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Research Article

The zooplankton of Santa Catarina continental shelf in southern Brazil with emphasis on Copepoda and Cladocera and their relationship with physical coastal processes

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ABSTRACT. Very few studies have been carried out to exclusively investigate the zooplankton community of Santa Catarina State continental shelf, despite the economic and ecological importance of the area. This coastal region of southern Brazil presents highly relevant oceanographic processes, such as the strong influence of continental inputs, resurgence in the Cabo de Santa Marta Grande and River Plata plume water to the south. Two sampling cruises were carried out, in December 2005 and May 2006, in order to study temporal hydrological variations, and their influence on the biota of the region. Zooplankton samples for analysis were obtained by oblique hauls with Bongo nets at 33 sampling stations arranged in profiles perpendicular to the coast on each cruise. The predominant groups found in the samples were Copepoda, Cladocera, Salpidae and Chaetognatha, which presented higher densities at the stations closer to the coast. In the case of the December 2005 cruise, the salinity and temperature gradients perpendicular to the coast, promoted by the continental inputs to the north of the area and by the upwelling to the south, determined the limits of distribution of *Acartia lilljeborgi* and *Penilia avirostris*. However, the temperature and salinity gradients longitudinal to the coast determined on the May 2006 cruise did not explain the species distribution, indicating that biotic forcing mechanisms may have been active in the ecology of the system during this period.

Keywords: Copepoda, Cladocera, indicators, oceanographic processes, water masses, southern Brazil.

El zooplancton de la plataforma continental de Santa Catarina, sur de Brasil con énfasis en Copepoda y Cladocera y sus relaciones con procesos físicos costeros

RESUMEN. A pesar de la importancia económica y ecológica del área todavía no habían sido realizados estudios exclusivamente destinados a la investigación de la comunidad zooplanctónica de la plataforma continental del Estado de Santa Catarina. Esta región costera del sur de Brasil presenta procesos oceanográficos de alta relevancia, tales como fuerte influencia de aportes continentales, resurgencia en el Cabo de Santa Marta Grande y la pluma de agua del río Plata en el sur. Se efectuaron dos cruceros de muestreo en diciembre 2005 y mayo 2006, para determinar las variaciones temporales de las condiciones hidrológicas y su influencia sobre la biota de la región. En cada crucero se analizaron muestras de zooplancton obtenidas por arrastres oblicuos con redes Bongo en 33 estaciones distribuidas en perfiles perpendiculares a la costa. Los grupos dominantes en las muestras fueron Copepoda, Cladocera, Salpidae y Chaetognatha, presentando mayores densidades en las estaciones más costeras. En el crucero de diciembre de 2005 los gradientes de salinidad y temperatura perpendiculares a la costa, producidos por los aportes continentales al norte y por la resurgencia al sur del área, determinaron los límites de distribución de *Acartia lilljeborgi* y *Penilia avirostris*. En el crucero de mayo de 2006 los gradientes de temperatura y salinidad longitudinales a la costa no explicaron la variación en la distribución de las especies, indicando que forzantes bióticos podrían ser predominantes en la ecología del sistema en este período.

Palabras clave: Copepoda, Cladocera, indicadores, procesos oceanográficos, masas de agua, sur de Brasil.

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INTRODUCTION

The zooplankton community occupies an important position in the marine pelagic food chain, as it transfers the energy produced by photosynthesizing unicellular algae to the upper trophic levels (Lenz, 2000). For this reason, information on its abundance and spatial/temporal distribution is essential in order to understand the biogeochemical cycles and the dynamics of the marine communities (Wishner *et al*., 1998). The zooplankton community includes many larvae (crustaceans, mollusks and fish), and important fishing resources and species of commercial interest. In general, the structure and distribution of zooplankton are influenced by biotic and abiotic processes that act in different temporal and spatial scales (Ashjian & Wishner, 1993; Wiafe & Frid, 1996).

The study of zooplankton found along the continental shelf in the south and southeast regions of Brazilian has led to several publications which address, among other subjects, the systematic organization of taxonomic groups (Björnberg, 1967; Alvarez, 1986; Campaner & Honda, 1987; Vega-Pérez & Bowman, 1992; Bersano & Boxshall, 1994), as well as the ecological aspects (Moreira, 1973; Björnberg, 1980; Campaner, 1985; Liang & Vega-Pérez, 1994, 1995; Vega-Pérez & Hernandez, 1997), physiological aspects (Yamashita, 1977; Yamashita & Moreira, 1981) and biogeographical aspects (Palácio, 1982) of different taxonomic groups.

However, there is a lack of information concerning the zooplankton community along the Santa Catarina coast, which has been highlighted in reviews published by Valentin *et al*. (1994), Brandini *et al.* (1997) and Lopes (2007). The biogeographical characteristics of zooplankton and species which represent bioindicators along the coast of Santa Catarina state (SC) have been presented by Resgalla Jr. (2011) and compared with data on the coastal regions of other states to the north and south of SC that have been more exhaustively investigated, that is, São Paulo (SP), Paraná (PR) and Rio Grande do Sul (RGS).

Of the marine zooplankton groups, Copepoda and Cladocera are the most important representatives of the coastal holoplankton (Omori & Ikeda, 1984; Resgalla Jr., 2011). In this study, these groups were associated with high frequencies of occurrence and abundance, and thus they were studied at the species level. In this context, the objective of this research was to relate the occurrence of species and groups of species with the typical water masses of the continental shelf of Santa Catarina State and with distinct oceanographic processes occurring during the two sampling periods.

Study area

The region considered in this study covers the continental shelf of Santa Catarina State, between its border with the adjacent states of Rio Grande do Sul and Paraná, and between the isobaths of 10 to 150 m (Fig. 1).

The largest portion of the Santa Catarina continental shelf lies within the Southeastern Brazilian Continental Shelf (SEBCS), to the north of the Cape of Santa Marta. Its most austral portion lies within the Southern Brazilian Continental Shelf (SBCS), which extends from the Cape of Santa Marta to the border with Uruguay (Hille *et al.*, 2008). In the SEBCS portion, the coast is aligned approximately north-south, while in the SBCS portion the alignment is northeast-southeast (Resgalla Jr. *et al.*, 2001).

The continental shelf break occurs at a depth of between 120 and 180 m, and its width ranges from 100 to 220 km, at the Cape of Santa Marta and the Babitonga Bay, respectively. The main water masses present in this portion of the Brazilian coast are: Tropical Water-TW (temperature >19°C and salinity >36), South Atlantic Central Water-SACW (temperature <19°C and salinity >35.3), Subtropical Shelf Water-STSW (variable temperature and salinity between 33.5 and 36), Coastal Water-CW and Plata Plume Water-PPW (variable temperature and salinity <33.5), and Subantarctic Shelf Water-SASW (variable temperature but <21°C and salinity between 33.5 and 34.2). These water masses have been described previously in relation to this region by Carvalho *et al.* (1998); Mémery *et al.* (2000); Piola *et al.* (2000, 2005); Silva *et al.* (2004); Schettini *et al.* (2005), Möller Jr. *et al.* (2008) and Hille *et al.* (2008).

Oceanographic conditions during the study period

The oceanographic conditions were studied by Hille *et al.* (2008), who identified the water masses occurring in the region. Due to the sampling technique used for the collections of zooplankton organisms, which involved the use of a Bongo nets, extending from the bottom to the surface of the water column (maximum depth of 130 m), the average temperature and salinity values were estimated and the dominant water masses characterized, in groups of sampling points for each cruise (Fig. 2). Thus, typical waters described by Hille *et al.* (2008) were redefined for the December 2005 cruises as: CW under Influence of Fluvial Region (IFR) in the north, STSW on the shelf, and SACW in the upwelling of Cape of Santa Marta. For the March

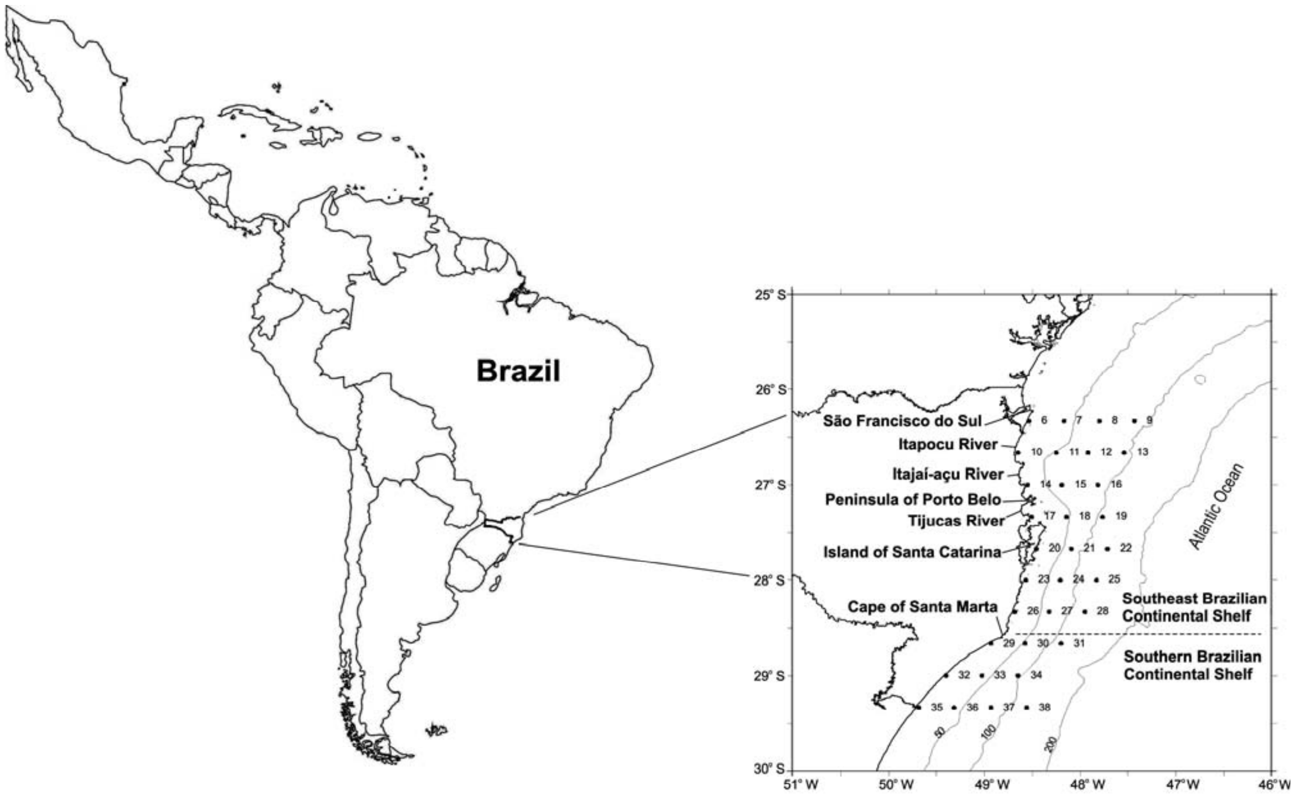

Figure 1. Map showing the coastline of Santa Catarina State and the location of the sampling points for December 2005 and May 2005, as part of the PROSAR Project.

