical coastal zone, Southeastern Brazil.

The dynamics and structure of plankton depend on local environmental conditions. In tropical seas, seasonal dynamics of communities are difficult to identify and are much less marked than those observed in temperate aquatic ecosystems. Seasonal variations recorded in tropical and subtropical coastal regions are mainly determined by local influences of the rainy and dry seasons, and by regional oceanographic phenomena (Nybakken and Bertness 2005).

In the southwestern Atlantic, as in other tropical areas, the plankton fauna has mainly been surveyed in the upper layers (0-200 m), and little is known about the composition of zooplankton at greater depths. Off the coast of central Brazil, the structure and characteristics of the plankton communities were mainly studied in estuaries and on the continental shelf. Investigations on the zooplankton of coastal Rio de Janeiro have been conducted since the 1930s through various

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oceanographic expeditions (Almeida-Prado 1961, Goy 1979, Monteiro-Ribas et al. 1979, Campaner 1985, Abreu and Nogueira 1989, Bonecker et al. 1990, Dias 1994).

Investigations on epipelagic copepods off Brazil, reviewed by Brandini et al. (1997), began at the end of the 1900s. Björnberg (1963) provided the 1st detailed account of the communities of epipelagic species in relation to the distribution of water masses. During the 1970s, studies on upwelling in the Cabo Frio area were conducted by Valentin et al. (1986 1987). Investigations on the northern coast of Rio de Janeiro, between the mouth of the Itabapoana River and the Marica Bar (21°00'-23°30'S) were initiated in the beginning of the 1990s (Bassani et al. 1999). Qualitative, quantitative, and seasonal studies characterizing the plankton communities in coastal and deep-oceanic regions below 700 m in the area of the Campos Basin were initiated in 2001.

The Campos Basin is a petroleum-rich area located on the coast of Rio de Janeiro, Brazil. Its total area is 10^5 km^2, of which only 500 km^2 are immersed, and extends from the state of Espírito Santo, near the city of Vitória, to the Arraial do Cabo off the northern coast of the state of Rio de Janeiro (Milani et al. 2000). This basin currently accounts for nearly 84% of Brazil's oil production. The local oceanographic dynamics impose specific conditions on the local water mass, i.e., horizontal vortices and vertical movements (upwelling and downwelling) associated with the influence of the winds and the deep morphology of the ocean floor (Stramma et al. 1990). These water movements lead to alterations in the physical and chemical compositions of the water mass, consequently affecting the structure and dynamics of local biological communities. Despite these water movements and the continental influence from the Paraíba do Sul River, which act to enrich the region, Campos Basin waters are oligotrophic. The low phytoplankton productivity influences the local food web (Tommasi 1994).

In the Rio de Janeiro area, certain groups of epizooplankton, including copepods, are relatively well known. However, the fauna of the deeper layers remains unstudied. In view of the sparse information on copepods off the northern continental shelf of Rio de Janeiro, this study describes the copepod community of the Campos Basin, from data obtained in the dry and wet seasons over a 1 yr period. Three additional questions were addressed: (1) Is there a different copepod assemblage in each water mass in the area?; (2) How do the water masses influence the copepod assemblages?; and (3) How is the copepod assemblage influenced by the dry and wet seasons? The results obtained will be useful in future monitoring studies.

MATERIALS AND METHODS

Study area

The surveyed area is located near the city of Campos in northern Rio de Janeiro state on the central Brazilian coast (22°22'15"S, 41° 47'13"W). The Campos Basin is bordered offshore by the Vitória Arc to the north, the Cabo Frio Arc to the south, and by the ocean crust within the continental shelf to the east. Onshore to the west, the basin is bordered by a crystalline gneissic basement (Carrasquilla and Ulugergerli 2006). The climate is humid, with a summer rainy season and a relatively dry winter.

Sampling method and treatment of samples

The biological material examined was obtained as part of a project to study the zooplankton fauna in deep oceanic regions, coordinated by CENPES/PETROBRAS (Campos Basin Deep Sea Environmental Characterization). Sampling was carried out during oceanographic cruises in the 2002 wet season (1-8 Dec.) and 2003 dry season (13-19 June). In each season, 10 stations were sampled: five in the northern and 5 in the southern part of the Campos Basin, at depths down to 2500 m (Fig. 1).

Water temperature and salinity were determined from CTD profiles, using a Falmouth Scientific Inc., Instruments model ICTD (Cataumet, Massachusetts, U.S.A.). Four water masses were identified according to the temperature and salinity data: tropical water (TW), South Atlantic central water (SACW), intermediate Antarctica water (IAW), and North Atlantic deep water (NADW).

Samples were collected by stratified vertical hauls (TW at 0-100 m, SACW at 100-600 m, IAW at 100-1100 m, and NADW down to the 2500 m deep) in the 4 previously identified water masses, with a total of 62 samples. Hauls were made using cylindrical-conical nets of 200 μm mesh size and 80 cm mouth diameter, with a double-trip closing mechanism, model 1000-DT (General Oceanics Inc.®, Miami, Florida, U.S.A.), fitted with a calibrated flow meter (filtered water volume: TW range,

15.4-90.2 m^3 and mean, 40.9 m^3; SACW range, 46.5-577.2 m^3 and mean, 201.4 m^3; IAW range, 67.0-859.2 m^3 and mean, 297.2 m^3; and NADW range, 168.2-1238.1 m^3 and mean, 528.8 m^3). Samples were fixed and preserved in 4% buffered formalin. Daytime sampling was done from 07:50 to 17:50 (local time) and night sampling from 18:15 to 02:20.

Samples were divided into fractions with a Folsom Plankton Sample Splitter (developed by Dr. Folsom of the Scripps Institution of Oceanography, La Jolla, California, U.S.A.) (McEwen et al. 1957), and 3 subsamples containing at least 100 copepods were taken for analysis (Frontier 1981). Taxon abundance per cubic meter and copepod species composition were determined for all samples, according to Björnberg (1981), Bradford-Grieve et al. (1999), and Dias and Araujo (2006). The total density of each species was estimated from adults and copepodites.

All specimens found were deposited in the copepod collection of the Integrated Zooplankton and Ichthyoplankton Laboratory of the Federal Univ. of Rio de Janeiro.

Data analysis

Differences between stations (north vs. south) and seasons (wet vs. dry) were tested using Student's *t*-test. Analysis of variance (ANOVA) was used at a significance level of $p < 0.05$ to identify statistical differences in copepod density among the water masses. All data were evaluated for normality and homogeneity prior to the analysis and [log(x + 1)] was used to obtain a homoscedastic data distribution (Legendre and Legendre 1983). The post-hoc Tukey's honest significant difference (HSD) test was used to identify differences among the collections when statistical differences were found.