Figura 1. Mapa de la línea costera del estado de Santa Catarina con las estaciones de muestras realizadas en diciembre 2005 y mayo 2006 en el Proyecto PROSAR.

2006 cruise, STSW to the north, PPW in the south and TW in the central region of the shelf were also defined. Based on this distribution, the temperature and salinity gradients perpendicular to the coast for December 2005 and those longitudinal to the coast for May 2006 were evident.

MATERIALS AND METHODS

The samples used in this study originated from the project “Prospecting for eggs and larvae of Sardinha-Verdadeira (*Sardinella brasiliensis*) on the Santa Catarina coast” (PROSAR) carried out by the University of Vale do Itajaí in partnership with the Itajaí Fishing Industry Workers’ Union (SITRA PESCA) and the Centre for Research and Management of Fishing Resources of the Southeast and South Coast (CEPSUL/IBAMA).

For this project, oceanographic cruises were carried out between 2005 and 2006 on the SC coast, limited by the borders with the states of PR (to the north) and RGS (to the south) (26°00-29°30’S, 49°41’-47°05’W) and between isobaths of 10 to 150 m.

The cruises were carried out by the IBAMA Research Ship the Soloncy Moura, in two campaigns, one in December 2005 and the other in May 2006. The sampling plan consisted of sampling stations distributed among ten profiles perpendicular to the coast, with a total of 33 samples collected per cruise (Fig. 1).

The temperature and salinity data were obtained on each cruise, using a SAIV A/S CTD probe model SD204, along vertical profiles at each oceanographic station (Hille *et al.*, 2008). On the cruise in December 2005 the mean temperature (°C) and salinity (minimum and maximum) were 20.7 (14.0-24.61) and 35.02 (10.99-36.79), respectively, while in May 2006 values for the average temperature (°C) of 21.58 (18.16-25.29) and salinity of 34.66 (9.92-36.86) were recorded.

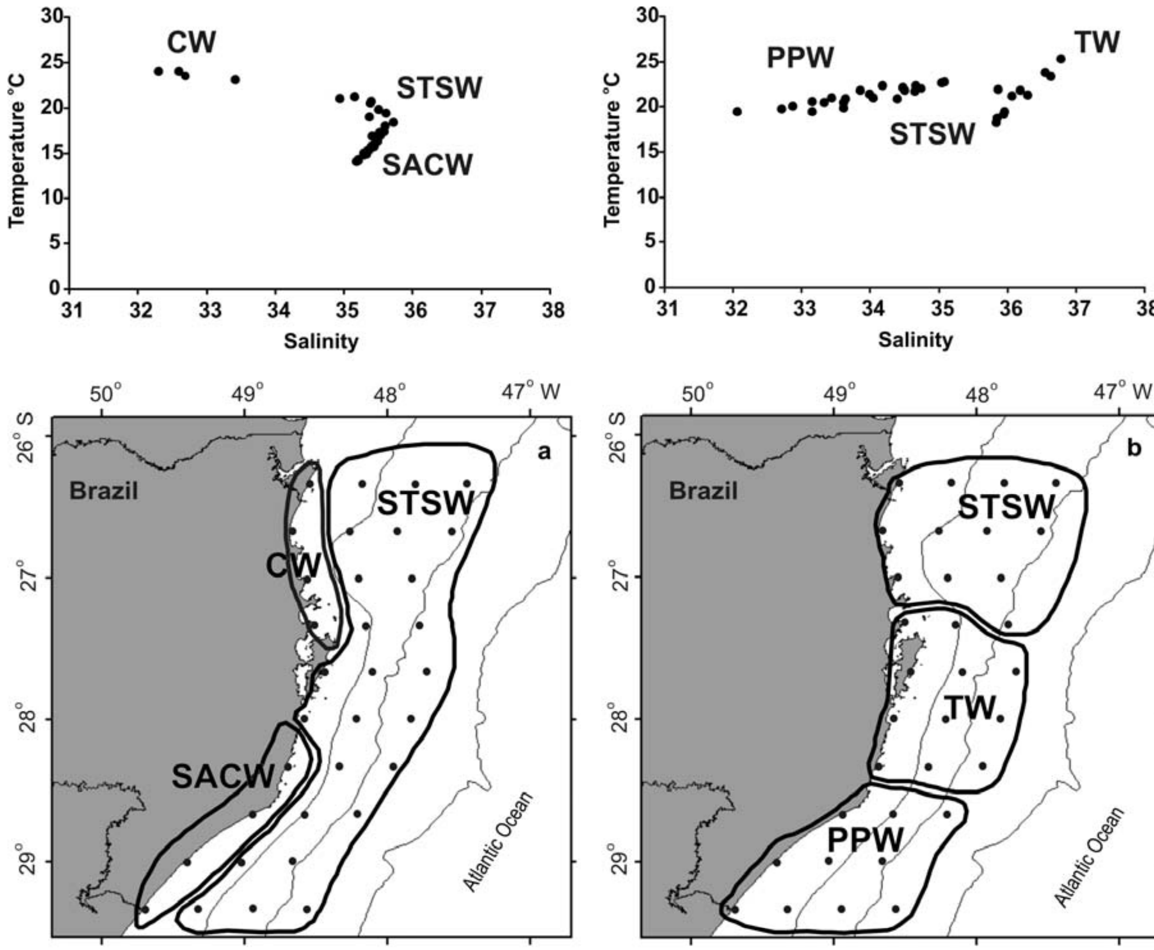

Figure 2. TS diagrams and classification of the water masses for a) December 2005, and b) May 2006, cruises of the PROSAR project (modified from Hille *et al.*, 2007) based on the mean values within the depth interval of the hauls of the Bongos net where CW: Coastal Water, STSW: Subtropical Shelf Water, TW: Tropical Water, SACW: South Atlantic Central Water and PPW: Plata Plume Water.

Figura 2. Diagramas TS y clasificación de las masas de agua en los cruceros de a) diciembre 2005, y b) mayo 2006 en el proyecto PROSAR (modificado de Hille *et al.*, 2007) en base de valores medios dentro del intervalo de profundidad de los arrastres de redes Bongo. Siendo CW: Agua Costera, STSW: Agua Subtropical de Plataforma, TW: Agua Tropical, SACW: Agua Central del Atlántico Sur, y PPW: Agua de la Pluma del Plata.

The zooplankton samples were obtained through oblique hauls extending from the bottom to the surface, using a Bongo nets with a 330 µm mesh size and mouth opening of 60 cm in diameter, equipped with a GO flowmeter. After the collections, samples were fixed in 4% formaldehyde solution and stored in the Biological Oceanography Laboratory of CTTMar/ UNIVALI.

In the laboratory, qualitative and quantitative analyses were performed in Bogorov chambers, under a stereoscopic microscope, following the recommend-dations of Boltovskoy (1981a), which consisted of the removal of aliquots ranging from 3 to 10% of the total sample, using a piston-type sub-sampler. All the zooplankton organisms present in the samples were quantified and classified to the lowest taxonomic level possible, based on publications by Ramírez (1981) and Onbé (1999) for Cladocera, and Björnberg (1981) and Hernández & Morales (1994), Bradford-Grieve *et al.* (1999), for Copepoda.

Density data were obtained based on estimates of the total density of the sample, expressed by the number of individuals per cubic meter (ind m^{-3}) of water filtered by the net.

In order to characterize the relation between Copepoda and Cladocera species and their association with the water masses, ordination analysis (Principal Components Analysis-PCA) was applied (Pielou,

1984) using the program MVSP (version 3.13n). This analysis identifies the groups of species with similar ecological requirements and the environmental forcing mechanisms that could influence the group formation. Based on this ordination, the gradients observed can respond to abiotic and biotic forcing, determined by their variation ranges. In this case, species which presented a frequency of occurrence higher than 20% were used (Tables 3 and 4), as well as mean temperature and salinity data for the depth interval of the oblique hauls. For the normal distribution, the values of the biotic and abiotic variables were transformed into log (x+1) prior to the analysis.

RESULTS

Zooplankton community

In terms of the density of the total zooplankton community along the Santa Catarina continental shelf, no clear seasonal patterns or spatial variations were observed. However, there was a tendency for the sampling stations closer to the coast to present higher concentrations of organisms. With regard to the cruises, the average density values were 482 ind m^{-3} for December 2005 and 503 ind m^{-3} for May 2006 (Fig. 3).

The samples of the zooplankton community consisted of 14 major zooplankton groups. In December 2005, the most abundant group was Copepoda (57.1%), followed by Cladocera (15.7%) and Salpidae (13.6%), while in May 2006, Copepoda was also predominant (74.6%), but there was a decrease in the representation of the other groups such as Salpidae (7.3%), Chaetognatha (5.7%) and Cladocera (3.7%) (Table 1). Less representative groups included Pteropoda, Mollusk larvae, Siphonophorae, Amphipoda, Hydromedusae, Cirripedia larvae, Euphausiacea, Ostracoda and Polychaeta. However, in terms of relative density and frequency of occurrence, Copepoda and Cladocera were the most important groups in both cruises.

Salpidae

In December 2005, Salpidae was present in 69.7% of the samples, with a preference for the more coastal stations to the south of the study area, associated with SACW under the influence of the Cape of Santa Marta upwelling. In May 2006, of the 57.6% stations in which this group occurred, nearly all lay to the north of Laguna, with no particular spatial pattern being observed (Fig. 4). The average density values were 36 ind m^{-3} for December 2005 and 19 ind m^{-3} for May 2006 (Fig. 4).

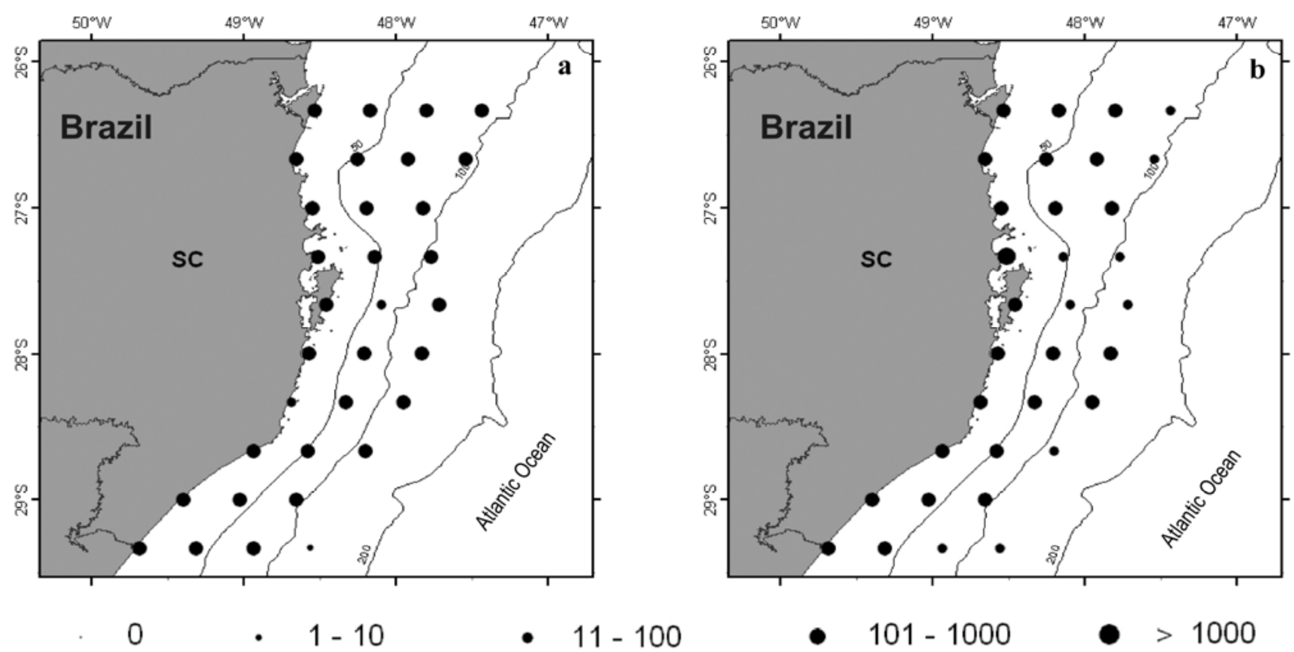

Figure 3. Spatial distribution of density for the total zooplankton (ind m^{-3}) in a) December 2005, and b) May 2006.

Figura 3. Distribución espacial de los valores de densidad para el zooplancton total (ind m^{-3}) en a) diciembre 2005, y b) mayo 2006.

Table 1. Mean relative abundance (RA) and frequency of occurrence (FO) of the main groups found on cruises carried out in December 2005 and May 2006.

Tabla 1. Abundancia relativa media (RA) y frecuencia de ocurrencia (FO) de los principales grupos encontrados en los cruceros de diciembre de 2005 y mayo de 2006.

Grupo taxonómico	December 2005		May 2006	
	RA (%)	FO (%)	RA (%)	FO (%)
Copepoda	60.38	100.00	71.94	100.00
Cladocera	12.47	100.00	3.99	90.91
Salpidae	14.09	69.70	5.22	57.58
Chaetognatha	3.41	100.00	8.18	93.94
Decapoda	4.15	100.00	5.12	100.00
Appendicularia	2.45	57.58	0.68	57.58
Others	1.80	-	3.92	-

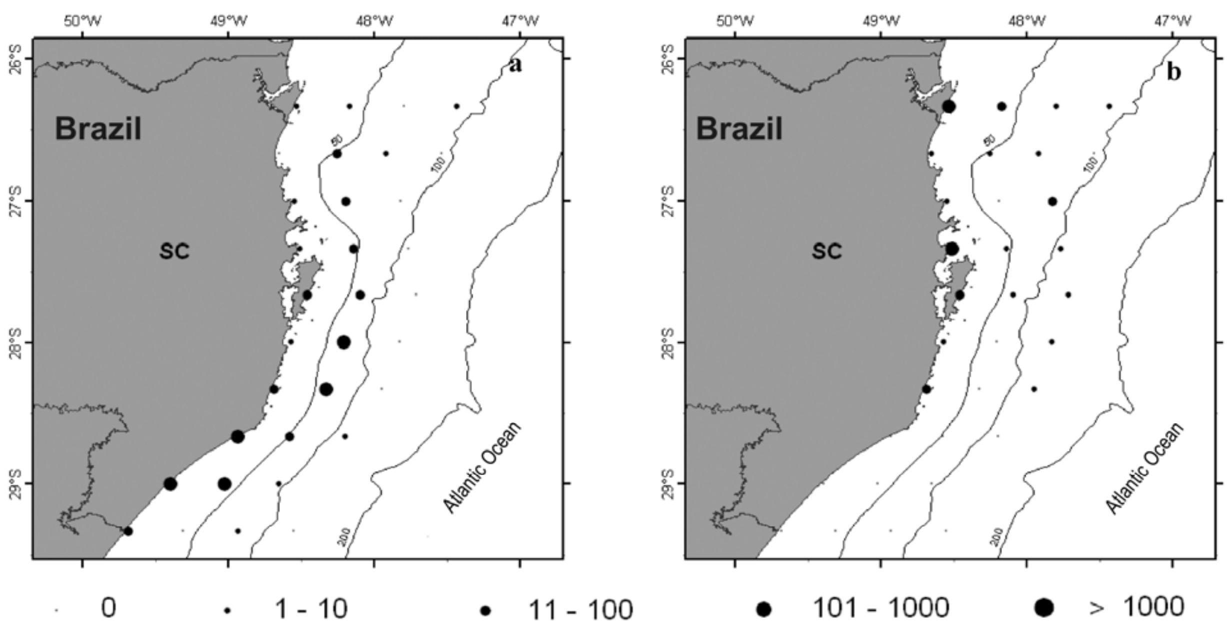

Figure 4. Distribution of spatial density (ind m^{-3}) of Salpidae for sampling cruises carried out in a) December 2005, and b) May 2006.

Figura 4. Distribución espacial de la densidad (ind m^{-3}) de Salpidae en los cruceros de a) diciembre 2005, y b) mayo 2006.

Chaetognatha

The group presented a high frequency of occurrence and a tendency toward higher density values at the stations closer to the coast. This evidence was clearer on the May 2006 cruise (Fig. 5). The average density values were 7 ind m^{-3} for December 2005 and 15 ind m^{-3} for May 2006 (Fig. 5).

Copepoda

In terms of spatial distribution, copepods presented the highest density values at the sampling stations on the coast and internal shelf for both cruises (Fig. 6).

In the samples collected on the two cruises, 43 taxa of Copepod were recorded, including the order, family, genus and species (Table 2). The average density values were 153 ind m^{-3} for December 2005 and 196 ind m^{-3} for May 2006.

For the December 2005 cruise, the species with the highest average densities (ind m^{-3}) were *Temora stylifera* (40), *Oithona plumifera* (18), *Oncaea venusta* (17), *T. turbinata* (16), *Centropages velificatus* (10) and *Acartia lilljeborgi* (4).

A. lilljeborgi was present at the stations closest to the coast, along with *Centropages velificatus* and *T.*

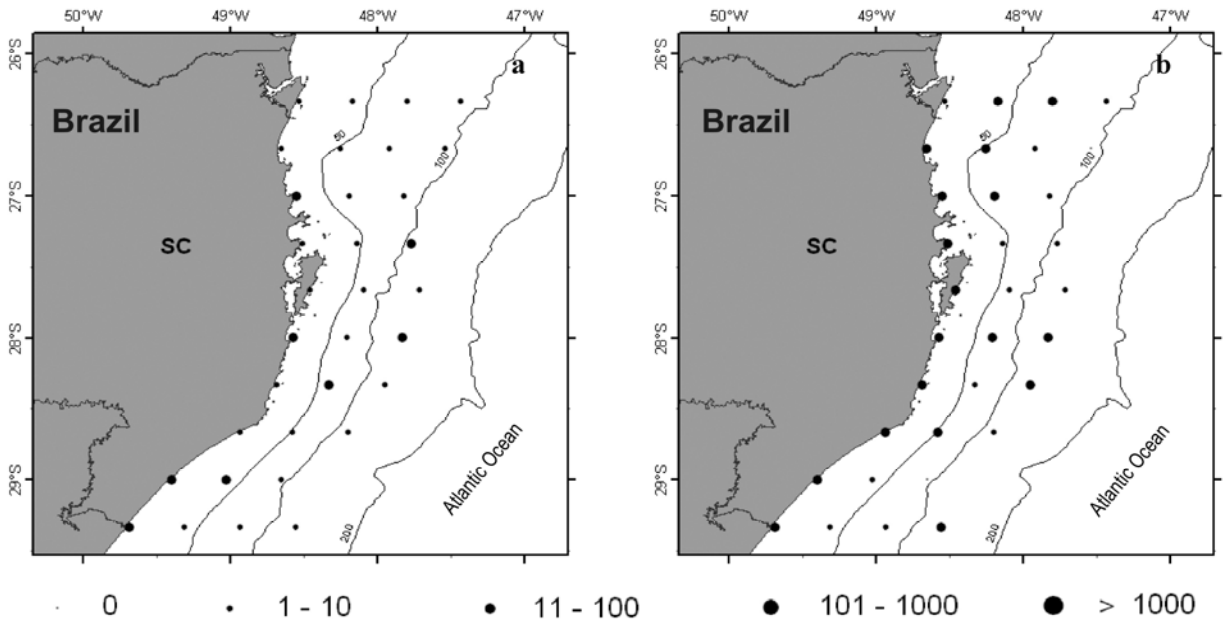

Figure 5. Distribution of spatial density (ind m^{-3}) of Chaetognatha for sampling cruises carried out in a) December 2005, and b) May 2006.

Figura 5. Distribución espacial de la densidad (ind m^{-3}) de Chaetognatha en los cruceros de a) diciembre 2005, y b) mayo 2006.

turbinata. The density of *Oithona plumifera* and *Oncaea venusta*, on the other hand, increased towards the sampling stations on the external shelf. *T. stylifera* was well-distributed throughout the Santa Catarina shelf (Fig. 7).

For the May 2006 cruise, the species with the highest average abundances (ind m^{-3}) were *A. lilljeborgi* (71), *Clausocalanus furcatus* (23), *T. stylifera* (18), *T. turbinata* (18), *Oncaea venusta* (16), *Oithona plumifera* (8), *Corycaeus giesbrechti* (6) and *Subeucalanus pileatus* (5).