A multivariate numerical ordination technique was used to classify stations into groups with different zooplankton community structures. Similarity based on species density with occurrences of > 10% among stations in the 2 yr was determined by multi-dimensional scaling (MDS), using the program package Primer 5 (Clarke and Warwick 1994). We used [log(x + 1)]-transformed density data to generate a Bray-Curtis similarity matrix. A stress value of the MDS representation of > 0.2 indicates a fairly accurate and useful 2 dimensional representation of inter-haul similarities (Clarke and Warwick 1994). Analysis of similarity (ANOSIM) was used to test if the sampling years showed differences in zooplankton assemblage structure. The SIMPER (similarity of percentages) test was used to identify those species that most contributed to similarities within groups. Correlations between the copepod density and environmental variables (temperature and salinity) were estimated using the Pearson *r*-index.

RESULTS

Environmental data

Four water masses were recognized in the study area (Fig. 2): over the slope, the TW was found to approximately 200 m in a vertical line (with a temperature of > 18.5°C and salinity of > 36.0 ppt); the SACW from approximately 200 (upper limit with a temperature of 18.5°C and salinity of

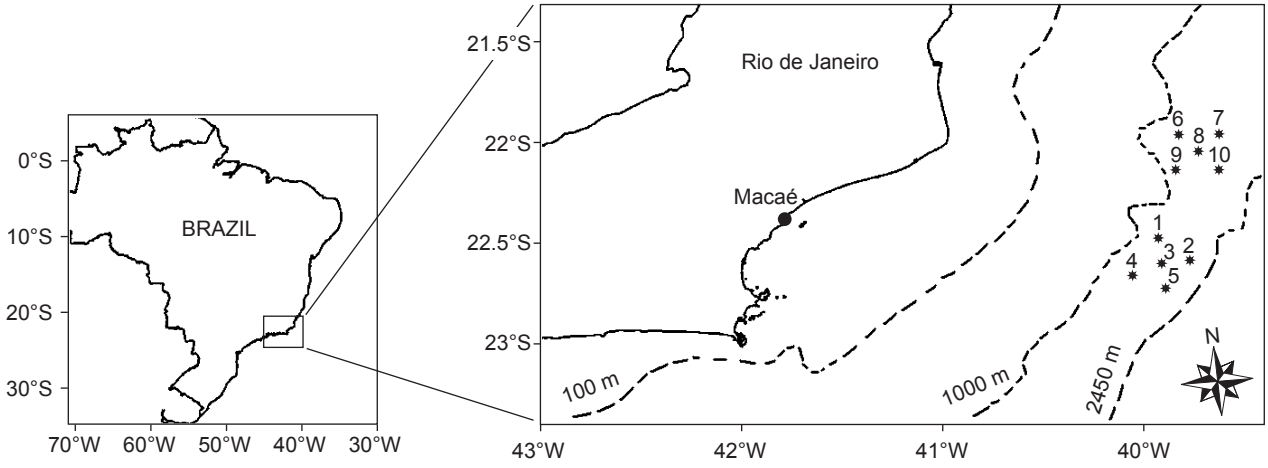

Fig. 1. Locations of sampling stations in the Campos Basin.

36.0 ppt) to 660 m (lower limit with a temperature of 6.0°C and salinity of 34.5 ppt); the IAW from approximately 660 (upper limit with a temperature of 7.5°C and salinity of 34.65 ppt) to 1300 m (lower limit with a temperature of 3.5°C and salinity of 34.4 ppt); and the NADW below 1340 m (with a temperature of < 3.6°C and salinity of > 34.65 ppt). A mixed water layer (MW), forming a stratum between the TW and SACW, was found at 40 m during the wet season, and at 80 m during the dry season.

Species composition and density

Copepod mean density did not differ ($p < 0.05$) among the stations (north vs. south) in the 2 sampling periods (2002 wet and 2003 dry seasons). The maximum and minimum densities were found at stations located in the southern part of the basin. The highest mean density was 555.42 individuals (ind.)/m^3 (standard deviation (SD), 989.12 ind./m^3) at station 5 (means of the 2 sampling periods: 2035.22 ind./m^3 for TW, 162.24 ind./m^3 for SACW, 24.22 ind./m^3 for IAW, and 0.01 ind./m^3 for NADW). The lowest mean density was 14.21 ind./m^3 (SD 24.98 ind./m^3) with 51.55 ind./m^3 for TW, 4.70 ind./m^3 for SACW, 0.31 ind./m^3 for IAW, and 0.29 ind./m^3 for NADW at station 4 (Fig. 3a).

The density of copepods was highest in the surface layer and decreased with increasing depth. The copepod mean density differed ($p < 0.05$) among the 4 water masses, and in each water mass in relation to the 2 sampling periods (2002 wet and 2003 dry seasons), with the exception of the SACW, in which the density showed no differences in the samples. The highest mean density was found in the TW (mean, 725.22 and SD, 999.71 ind./m^3 in the 2002 wet season, and mean, 757.70 and SD, 783.71 ind./m^3 in the 2003 dry season). The lowest mean density was recorded in the NADW (mean, 1.60 and SD, 5.05 ind./m^3 in the 2002 wet season, and mean, 0.06 and SD, 0.10 ind./m^3 in the 2003 dry season) (Fig. 3b).

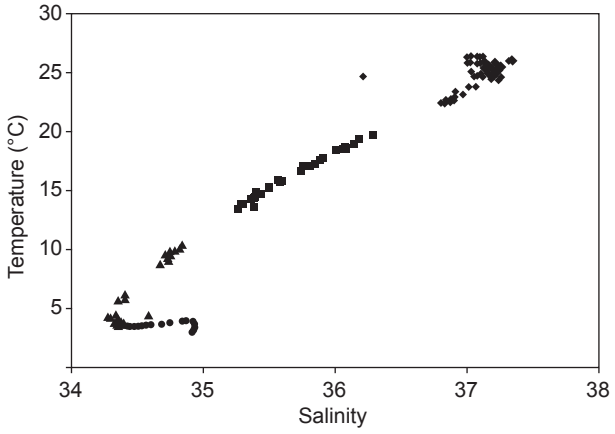

Fig. 2. Temperature-salinity diagram of the water masses found in the Campos Basin: diamonds, tropical water; squares, South Atlantic central water; triangles, intermediate Antarctic water; circles North Atlantic deep water.