In terms of spatial distribution, *A. lilljeborgi* occurred throughout the shelf, but with the highest density values observed to the north of the Island of Santa Catarina. The species *Clausocalanus furcatus*, *Corycaeus giesbrecthi*, *Oithona plumifera*, *Oncaea venusta and T. stylifera* did not present any clearly-defined distribution pattern, occurring throughout the shelf**.** *Temora turbinata* occurred mainly at the sampling stations closer to the coast, while *Subeucalanus pileatus* showed higher densities to the south of the study area (Figs. 8 and 9).

Cladocera

The spatial distribution of this group indicated that it was present mainly closer to the coast, with occurrences all along the coast for the December 2005 cruise, and limited to the north region of the study area on the May 2006 cruise (Fig. 10). The average density values for Cladocera were 42 ind m^{-3} for December 2005 and 10 ind m^{-3} for May 2006.

Four taxa of Cladocera were observed in samples collected on both cruises. The species *Penilia avirostris* was the most abundant and frequent of the species, followed by *Pseudoevadne tergestina* (Table 3).

For the December 2005 cruise, *Penilia avirostris* was the most abundant species of Cladocera (average 36 ind m^{-3}) and its distribution did not present a clear pattern, occurring throughout the Santa Catarina shelf. *Pleopis schmackeri* occurred at disperse points throughout the coast in low density (average <1 ind m^{-3}), but was most strongly associated with SACW. *Evadne spinifera* was mainly distributed along the external stations of the shelf associated with the STSW. *Pseudoevadne tergestina*, which was the second most frequent species, presented higher densities to the south of the study area (Fig. 11).

In May 2006, *Penilia avirostris* presented a more specific distribution, occurring mainly to the north of the study area, with the highest values obtained in the STSW (Fig. 12). *Pleopis schmackeri* was distributed close to the coast associated with the SACW and TW, while *Evadne spinifera* showed a preference for points on the external shelf. *Pseudoevadne tergestina* was the most frequent species of Cladocera, and was widely distributed, with the exception of the STSW to the north of the study area.

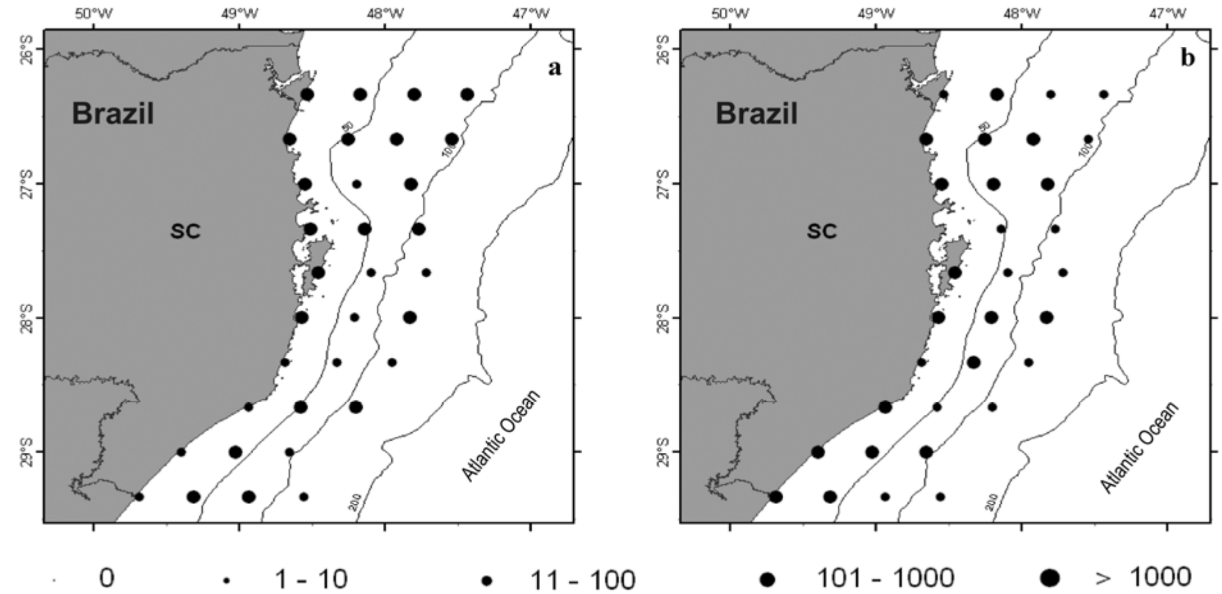

Figure 6. Distribution of spatial density (ind m^{-3}) of Copepoda for sampling cruises carried out in a) December 2005, and b) May 2006.

Figura 6. Distribución espacial de la densidad (ind m^{-3}) de Copepoda en los cruceros de a) diciembre 2005, y b) mayo 2006.

Table 2. Frequency of occurrence (FO) and mean relative abundance (RA) for the species of Copepod in samples collected on the December 2005 and May 2006 cruises.

Tabla 2. Frecuencia de ocurrencia (FO) y abundancia relativa media (AR) para las especies de Copepoda en los cruceros de diciembre de 2005 y mayo de 2006.

Taxa	FO (%)		RA%)	
	December 2005	May 2006	December 2005	May 2006
COPEPODA	100.00	100.00	60.38	71.95
Nauplius	24.24	21.05	0.64	0.34
Copepodids	100.00	84.21	14.69	10.54
Order Calanoida				
Calanidae				
Calanoides carinatus (Kroyer, 1849)	3.03	2.63	0.08	0.00
Nannocalanus minor (Claus,1863)	0.00	50.00	0.00	2.36
Neocalanus gracilis (Dana, 1849)	6.06	18.42	0.21	0.33
Undinula vulgaris (Dana, 1849)	24.24	39.47	0.78	0.05
Paracalanidae				
Calocalanus pavo (Dana, 1852)	3.03	23.68	0.08	0.38
Paracalanus sp.	63.64	0.00	1.28	0.00
Paracalanus quasimodo Bowman, 1971	9.09	2.63	0.46	0.01
Eucalanidae				
Eucalanus sp.	54.55	28.95	6.26	1.79
Pareucalanus sewelli (Fleminger, 1973)	3.03	10.52	0.03	12.55
Subeucalanus crassus (Giesbrecht, 1888)	0.00	10.52	0.00	2.76
Subeucalanus pileatus (Giesbrecht, 1888)	9.09	47.26	0.95	1.20
Clausocalanidae				
Clausocalanus furcatus (Brady, 1883)	0.00	57.89	0.00	15.87

Taxa	FO (%)		RA%)	
	December 2005	May 2006	December 2005	May 2006
COPEPODA	100.00	100.00	60.38	71.95
Aetideidae				
Euchaeta marina (Prestandrea, 1833)	3.03	36.84	0.04	0.54
Euchaeta media Giesbrecht, 1888	3.03	2.63	0.03	0.01
Scolecitrichidae				
Scolecithrix bradyi Giesbrecht, 1888	0.00	5.26	0.00	0.23
Scolecithrix danae (Lubbock, 1856)	3.03	21.05	0.02	0.34
Lucicutiidae				
Lucicutia flavicornis (Claus, 1863)	0.00	5.26	0.00	0.02
Centropagidae				
Centropages velificatus (Oliveira, 1947)	57.58	60.53	6.39	1.74
Temoridae				
Temora stylifera (Dana, 1849)	96.97	81.58	25.75	6.66
Temora turbinata (Dana, 1849)	78.79	55.26	7.30	0.04
Candaciidae				
Candacia curta (Dana, 1849)	6.06	26.32	0.08	0.28
Candacia pachydactila (Dana, 1849)	3.03	21.05	0.02	0.25
Paracandacia simplex (Giesbrecht, 1889)	0.00	10.53	0.00	0.07
Pontellidae				
Labidocera fluviatilis Dahl, 1894	12.12	13.16	0.13	0.14
Acartiidae				
Acartia sp.	6,06	0,00	0,04	0,00
Acartia lilljeborgi Giesbrecht, 1889	36.36	39.47	1.78	10.96
Order Cyclopoida				
Oithonidae				
Oithona plumifera Baird, 1843	87.88	76.32	12.81	7.64
Oithona setigera (Dana, 1849)	0.00	5.26	0.00	0.03
Order Harpacticoida				
Ectinosomatidae				
Microsetella rosea (Dana, 1849)	15.15	2.63	0.32	0.04
Miraciidae				
Macrosetella gracilis (Dana, 1847)	0.00	26.32	0.00	0.17
Miracia efferata Dana, 1849	0.00	13.16	0.00	0.13
Order Poecilostomatoida				
Oncaeidae				
Oncaea sp.	21.21	5.26	1.85	0.71
Oncaea antarctica Heron, 1977	0.00	10.53	0.00	0.07
Oncaea venusta Philippi, 1843	63.64	84.21	11.98	12.54
Sapphirinidae				
Copilia mirabilis Dana, 1852	0.00	10.53	0.00	0.12
Sapphirina sp.	3.03	7.89	0.26	0.01
Corycaeidae				
Corycaeus sp.	3.03	7.89	5.38	0.83
Corycaues giesbrechti (F. Dahl, 1894)	6.06	63.16	0.27	4.37
Corycaeus speciosus Dana, 1849	72.73	57.89	0.03	3.45
Farranula gracilis (Dana, 1849)	3.03	7.89	0.04	0.22