The relative compositions of the Calanoida, Cyclopoida, Harpacticoida, and Poecilostomatoida were stable with depth. In terms of density, Calanoida (67.20% ± 8.69%, mean ± SD) and Poecilostomatoida (19.21% ± 4.77%) were the dominant groups. The Harpacticoida and Cyclopoida occurred in all water masses, but their fractions were small (< 10%).

Eighty-nine taxa of copepods with 70 species were recorded from the 0-2300 m water column (Table 1). Suspension-feeders included 55 taxa, detritivores consisted of 19 taxa, and carnivores included 15 taxa. The most numerous calanoid copepods belonged to the family Clausocalanidae (mainly *Clausocalanus furcatus*), which are suspension-feeders. The poecilostomatoid detritivores *Farranula gracilis* and *Oncaea venusta* were also abundant.

The copepod assemblage of the Campos Basin showed tropical characteristics and was numerically dominated by the epipelagic species, *Cla. furcatus*, *Onc. venusta,* and *Far. gracilis*, which represented 36% of the total density of copepods collected in the TW (Fig. 4); the family Metridinidae (mainly *Pleuromamma abdominalis*), *Macrosetella gracilis*, *Onc. venusta,* and *Cla. furcatus* (representing 33% of total density in the SACW) (Figs. 4, 5); the family Clausocalanidae (mainly *Cla. furcatus*), the family Oncaeidae (*Onc. venusta* and *Triconia conifera*) and *Calanoides carinatus* (representing 38% of the total density in the IAW) (Figs. 4, 5, 6); and the family Oncaeidae (mainly *Onc. venusta*), *Oithona similis*, the family Clausocalanidae (mainly *Cla. furcatus*), *Far. gracilis,* and *Mecynocera clausi* (representing 41% of the total density in the NADW) (Figs. 4, 5, 6, 7). The dominant species were suspension-feeders or detritivores, and with the exception of *Pleuromamma abdominalis* and *Cal. carinatus* were not necessarily dominant in biomass.

In total, 19 exclusive species were recorded in the 4 water masses in the area: TW (the epipelagic species *Acrocalanus longicornis*, *Subeucalanus pileatus*, *Centropages violaceus*, *Corycaeus latus*,

Copilia mirabilis, and *Sapphirina nigromaculata*); SACW (the epi-mesopelagic species *Lucicutia clausi*, *Scaphocalanus echinatus*, and *Haloptilus austini* and the meso-bathypelagic species *Scottocalanus securifrons*, *Hal. longicornis*, and *Eaugaptilus filiger*); IAW (the epi-mesopelagic species *Subeucalanus longiceps* and the meso-bathypelagic species *Gaetanus brevicornis*, *Undeuchaeta major*, *Lophothrix latipes*, *Lucicutia longicornis,* and *Luc. ovalis*); and NADW (the epi-mesopelagic species *Euchaeta acuta*) (Table 1).

Copepods were not only most abundant but also the most species-rich in the TW, where 49 species were found. Species richness decreased

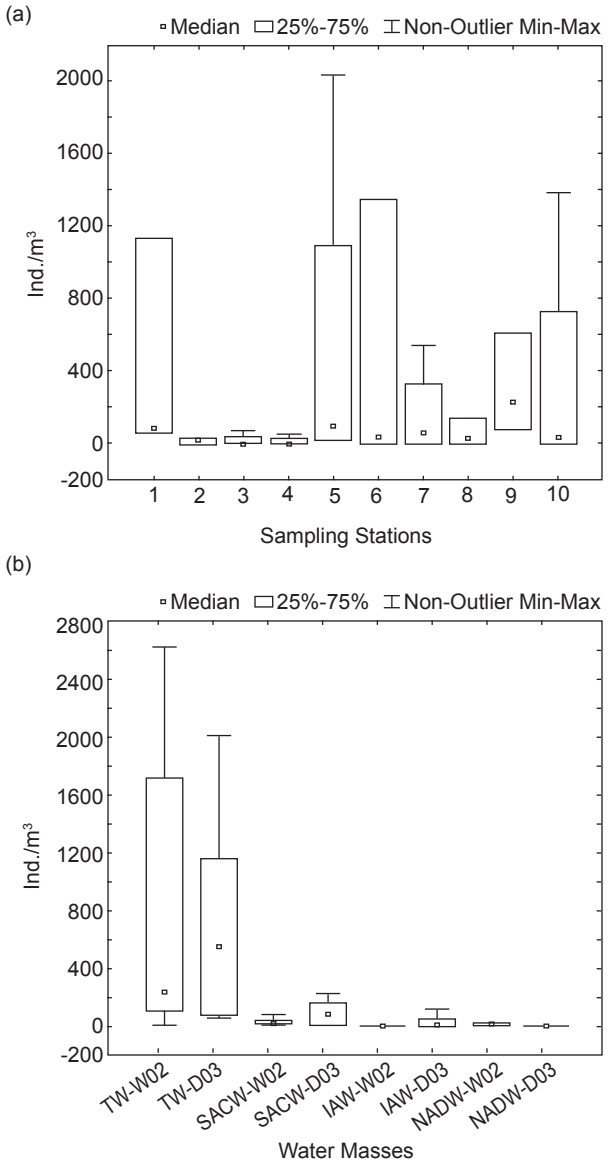

Fig. 3. Variations in mean copepod density (individuals (ind.)/m^3) in the Campos Basin: (a) at the sampling stations, and (b) in the water masses (2002 wet season and 2003 dry season): tropical water (TW), South Atlantic central water (SACW), intermediate Antarctica water (IAW), and deep water of the North Atlantic (NADW).

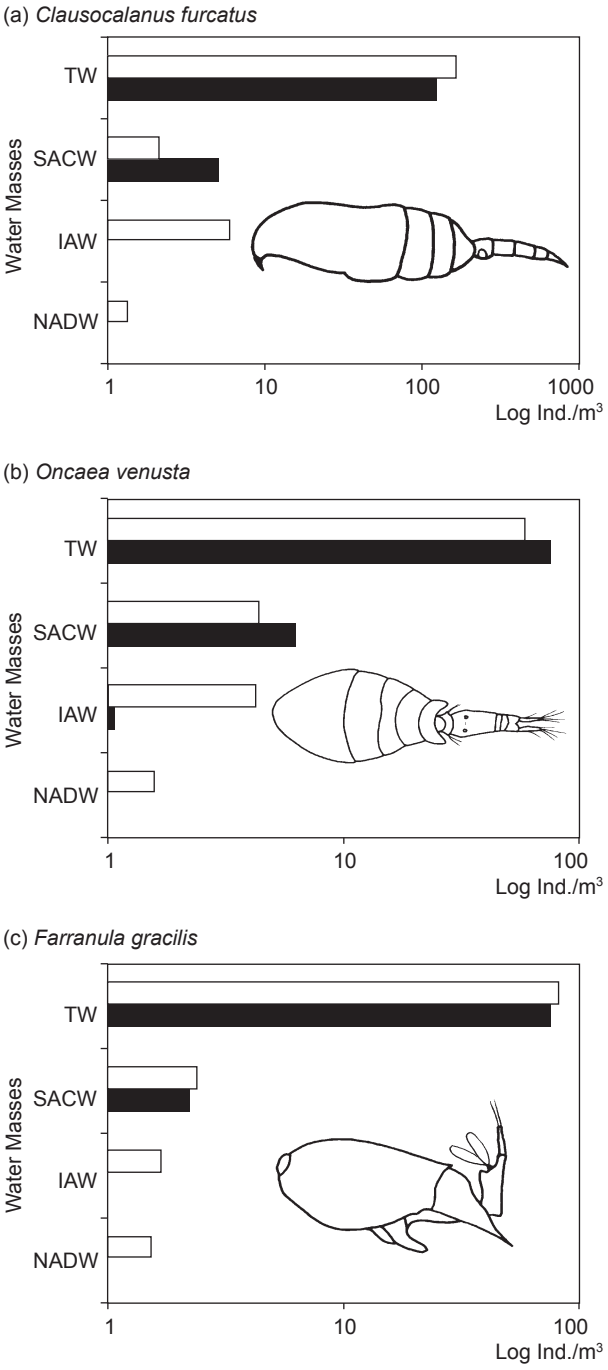

Fig. 4. Mean density (individuals (ind.)/m^3) of the dominant copepod species in the tropical water (TW): (a) *Clausocalanus furcatus*, (b) *Oncaea venusta,* and (c) *Farranula gracilis* (open bars, 2002 wet season; black bars, 2003 dry season).

with depth, down to the NADW with 28 species.

Multidimensional scaling revealed that variations in species density were an important factor determining changes in the copepod community (density of copepod species for n = 35, which occurred in more than 10% of samples). Results from pairwise tests of the ANOSIM performed during the 2 sampling periods demonstrated that groups of water masses separated according to different copepod assemblages all differed from each other, with the exception of the IAW and NADW (Table 2). The compositions of the copepod assemblages found in the TW and SACW differed from those found in the IAW and NADW (frames in Figure 8).

The copepod assemblage of the TW (center left) contained samples collected during the 2 sampling periods (the 2002 wet season and 2003 dry season). Nine taxa accounted for 92% of the similarity in this group (SIMPER test): *Cla. furcatus*

Table 1. Occurrence and density (individuals (ind.)/m^3) of the copepod taxa in water masses of the Campos Basin (FP, feeding pattern; SF, suspension feeders; CN, carnivores; DT, detritivores; PR, parasitic; X, occurrence; X*, exclusive taxa; X**, co-occurring taxa)

Species	FP	ind./m^3	TW	SACW	IAW	NADW
Family Calanidae (copepodids)	SF	730.71	X**	X**	X**	X**
Calanoides carinatus (Krøyer, 1849)	SF	96.62	X**	X**	X**	X**
Nannocalanus minor (Claus, 1863)	SF	392.02	X**	X**	X**	X**
Undinula vulgaris vulgaris (Dana, 1849)	SF	348.32	X**	X**	X**	X**
Family Eucalanidae (copepodids)	SF	34.25	X**	X**	X**	X**
Pareucalanus sewelli (Fleminger 1973)	SF	5.12	X		X	X
Subeucalanus longiceps (Matthews 1925)	SF	3.39			X*	
Subeucalanus pileatus (Giesbrecht, 1888)	SF	49.05	X*			
Rhincalanus cornutus (Dana, 1849)	SF	2.49			X	X
Family Centropagidae (copepodids)	SF	0.54	X	X		
Centropages violaceus (Claus, 1863)	SF	17.56	X*			
Temeropia mayumbaensis T. Scott, 1894	SF	11.73	X	X	X	
Temora stylifera (Dana, 1849)	SF	170.9	X	X	X	
Family Acartiidae (copepodids)	SF	51.24	X**	X**	X**	X**
Acartia danae Giesbrecht, 1889	SF	189.53	X	X		
Mecynocera clausi I. C. Thompson, 1888	SF	112.88	X**	X**	X**	X**
Family Candaciidae (copepodids)	CN	170.41	X	X	X	
Candacia bipinnata (Giesbrecht, 1889)	CN	7.86	X	X	X	
Candacia bispinosa (Claus, 1863)	CN	28.7	X	X		
Candacia pachydactyla (Dana, 1849)	CN	17.6	X	X	X	
Candacia simplex (Giesbrecht, 1889)	CN	9.83	X	X		
Family Aetideidae (copepodids)	SF	1.85	X	X	X	
Aetideus giesbrechti Cleve, 1904	SF	2.7	X	X		
Gaetanus brevicornis Esterly, 1906	SF	0.003			X*	
Gaetanus minor Farran, 1905	SF	3.11	X	X	X	
Undeuchaeta major Giesbrecht, 1888	SF	3.92			X*	
Family Clausocalanidae (copepodids)	SF	729.37	X**	X**	X**	X**
Clausocalanus arcuicornis (Dana, 1849)	SF	7.97	X	X	X	
Clausocalanus furcatus (Brady, 1883)	SF	2839.46	X**	X**	X**	X**
Clausocalanus mastigophorus (Claus, 1863)	SF	2.13	X		X	
Ctenocalanus citer Heron and Bowman, 1971	SF	2.36			X	X
Famila Scolecitrichidae (copepodids)	DT	57.89	X**	X**	X**	X**
Lophothrix latipes (T. Scott, 1894)	DT	0.003			X*	
Scaphocalanus echinatus (Farran 1905)	DT	0.06		X*		
Scolecithrix danae (Lubbock, 1856)	DT	77.71	X**	X**	X**	X**
Scottocalanus securifrons (T. Scott, 1894)	DT	0.01		X*		
Family Lucicutiidae (copepodids)	SF	6.03	X**	X**	X**	X**

Table 1. (Continued)