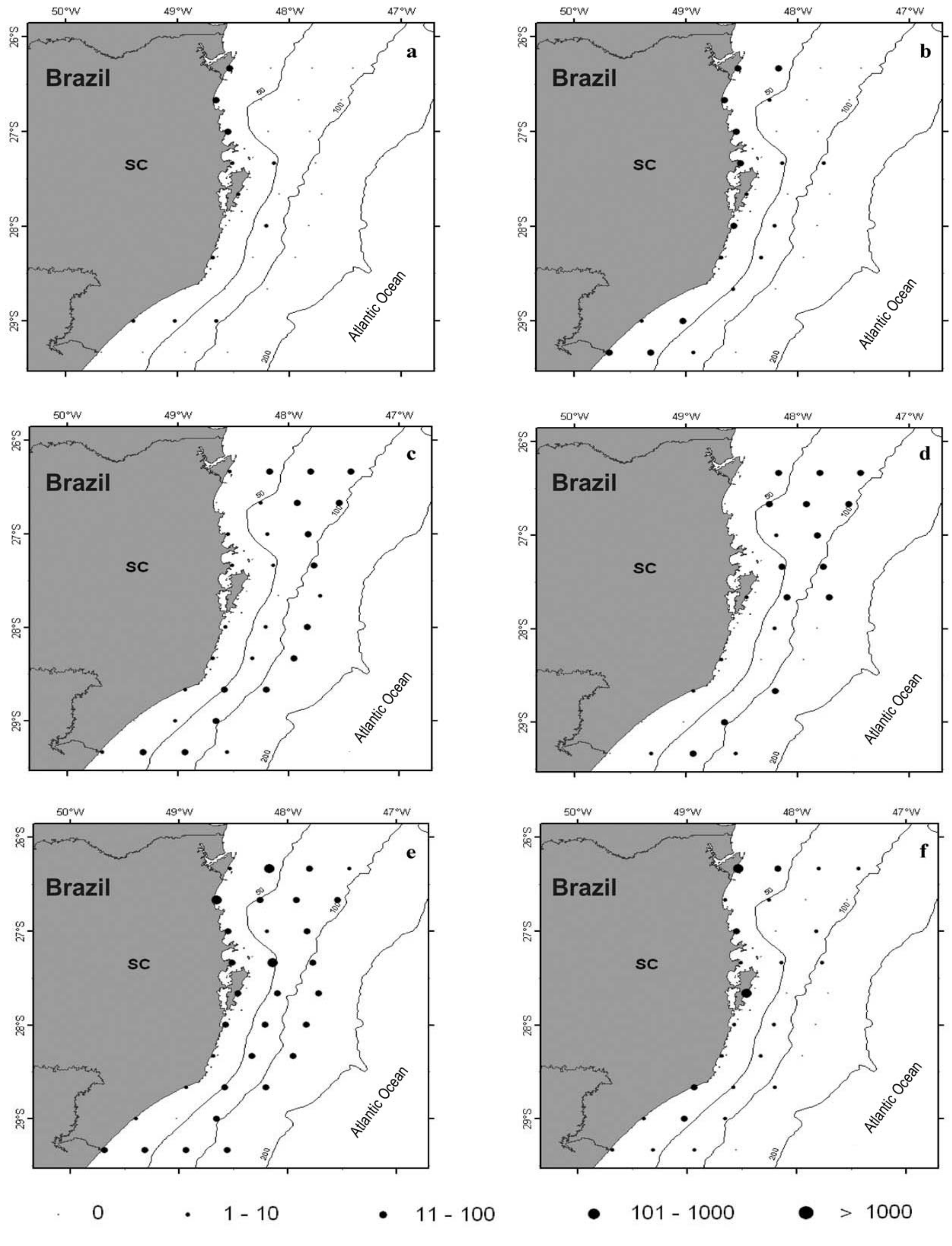

Figure 7. Spatial distribution of density (ind m^{-3}) of Copepoda species: a) in December 2005 cruise *Acartia lilljeborgi*, b) *Centropages velificatus*, c) *Oithona plumifera*, d) *Oncaea venusta*, e) *Temora stylifera*, and f) *Temora turbinata*, for the December 2005 cruise.

Figura 7. Distribución espacial de la densidad (ind m^{-3}) de las especies de Copepoda: en el crucero de diciembre 2005 a) *Acartia lilljeborgi*, b) *Centropages velificatus*, c) *Oithona plumifera*, d) *Oncaea venusta*, e) *Temora stylifera*, y f) *Temora turbinata*, durante el crucero de diciembre 2005.

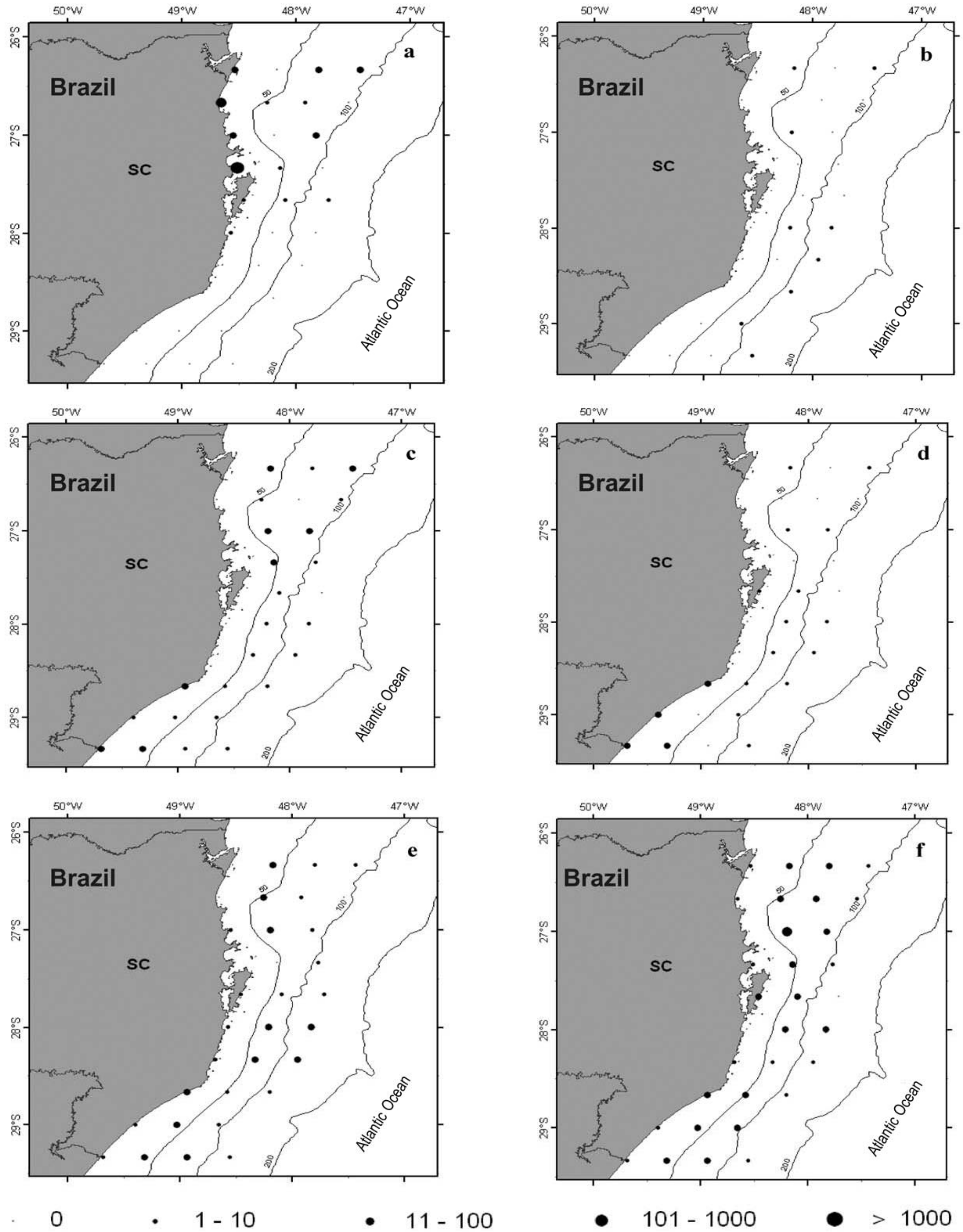

Figure 8. Spatial distribution of density (ind m^{-3}) of Copepoda species: a) *Acartia lilljeborgi*¸ b) *Clausocalanus furcatus*, c) *Corycaeus gisbrecthi*, d) *Subeucalanus pileatus*, e) *Oithona plumifera*, and f) *Oncaea venusta* for the May 2006 cruise.

Figura 8. Distribución espacial de la densidad (ind m^{-3}) de las especies de Copepoda: a) *Acartia lilljeb*orgi, b) *Clausocalanus furcatus*, c) *Corycaeus gisbrecthi*, d) *Subeucalanus pileatus*, e) *Oithona plumifera*, y f) *Oncaea venusta*, durante el crucero de mayo 2006.

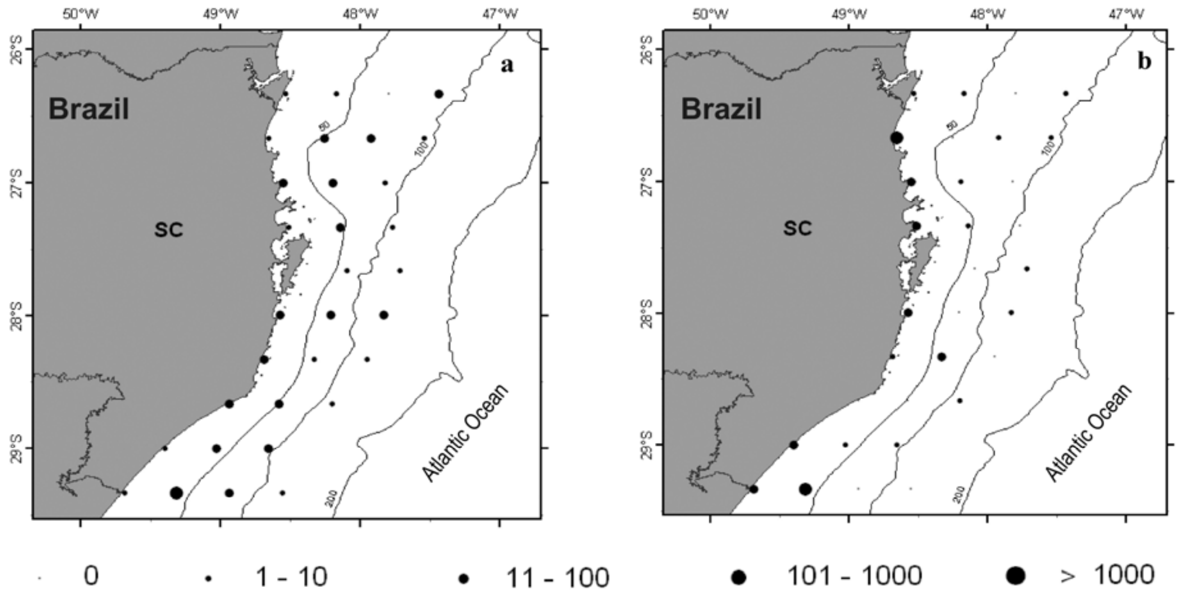

Figure 9. Spatial distribution of density (ind m^{-3}) of Copepoda species: a) *Temora stylifera,* and b) *Temora turbinata*, for the May 2006 cruise.

Figura 9. Distribución espacial de la densidad (ind m^{-3}) de las especies de Copepoda: a) *Temora stylifera,* y b) *Temora turbinata*, referente al crucero de mayo 2006.

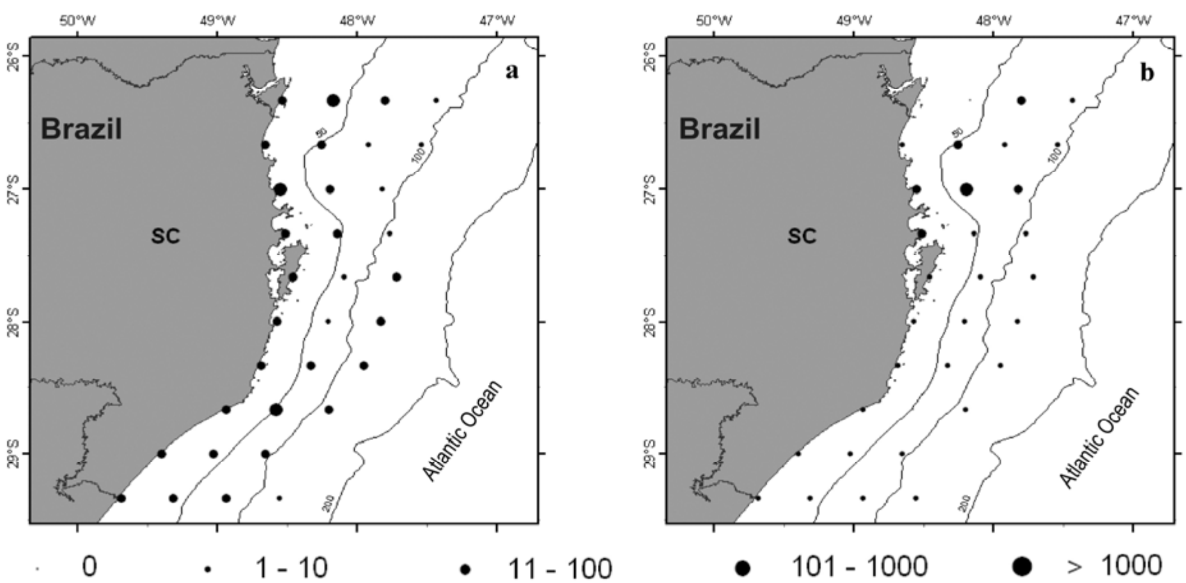

Figure 10. Spatial distribution of density (ind m^{-3}) of Cladocera for sampling cruises carried out in: a) December 2005, and b) May 2006.

Figura 10. Distribución espacial de la densidad (ind m^{-3}) de Cladocera en los cruceros de: a) diciembre 2005, y b) mayo 2006.

Environmental variables and zooplankton community

The results for the Principal Components Analysis (PCA), of the data associated with the December 2005 cruise, presented an accumulated percentage of explicability of 56.0% for the first two axes, showing temperature and salinity with a high weighting over axis 1. Temperature was positively correlated and salinity negatively correlated. These variables correlate with a group of species consisting of *Centropages velificatus*, *Acartia lilljeborgi*, *Temora turbinata* and *Penilia avirostris*, that is, species

Table 3. Frequency of occurrence (FO) and mean relative abundance (RA) for the species of Cladocera determinated in samples collected on the December 2005 and May 2006 cruises.

Tabla 3. Frecuencia de ocurrencia (FO) y abundancia relativa media (AR) para las especies de Cladocera determinados en los cruceros de diciembre de 2005 y mayo de 2006.

Taxa	FO (%)		RA (%)	
	December 2005	May 2006	December 2005	May 2006
CLADOCERA	100.00	91.00	12.47	3.99
Order Ctenopoda				
Sididae				
Penilia avirostris Dana, 1849	93.94	51.52	63.37	33.77
Order Onychopoda				
Podonidae				
Pleopsis schmackeri (Poppe, 1889)	18.18	27.27	3.51	4.61
Evadne spinifera P.E. Müller, 1867	33.33	36.36	11.14	12.23
Pseudevadne tergestina (Claus, 1877)	72.73	75.76	21.98	40.30

occurring in waters with higher temperatures and lower salinities (Fig. 13).

The PCA for the May 2006 cruise did not show a high weighting for the abiotic variables (temperature and salinity) over axis 1, and lower explicability for the first two axes (43.7%). Based on the classification of axis 1, two groups of species were observed, one positively correlated consisting of *Calocalanus pavo, Clausocalanus furcatus*, *Corycaeus giesbrechti*, *Corycaeus speciosus*, *Euchaeta marina*, *Macrosetella gracilis*, *Nannocalanus minor*, *Neocalanus gracilis*, *Oithona plumifera*, *Oncaea venusta*, *Scolecithrix danae* and *Undinula vulgaris* and the other negatively correlated, consisting only of *Acartia lilljeborgi* (Fig. 14).

DISCUSSION

The hydrological complexity of the study area determines a faunistic complexity that often restricts the use of zooplankton organisms as hydrological indicators when sampler limitations exist. In the present study, the use of a sampler that extends throughout the water column hinders a refinement in the interpretation of the occurrence and distribution of the organisms.

The zooplankton community was comprised of 14 major groups, and the spatial distribution found for the two cruises was similar to that reported by Vega-Pérez (1993), Muxagata (1999) and Sant'anna & Björnberg (2006), in their studies of the south and southeast Brazilian coast, *i.e.* the highest abundances were observed on the inner shelf.

For both oceanographic cruises, Copepoda, Cladocera, Salpidae and Chaetognatha were the most representative of the holoplankton groups observed in the samples collected from the Santa Catarina coast, however Copepoda and Cladocera are the most representative groups in Coastal Waters (Resgalla Jr., 2011).

In relation to the distribution pattern of the Salpidae group, on the December 2005 cruise a higher density was observed in the Cape of Santa Marta region, indicating an association with the intrusion of SACW, as highlighted by Hille *et al.* (2008). Muxagata (1999) found, at a point located to the southeast of Guanabara Bay /Rio de Janeiro (RJ), that the highest concentration of Salpidae was associated with the presence of TW and SACW. It was noted by Resgalla Jr. (2011) that this organism cannot be related to upwelling processes of short-duration due to the prevalence of northeast winds in this region. With these intrusions of deeper water into the euphotic zone, there is an increase in phytoplankton biomass, leaving an excess of primary production for the microbial loop that favors the development of organisms that feed on mucus (Resgalla Jr. *et al.*, 2001).

Chaetognatha occurred mainly at the points of the study area closest to the coast. The distribution of this group has been related to the occurrence of Copepoda, its preferential food (Boltovskoy, 1981b). Liang & Vega-Pérez (1994) also discussed this relationship between the groups for the Ubatuba region, reporting higher densities of Chaetognatha in coastal waters. Muxagata (1999) found the highest concentrations of these organisms in the area to the north of Cabo

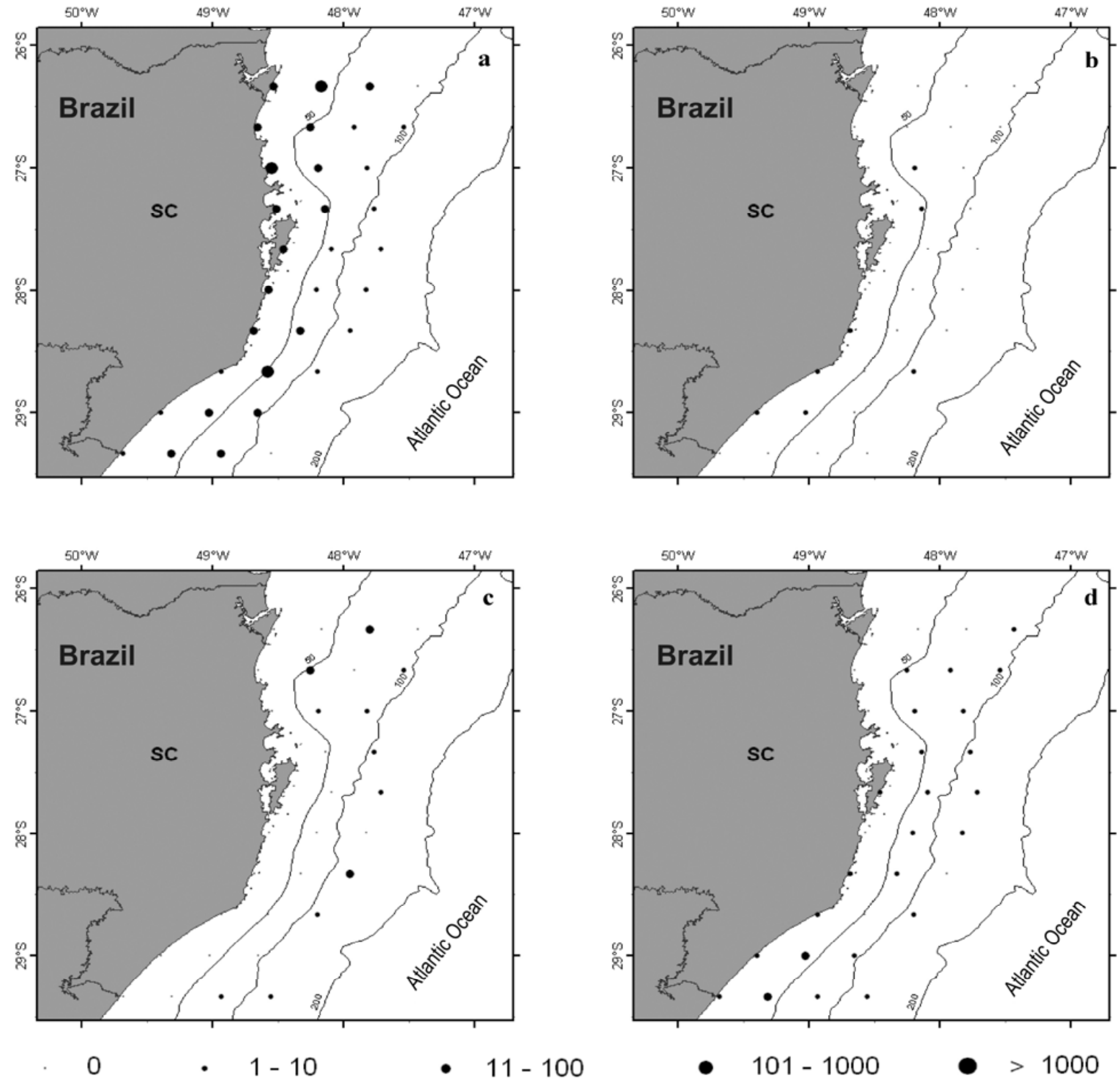

Figure 11. Spatial distribution of density (ind m^{-3}) of Cladocera species: a) *Penilia avirostris*, b) *Pleopis schmackeri*, c) *Evadne spinifera*, and d) *Pseudoevadne tergestina*, for the December 2005 cruise.