Species	FP	ind./m^3	TW	SACW	IAW	NADW
Lucicutia clausi (Giesbrecht, 1889)	SF	0.22		X*		
Lucicutia flavicornis (Claus, 1863)	SF	88.86	X**	X**	X**	X**
Lucicutia gaussae Grice, 1963	SF	0.11			X	X
Lucicutia longicornis (Giesbrecht, 1889)	SF	0.01			X*	
Lucicutia ovalis (Giesbrecht, 1889)	SF	0.08			X*	
Lucicutia sp. 1	SF	25.98		X		
Lucicutia sp. 2	SF	19.65		X		
Family Paracalanidae (copepodids)	SF	2.25	X	X	X	
Acrocalanus longicornis Giesbrecht, 1888	SF	67.64	X*			
Calocalanus contractus Farran, 1926	SF	2.28	X		X	
Calocalanus pavoninus Farran, 1936	SF	234.53	X	X	X	
Calocalanus sp.	SF	100.75	X			
Family Augaptilidae (copepodids)	CN	18.57		X	X	
*Euaugaptilus filiger*us (Claus, 1863)	CN	1.55		X*		
Haloptilus austini Grice, 1959	CN	1.78		X*		
Haloptilus longicornis (Claus, 1863)	CN	0.06		X*		
Pleuromamma abdominalis (Lubbock, 1856)	SF	63.74	X**	X**	X**	X**
Pleuromamma gracilis gracilis (Claus, 1863)	SF	31.41	X**	X**	X**	X**
Pleuromamma piseki Farran, 1929	SF	7.39		X	X	
Pleuromamma xiphias (Giesbrecht, 1889)	SF	7.96	X	X	X	
Pleuromamma sp.	SF	55.76	X**	X**	X**	X**
Family Heterorhabdidae (copepodids)	CN	19.09	X**	X**	X**	X**
Heterorhabdus papilliger (Claus, 1863)	CN	11.18	X**	X**	X**	X**
Family Euchaetidae (copepodids)	CN	223.69	X**	X**	X**	X**
Euchaeta acuta Giesbrecht, 1893	CN	0.004				X*
Euchaeta marina (Prestandrea, 1833)	CN	8.25	X	X	X	
Family Oithonidae (copepodids)	SF	298.32	X**	X**	X**	X**
Oithona plumifera Baird, 1843	SF	111.28	X	X		
Oithona robusta Giesbrecht, 1891	SF	5.18	X	X		
Oithona setigera Dana, 1849	SF	61.06	X	X	X	X
Oithona similis Claus, 1866	SF	909.18	X**	X**	X**	X**
Oithona tenuis Rosendorn, 1917	SF	6.44	X**	X**	X**	X**
Family Oncaeidae (copepodids)	DT	219.67	X**	X**	X**	X**
Oncaea venusta Philipp, 1843	DT	1370.85	X**	X**	X**	X**
Triconia conifera (Giesbrecht, 1891)	DT	27.6	X**	X**	X**	X**
Lubbockia squillimana Claus, 1863	DT	14.46	X**	X**	X**	X**
Family Corycaeidae (copepodids)	DT	222.91	X**	X**	X**	X**
Corycaeus giesbrechti F. Dahl, 1894	DT	119.84	X	X	X	
Corycaeus latus Dana, 1849	DT	1.89	X*			
Corycaeus lautus Dana, 1849	DT	2.64	X	X	X	
Corycaeus limbatus Brady, 1883	DT	143.36	X**	X**	X**	X**
Corycaeus speciosus Dana, 1849	DT	155.63	X**	X**	X**	X**
Farranula gracilis (Dana, 1849)	DT	1432.5	X**	X**	X**	X**
Copilia mirabilis Dana, 1849	DT	43.44	X*			
Sapphirina nigromaculata Claus, 1863	DT	1.89	X*			
Sapphirina sp.	DT	23.6	X		X	X
Clytemnestra scutellata Dana, 1849	SF	0.004			X	X
Macrosetella gracilis (Dana, 1847)	SF	907.38	X**	X**	X**	X**
Miracia efferata Dana, 1849	SF	8.51	X		X	X
Microsetella norvegica (Boeck, 1865)	SF	1.34	X		X	
Microsetella rosea (Dana, 1848)	SF	2.14	X		X	X
Parasitic Copepoda	PR	0.01		X*		

(18.9%), *Oithona similis* (17.8%), *Far. gracilis* (16.5%), *Oncaea venusta* (13.4%), *Macrosetella gracilis* (7.9%), *Calocalanus pavoninus* (7.2%), *Nannocalanus minor* (4.2%), *Undinula vulgaris* (4.1%), and *Oit. plumifera* (2.0%) (Table 1, Fig. 8). *Nannocalanus minor* and *Und. vulgaris vulgaris* are considered indicators of the Brazil Current. These species occurred in all of the water

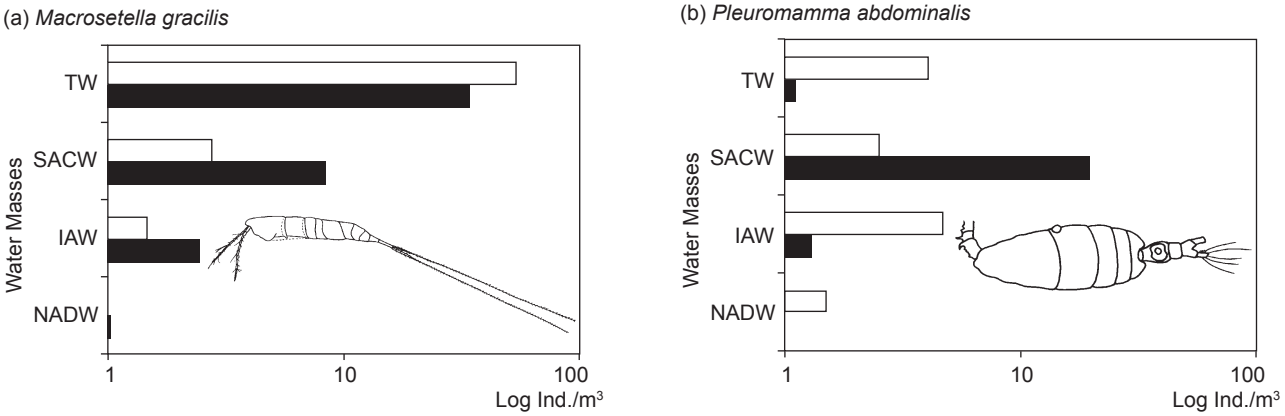

Fig. 5. Mean density (individuals (ind.)/m^3) of the dominant copepod species in the South Atlantic central water (SACW): (a) *Macrosetella gracilis* and (b) *Pleuromamma abdominalis* (open bars, 2002 wet season; black bars, 2003 dry season).