Figura 11. Distribución espacial de la densidad (ind m^{-3}) de las especies de Cladocera: a) *Penilia avirostris*, b) *Pleopis schmackeri*, c) *Evadne spinifera,* y d) *Pseudoevadne tergestina,* referente al crucero de diciembre 2005.

Frio/RJ, to the south of São Sebastião/SP and to the north of Paranaguá/PR, and suggested a prior occurrence of upwelling in the region of Cabo Frio. According to Parsons *et al.* (1984), high numbers of predators are common after the first days of resurgence, when there is a high density of herbivorous organisms. Despite the widespread distribution of Copepoda and Chaetognatha observed in the present study, no notable relation could be seen between these groups.

Copepoda

Copepoda was the dominant group in terms of density and abundance, and is a group with recognized importance in the marine zooplankton (Omori & Ikeda, 1984). There were 43 taxa of Copepod, including order, family, genus and species. The species with greater abundance in December 2005 were *Acartia lilljeborgi, Centropages velificatus, Oithona plumifera, Oncaea venusta, Temora turbinata* and *Temora stylifera.* The species with greater

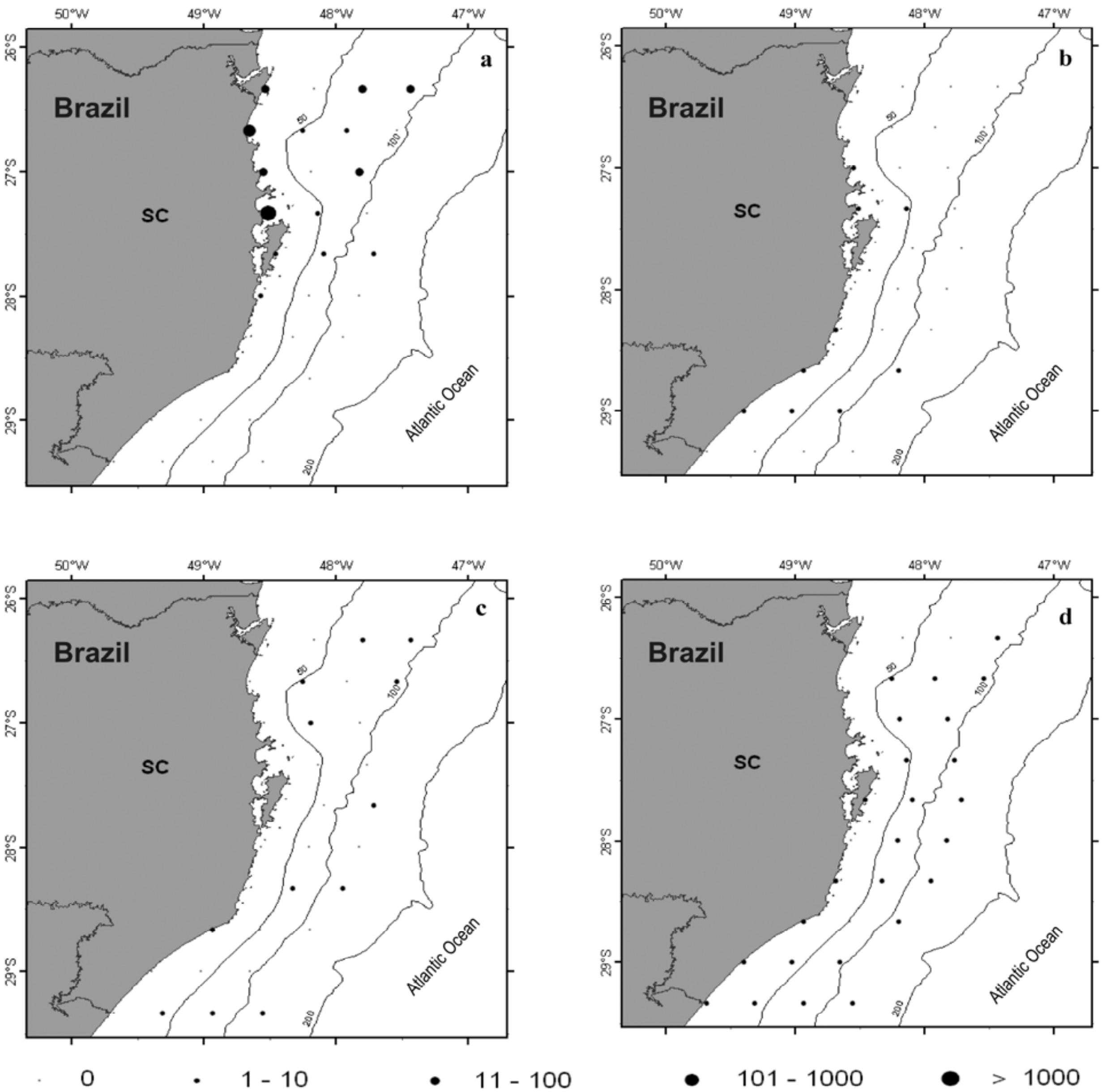

Figure 12. Spatial distribution of density (ind m^{-3}) of Cladocera species: for the May 2006 cruise. a) *Penilia avirostris,* b) *Pleopis schmackeri*, c) *Evadne spinifera,* and d) *Pseudoevadne tergestina*

Figura 12. Distribución espacial de la densidad (ind m^{-3}) de las especies de Cladocera: en el crucero de mayo 2005. a) *Penilia avirostris,* b) *Pleopis schmackeri*, c) *Evadne spinifera,* y d) *Pseudoevadne tergestina*.

abundance in May 2006 were *Acartia lilljeborgi*¸ *Clausocalanus furcatus, Corycaeus giesbrechti, Oithona plumifera, Oncaea venusta, Temora stylifera, Temora turbinata* and *Subeucalanus pileatus*. All of these species are considered to be typical of Brazilian coastal waters (Björnberg, 1981).

The number of *taxa* was higher for the May 2006 cruise, with 11 exclusive species. This finding suggests that the oceanographic conditions observed for this period are associated with lesser abiotic gradients, which is confirmed by the TS diagrams shown in Figure 2.

The gradients perpendicular to the coast recorded for December 2005, and those longitudinal to the coast for the May 2006 cruise, also reflect the spatial distribution of the Copepoda species. For example, *A. lilljeborgi* was a coastal species in December and restricted to the north region in March. Likewise, *Oithona plumifera* and *O. clevei* occurred on the external shelf in December, but were widely

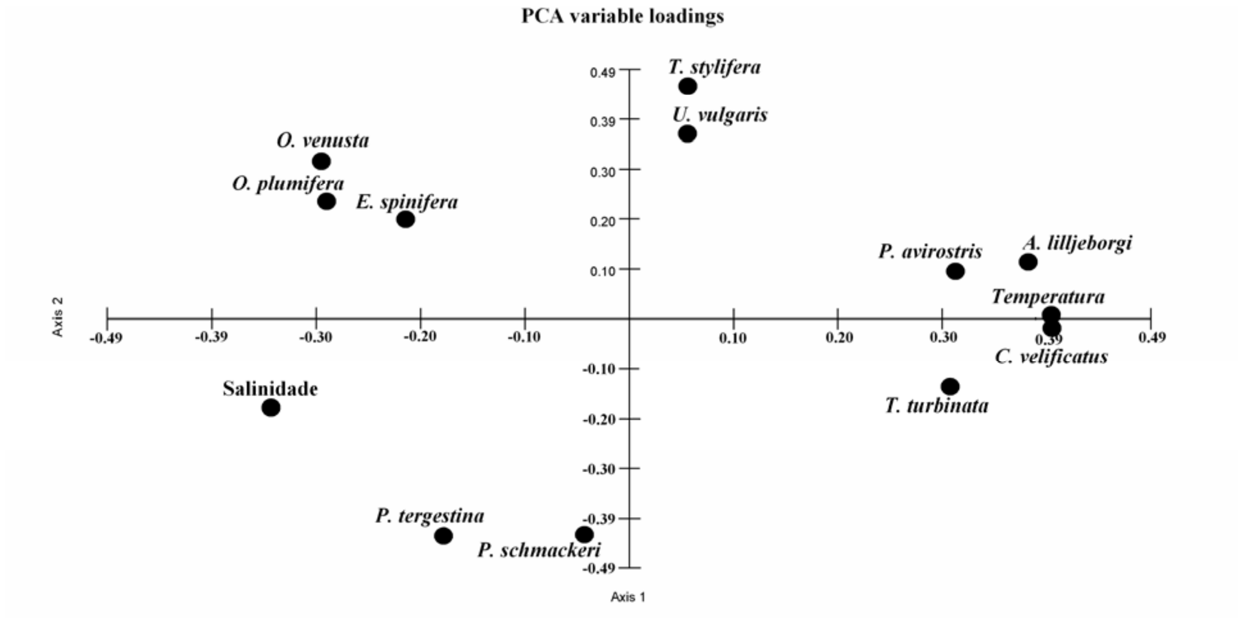

Figure 13. PCA results for the zooplankton community and the environmental parameters for the December 2005 cruise.

Figura 13. Resultado de la PCA para la comunidad zooplanctónica y los parámetros ambientales en el crucero de diciembre 2005.