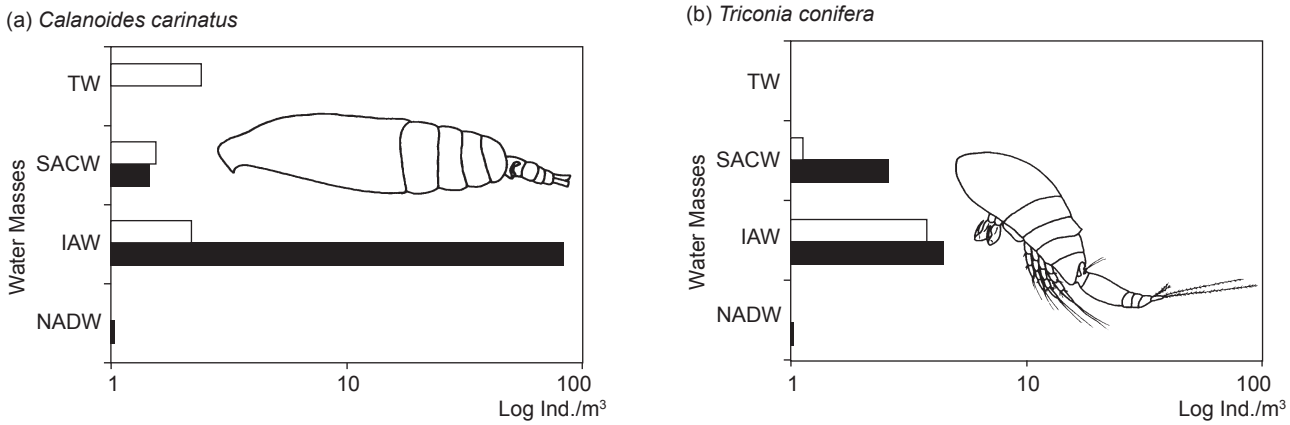

Fig. 6. Mean density (individuals (ind.)/m^3) of the dominant copepod species in the intermediate Antarctica water (IAW): (a) *Calanoides carinatus* and (b) *Triconia conifera* (open bars, 2002 wet season; black bars, 2003 dry season).

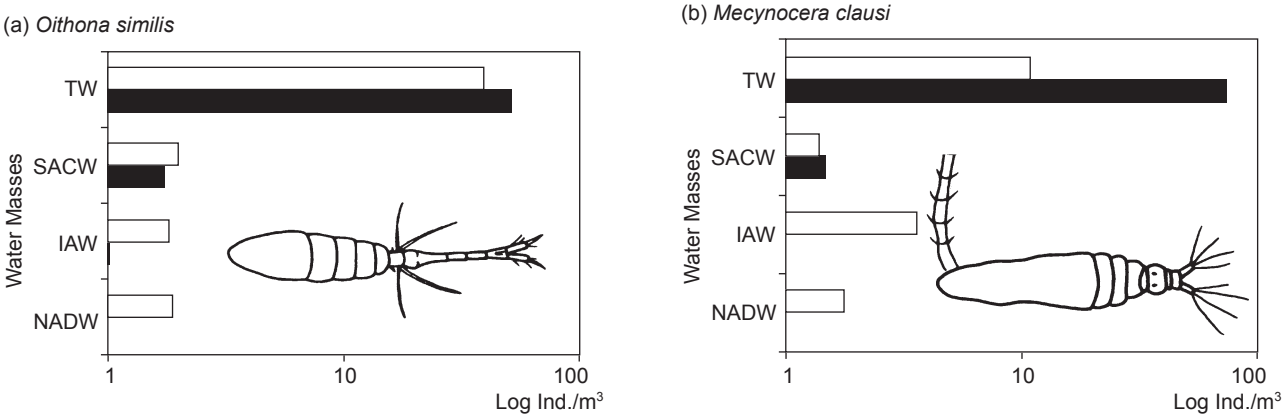

Fig. 7. Mean density (individuals (ind.)/m^3) of dominant copepod species in the North Atlantic deep water (NADW): (a) *Oithona similis* and (b) *Mecynocera clausi* (open bars, 2002 wet season; black bars, 2003 dry season).

masses, and were most abundant in the TW.

The SACW copepod assemblage (center) contained samples collected during both the 2002 wet season and 2003 dry season. *Oncaea venusta*, *Macrosetella gracilis*, *Oit. setigera*, *Ple. abdominalis, Oit. similis*, *Far. gracilis*, *Luc. flavicornis*, *Ple. gracilis gracilis*, *Cla. furcatus*, *Corycaeus limbatus,* and *Triconia conifera* were the main taxa responsible for the delimitation of this group of samples, accounting for 23.7%, 16.4%, 10.4%, 8.3%, 7.6%, 6.8%, 4.%, 4.5%, 3.4%, 2.7% and 1.9% of the internal similarities, respectively (Table 1, Fig. 8).

The copepod assemblage of the IAW (temperature variation of 3.65-10.43°C and salinities of 34.29-34.85 ppt) and the NADW (temperature variation of 3.02-3.97°C and salinities of 34.35-34.95 ppt) were separated from the remaining assemblages. These 2 assemblages included *Cal. carinatus*, with its highest density values in the IAW (reaching 47 ind./m^3). This species occasionally occurred in other water masses, and its copepodites were the most abundant. The NADW showed a significant correlation with abiotic parameters (r = 0.97 for surface temperature and r = 0.96 for surface salinity). The species *Onc. venusta* and *Macrosetella gracilis* occurred in all 3 copepod assemblages.

In contrast to the water masses, in the Campos Basin no significant differences in copepod assemblage structures were observed between the sampling periods (the 2002 wet season and 2003 dry season) (TW, ANOSIM significance level of sample statistic = 18.3% and global R = 0.049; SACW, ANOSIM significance level of sample statistic = 11.6% and global R = 0.075; IAW, ANOSIM significance level of sample statistic = 14.4% and global R = 0.096; and NADW, ANOSIM significance level of sample statistic = 20% and global R = 0.304).