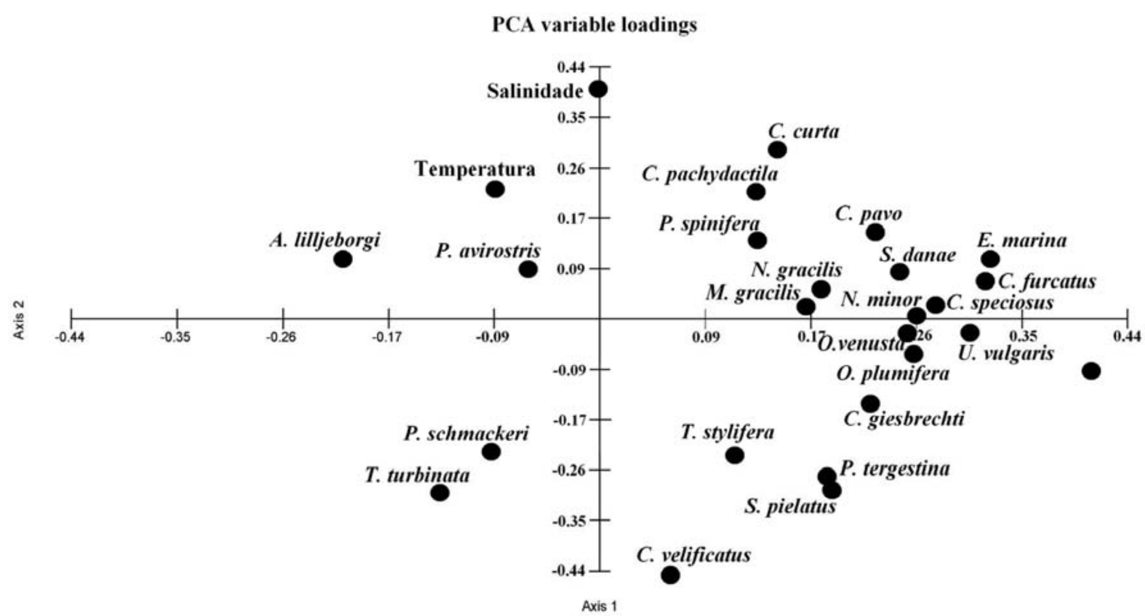

Figure 14. PCA results for the zooplankton community and the environmental parameters for the May 2006 cruise.

Figura 14. Resultado de la PCA para la comunidad zooplanctónica y los parámetros ambientales en el crucero de mayo 2006.

distributed in May. In addition, the majority of species exclusive to the May 2006 cruise, such as *Clausocalanus furcatus* and *Corycaeus giesbrechti*, were widely distributed on the continental shelf. This pattern of distribution, formed by the abiotic gradients, is frequently observed in studies on biological indicators applied to zooplankton (Boltovskoy, 1979; Resgalla Jr., 2008).

In terms of frequency of occurrence, the species of Copepoda which can be described for use in the environmental characterization of the continental shelf of Santa Catarina State are described below.

Acartia lilljeborgi is a common species along the SC coast, for instance, in the Saco dos Limões bay (Florianopolis) and the Armação do Itapocoroi bay (Penha) (Veado & Resgalla Jr, 2005), with a wide distribution being found in both of these coastal areas (Resgalla Jr., 2011). This species is primarily thermophilic, being associated with CW and indicating abiotic gradients on the two cruises studied.

Clausocalanus furcatus and *Corycaeus giesbrechti* are also common species on the Santa Catarina shelf, recorded at all sampling points in a study by Muxagata (1999) on the southeast continental shelf of Brazil. *C. furcatus* was present only on the March 2006 cruise, and both species are indicators of the Brazil Current of the Southern Brazilian Shelf (Björnberg, 1981).

Oithona plumifera is widely distributed in both tropical and subtropical waters in the Atlantic, Pacific and Indian oceans (Björnberg, 1981; Montú & Gloeden, 1986; Bradford-Grieve *et al.*, 1999; Dias & Araujo, 2006). It is also abundant in the northeast of Brazil (Cavalcanti & Larrazabál, 2004; Neumann-Leitão *et al.*, 1999, 2008). It is a typical species of the coast of SC and an indicator of warm waters (Resgalla Jr., 2011). In this study it was found to respond to the abiotic gradients perpendicular to the coast.

Oncaea venusta presented a wide distribution. For SBCS, according to Muxagata (1999), the species was found in TW, SACW and cold CW. On the other hand, Björnberg (1981) associated this species with sub Antarctic and subtropical water. In this study, it was recorded on both cruises and responded to abiotic gradients, similarly to *Oithona plumifera*.

Temora stylifera is abundant and common in cold CW, surface and bottom shelf waters, and TW. In this study, it was found in greater density on the December 2005 cruise, where the average temperature was higher. Lopes *et al.* (1999) linked *T. stylifera* to water masses with higher temperatures in Cabo Frio/RJ. Lindley & Daykin (2005) observed that the abundance of the species to the north of the Atlantic Ocean responds positively to temperature.

Temora turbinata presented a greater tendency toward a coastal distribution than *T. stylifera*, and was more tolerant to water with lower salinities (Resgalla Jr. *et al.*, 2008). This is considered an invasive species on the Brazilian coast (Lopes, 2004).

Centropages velificatus is a typically coastal species, occurring along the north, northeast, central and south coasts of Brazil (Björnberg, 1981; Bradford-Grieve *et al.*, 1999; Dias & Araujo, 2006). It is reportedly a common species in the coastal waters of SC (Resgalla Jr., 2011), as also observed in this study.

Subeucalanus pileatus has been described by Ávila *et al*. (2009) as a typical species of the coast of RGS, which tolerates shifting to waters of greater depth. In this study, its highest density was related to the shelf water under the influence of the SACW upwelling in December 2005.

Cladocera

The Cladocera group was common and abundant in the samples collected on both cruises. It is typically a coastal group, and an indicator of the seasonal variations of low salinity CW (Ramírez, 1981). The species found, *Evadne spinifera*, *Penilia avirostris*, *Pleopis schmackeri*, and *Pseudoevadne tergestina*, are in agreement with those reported by Muxagata (1999) and Rocha (1985) along the coast of São Paulo, and are typical of warm coastal and shelf waters.

Evadne spinifera showed a preference for sampling stations on the external shelf on both cruises. According to Raymont (1983), this is the least coastal of the Cladocera species, and appears to avoid waters of lower salinity and poorer quality.

Penilia avirostris, typical of CW, was the only species found throughout the shelf. On the May 2006 cruise it presented a preference for the north of the study area, where the water temperature was higher. This behavior in relation to temperature can be explained by the thermophilic nature of this species (Ramírez, 1981; Raymont, 1983; Rocha, 1985). It was the only Cladocera species that presented a response to the abiotic gradients perpendicular and longitudinal to the coast.

Pleopsis schmackeri showed the greatest occurrence at the coastal points associated with SASW. Considered an invasive species, it is now established in the coastal waters of Brazil and its distribution has been recorded from Guanabara Bay (RJ) to RGS (Lopes, 2004). It is indicative of warm waters, and together with the occurrence of *P. avirostris*, it has been associated with the prevalence of the Brazil Current, characterized by clear water with high salinity, in the coastal region of RGS (Resgalla Jr. & Montú, 1993; Resgalla Jr., 2008) and in the coastal region of RJ (Marazzo & Valentin, 2003).

Pseudoevadne tergestina indicates warm coastal and oceanic waters, and may also be present in temperate and tropical waters in both hemispheres (Ramírez, 1981; Onbé, 1999). It occurs throughout the shelf, with no distinct distribution pattern, but with a higher density in May 2006, indicating the thermophilic characteristic of the species.

Associations and hydrological indicators

The classification of water masses presented in Figure 2 highlights that the abiotic forces of temperature and salinity were evident for the December 2005 cruise, involving, in this case, gradients perpendicular to the coast. For the May 2006 cruise, only salinity presented gradients longitudinal to the coast.

These differences were evident for the more abundant species of Copepoda and Cladocera, with *Acartia lilljeborgi* being distributed along the sampling points of the internal shelf in December 2005 and limited to the north of the study area in May 2006. The same behavior was observed for *Penilia avirostris* indicating horizontal stratifications within the study area for this species, which is typical of warm coastal waters.

For the Principal Components Analysis (PCA) in December 2005, the environmental variables presented higher weighting over the first axis, indicating that these forcing mechanisms may explain the distribution of the zooplankton species. On the other hand, in the case of the samples collected in May 2006, the absence of high weightings for the abiotic variables (temperature and salinity) in relation to axis 1 and the lower percentage of explicability of the axes suggest that biotic forcing mechanisms may have a greater weight in relation to the distribution of the species that occur in the study area. According to Fager (1963), the more the abiotic forcing mechanisms cause a decrease in variation, the greater the influence of the biotic forcing mechanisms. Thus, the PCA confirmed some distribution patterns of the species, *i.e.*, the distinction between coastal species and those of the external shelf for the December 2005 cruise, and a wide distribution for the vast majority of species on the May 2006 cruise.

However, the physical processes of upwelling and the entrance of the Plata front into the study area do not demonstrate typical associations, according to studies carried out by other authors. *Calanoides carinatus*, observed on both sampling occasions, is an indicator of upwelling processes, but is only associated with the occurrence of *Ctenocalanus vanus* (not observed in this study), as highlighted by Valentin *et al.* (1976) and Campaner (1985) in the region of Cabo Frio (RJ). Thus, these processes involving the entry of waters with lower temperatures, highlighted by physical-chemical parameters, were not confirmed by the biological indicators, such as the absence of species of Cladocera *Pleopis polyphemoides* and *Podon intermedius* previously reported for studies carried out along the Santa Catarina coast (Resgalla Jr., 2011). The type of sampler used (depth limitation), and the sampling period (initial stage of development of the physical process), may have limited the use of hydrological indicators.

On the other hand, the PCA indicated species typical of IFR, i.e. species inversely correlated with high salinities, such as *Acartia lilljeborgi*, *Temora turbina*, *Centropages velificatus* and *Penilia avirostris* for the cruise of December 2005. For the May 2006 samples, the separation between *Acartia lilljeborgi* from the group of species distributed on the middle and external shelf (*e.g.* *Clausocalanus furcatus*, *Corycaeus giesbrechti* and *Corycaeus speciosus*) also suggests differences in tolerance and salinity, which were not confirmed by the PCA indicating that, in this case, the formation of these groups may be influenced by biotic forcing mechanisms, such as competition and predation, which are normally difficult to explain (Resgalla Jr., 2008). These biotic forcing mechanisms may be promoted by the higher prevalence of the species (higher number of taxa) observed in May 2006, a period with a greater overlapping of niches and biological interactions (Whittaker, 1972).

In conclusion, it was noted in this study that the zooplankton community along the Santa Catarina coast presents typical groups of the marine holoplankton, such as Copepoda, Cladocera, Salpidae and Chaetognatha (as previously reported by Resgalla Jr., 2011), with greater abundance observed at the sampling points closer to the coast. The species of Copepoda and Cladocera recorded indicate great similarity with the fauna of the southeast region, typical of warm coastal and shelf waters. Also, gradients perpendicular and longitudinal to the coast provided by continental processes and inputs, upwelling and the Plata Plume Water, can determine the distribution of more abundant species, such as *Acartia lilljeborgi* and *Penilia avirostris*, with perpendicular gradients (continental inputs and upwelling), being more influential in this regard than longitudinal gradients (Plata Plume). However, these behaviors can be attributed to the mid-season period, when the physical processes observed are not occurring to their full extent.

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