Table 2. ANOSIM analyses of similarity between groups of water masses in the sampling periods in the Campos Basin. R, strength of the difference between groups (* - significant differences to p < 0.05)

Groups of water masses	R statistic
TW vs. SACW	0.4*
TW vs. IAW	0.673*
TW vs. NADW	0.902*
SACW vs. IAW	0.208*
SACW vs. NADW	0.459*
IAW vs. NADW	0.149

DISCUSSION

The oceanographic structure of the Campos Basin is basically formed by the same water masses as off southern Brazil, as described by Emilsson (1961). TWs of the Brazil Current are transported from the northeast towards the southwest along the coast of Brazil from about 9°S to about 38°S, as part of the South Atlantic western boundary current system. The southward current is generally confined to the upper 600 m of the water column (Stramma et al. 1990, Podesta et al. 1991). In surface layers of the outer shelf and offshore regions, salinity is > 36 ppt and the temperature is > 20°C. The water-column structure and distributions of the different water masses over the continental shelf and slope of the Campos Basin are the main factors that characterize the environment, being determined by temperature and salinity. The main water masses present in the region during the sampling periods were the TW in the surface layers, and the SACW, IAW, and NADW in deeper layers. The MW found between the TW and SACW was formed by seasonal cooling of the upper layers.

In Brazil, available knowledge on the oceanic

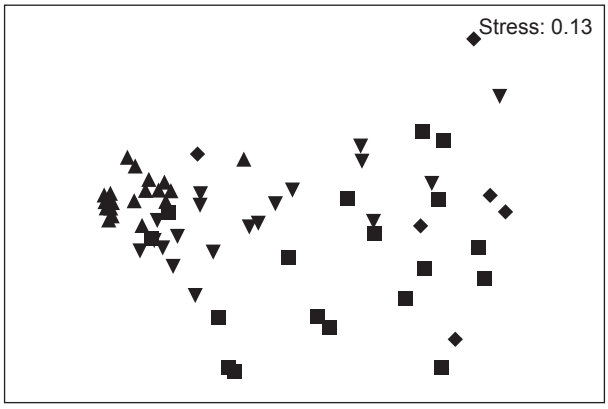

Fig. 8. Multidimensional scaling plot of the copepod assemblage structure (individuals (ind.)/m^3) found during the 2 sampling periods in the Campos Basin (2002 wet season and 2003 dry season): black triangles, tropical water; inverted triangles, South Atlantic central water; black squares, intermediate Antarctic water; black diamonds, North Atlantic deep water.

zooplankton community indicates that it shows low density and high species diversity (Cavalcanti and Larrazábal 2004). In the present study, the area showed low densities and high species richness of copepods compared to areas adjacent to the coast, in agreement with observations of Boltovskoy (1981) and Cavalcanti and Larrazábal (2004). The oligotrophic nature of the Brazil Current and the lack of significant continental-water drainage result in relative environmental homogeneity. The copepod density and the structure of the copepod community were primarily associated with distributions of the water masses present in the region and seasonal conditions (the 2002 wet season and 2003 dry season).

Despite the oligotrophic nature of the Brazil Current, the densities found in the present study (of < 2700 ind./m^3 during the 2002 wet season in the TW) were higher than those observed along the Brazilian coast. For instance, Cavalcanti and Larrazábal (2004) found densities of < 5 ind./m^3 off the northeastern coast of Brazil at 7°28'56"S; 34°32'45"W to 3°21'08"S; 38°40'29"W, at 21 stations sampled to a depth of 200 m with a 300 μm net. The use of a net with a larger mesh size in that study may have underestimated the abundance of juvenile copepods. Lopes et al. (1999), who studied the spatial distribution of copepod populations on the eastern continental shelf off the state of Rio de Janeiro between Cabo Frio and Cabo de São Tomé, found high copepod densities (up to 61,207 ind./m^3) in the Cabo Frio region under the influence of the cold, nutrient-rich SACW during the dry season. In the tropical San Blas Archipelago, an oligotrophic environment of the Caribbean off Panama, during the dry and rainy seasons, D'Croz et al. (1999) found density values lower than those in the area studied here (zooplankton densities of < 300 ind./m^3 and calanoid copepod densities of < 90 ind./m^3). Similarly to Cavalcanti and Larrazábal (2004), those authors collected with a 400 μm net, which may have underestimated the abundance of copepods. The same was observed by Weikert et al. (2001) for deep-sea plankton communities in the oligotrophic Levantine Sea in the Eastern Mediterranean (34°20'N; 25°50'E), collected using a net with a 300 μm mesh. Copepod densities were again lower than those found in the present study. Mesozooplankton decreased exponentially with increasing depth in the upper bathypelagic zone. Higher densities were associated with salinities of > 38.8 ppt.

Differences between the copepod densities in the water masses were observed during the present study, with the highest densities found in the TW, and densities decreased with depth. The copepod density showed seasonal variations. Except for the SACW, the water masses showed seasonal differences in the 2 sampling periods (the 2002 wet season and 2003 dry season). Temporal variations in oceanic zooplankton communities of tropical and subtropical areas are derived from single events or factors of poorly understood regularity, different from observations in temperate and polar seas, where annual variations of biomass are readily predictable (Nybakken and Bertness 2005). The small seasonal differences observed in the Campos Basin may have occurred as a function of the formation of vortices due to eddies of the Brazil Current (Silveira et al. 2000).

The copepod assemblage contained 70 species, a higher richness than that observed off Rio de Janeiro and other stretches of the Brazilian coast. The species found on the continental shelf of the Campos Basin have also been observed along the Brazilian coast, but some of them were not previously reported from the region. In the study area, the increase in the depth range contributed to an increased number of copepod species found in the region, in comparison to studies that considered the neritic and oceanic regions of more-extended areas. In 63 sampling stations down to the 200 m isobath, between Saquarema and Parati and in the region of the Vitória-Trindade chain (state of Espírito Santo), 60 and 59 species were respectively found by Dias (1994 1996). Bassani et al. (1999) synthesized knowledge of zooplankton off the northern coast of Rio de Janeiro between the mouth of the Itabapoana River and Maricá, and recorded 96 species of Copepoda. Lopes et al. (1999), who studied the shelf areas off Rio de Janeiro influenced by SACW intrusions, found 43 copepod taxa in 40 sampling stations, of which 65% of the taxa occurred down to the 100 m isobath. Off the northeastern coast of Brazil between the states of Pernambuco and Ceará, Gusmão et al. (1997) and Cavalcanti and Larrazábal (2004) found 52 species at 0-100 m in depth and 53 species of copepods at 0-200 m in depth. The former authors used a baby Bongo net with a 120 μm mesh size, and the latter authors used nets with different mesh sizes (120 and 300 μm). In spite of the differences in method, there were no differences in species richness in the same study area.

The copepod community was dominated by epipelagic species, which are suspension-feeders

or detritivores. Of the suspension-feeders, the numerically dominant (but with smaller biomass) species was *Clausocalanus furcatus*, in contrast to those numerically less dominant but of larger biomass such as the Calanidae. The smaller biomass of numerically dominant forms resulted from either smaller adult sizes or a predominance of earlier copepodid stages (Yamaguchi et al. 2002). A highly diversified and comparatively less-abundant copepod assemblage, dominated by *Cla. furcatus*, *Far. gracilis,* and *Onc. venusta*, was previously recorded in outer-shelf stations occupied by the oligotrophic TW of the Brazil Current and under the influence of the SACW (Björnberg 1981, Bradford-Grieve et al. 1999).

The taxonomic richness found in the Campos Basin was expected, as other authors have considered the region between 20°S and Cabo de São Tomé as a transition area where tropical and subtropical species coexist (Valentin and Monteiro-Ribas 1993). These species are also prominent above 200 m deep in oceanic waters off Rio de Janeiro and Espírito Santo (Dias 1994 1996). The copepod community was similar to that found on the Brazilian east coast by Lopes et al. (1999) and other oceanic localities where the TW predominates (Cavalcanti and Larrazabal 2004). *Farranula gracilis* and *Cla. furcatus* are frequent in the west-central Gulf of Mexico, and are also typical of surface oceanic waters of the Caribbean Sea. This may be associated with the fact that the anticyclone in the Gulf carries mixed oligotrophic waters in from the Caribbean (López-Salgado et al. 2000).

Undinula vulgaris vulgaris and *Nannocalanus minor* are considered indicators of the Brazil Current, and they were prominent in the TW, and contributed to the formation of this copepod assemblage. The epipelagic copepods *Nan. minor* and *Und. vulgaris vulgaris* are indicators of oligotrophic conditions in oceanic waters and neritic regions, with wide distributions in tropical and subtropical waters of the Atlantic, Pacific, and Indian Oceans (Björnberg 1981, Bradford-Grieve et al. 1999). *Nannocalanus minor* is concentrated in the lower strata, generally to a level of 200 m (Björnberg 1981). *Corycaeus speciosus* is also typical of the Brazil Current and is an indicator of oligotrophic areas (Björnberg 1981). Although *Cor. speciosus* was recorded in all of the water masses, it reached its highest densities in the TW. This species is very frequent and abundant in oceanic waters, with temperatures of around 26°C and salinities of 35 ppt and also has a wide tropical and subtropical distribution (Bradford-Grieve et al. 1999). These 3 species were more frequent and abundant in samples at 0-200 m depths, reflecting the oligotrophic conditions of these waters. High concentrations of these species in 0-200 m depths were also observed by Gusmão et al. (1997) when analyzing the mesozooplankton of northeastern Brazil. In the eastern tropical Pacific (northwestern Mexican coast), Suárez-Morales et al. (2000) identified 44 copepod species of which *Und. vulgaris vulgaris* was one of the most abundant, evidencing the tropical conditions, as also reported by Boltovskoy (1981), Cavalcanti and Larrazabal (2004), and this study.

In the other water masses, mesopelagic and bathypelagic taxa were prominent, as expected. In the mesopelagic environment, changes in species dominance were observed. Only *Cla. furcatus* showed high densities in this environment. *Pleuromamma gracilis gracilis* (SACW), *Ple. abdominalis* (IAW), *Macrosetella gracilis* (SACW and IAW), *Cal. carinatus,* and *Triconia conifera* (IAW) were most abundant in the SACW and IAW. *Pleuromamma gracilis gracilis* and *Ple. abdominalis* occur in the Mediterranean Sea and North Atlantic, occupying depths of 150-200 and 200-400 m, respectively (Andersen et al. 2001 2004).

With the exception of *Far. gracilis* and *Cal. carinatus*, all of the other species mentioned are also prominent in the upper 120 m in the eastern tropical Atlantic Ocean from 6°S to 4°N and at 6, 12, 18, and 24°W (Piontovski et al. 2003). *Calanoides carinatus* reached its highest densities in the IAW. This species is characteristic of the mesopelagic environment, and is dominant in productive coastal upwelling regions on the west coast of Africa, the east coast of South America, and off Somalia in the Indian Ocean (Sabatini et al. 2007). During the wet season, we expected to find higher densities of *Cal. carinatus* in the upper layers, as a result of the penetration of deep cold waters belonging to the SACW towards the coast (Castro and Miranda 1998, Lopes et al. 1999). This did not occur because of stochastic perturbations, including a strong storm during the sampling period.

Several species were exclusive to the different water masses. The TW, SACW, and IAW each contained 6 exclusive species. Only 1 exclusive species was found in the NADW. The vertical distributions of the exclusive species were well correlated with the literature data. The epipelagic species *Acrocalanus longicornis*,

Copilia mirabilis, and *Sapphirina nigromaculata* were exclusive to the TW, and the mesopelagic forms, *Scaphocalanus echinatus*, *Lucicutia clausi,* and *Hal. longicornis,* were exclusive to the SACW. The bathypelagic species *Undeuchaeta major* was restricted to the IAW. *Euchaeta acuta*, the only exclusive species of the NADW, is classified as epipelagic in the South Atlantic (Boltovskoy 1999), but it was found in the entire water column (to 850 m in depth) at the "exit" of the Mediterranean Sea to the Atlantic Ocean (Andersen et al. 2001).

Differences in the copepod community along the water column were closely related to the distinct water masses occurring in the present study. The sample association showed 3 groups: the 1st characterized by 0-200 m samples from the TW, the 2nd by 200-600 m samples from the SACW, and the 3rd below 600 m from the IAW and NADW. Vertical distribution patterns were found for several copepod species, as a probable effect of the pronounced layering of the contrasting water masses. Copepod density was highest in the 1st group, mainly formed by tropical species. The copepod assemblages of the IAW and NADW were distinct from the remaining assemblages, because of the presence of *Cal. carinatus* which had the highest density in the IAW. Tropical copepods such as *Cla. furcatus* showed opposite behavior, reaching high abundances only in those areas not affected by the cold waters. This pattern was also observed by Lopes at al. (1999), who studied the shelf areas off Rio de Janeiro. Differences in copepod compositions and abundances were possibly a consequence of the influence between oceanic and shelf waters, with contributions of deep-water species in the upper water masses. This can be correlated with the daily vertical migration of zooplankton (Nybakken and Bertness 2005).

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