

Research Article

Pteropoda, Cladocera, and Chaetognatha associations as hydrological indicators in the southern Brazilian Shelf

Charrid Resgalla Jr.

CTTMar, Universidade do Vale do Itajaí (UNIVALI), P.O. Box 360 - 88.302-202 Itajaí, SC, Brazil

ABSTRACT. Associations of pteropod, cladoceran, and chaetognath species were analyzed for the southern coast of Brazil in order to present a biological diagnosis of the oceanographic conditions in winter and summer. The density data from the different species were analyzed using nodal and ordination cluster techniques, linking the species associations with salinity and temperature and, consequently, with the water masses occurring in each period. *Sagitta tenuis* and *Pleopsis polyphemoides* were found to characterize the coastal water and, when associated with *Evadne nordmanni* and *Pleopsis schmackeri*, differentiated between the thermal characteristics of winter and summer, respectively. The Sub-Antarctic Shelf Water was characterized by the association of *Sagitta tasmanica* and *Limacina retroversa* in winter. The Tropical Water of the Brazil current presented several different associations, with *Penilia avirostris*, *Sagitta enflata*, and *Creseis virgula* dominating the shelf Tropical Water and *Sagitta serratodentata*, *Limacina trochiformis*, and *Evadne spinifera* characterizing the oceanic Tropical Water. The Sub-tropical Water, typical of upwelling processes, was characterized by the association of the chaetognaths *Sagitta decipiens* and *Krohnitta subtilis*, both in winter and summer. The species associations defined in this study agree with others carried out in neighboring areas and in previous sampling periods, characterizing the region as the southern transition zone.

Keywords: zooplankton, species associations, hydrological indicators, coastal water, southern Brazil.

Asociaciones de Pteropoda, Cladocera y Chaetognatha como indicadores hidrológicos de la plataforma del extremo sur de Brasil

RESUMEN. Se analizó las asociaciones de especies de Pteropoda, Cladocera y Chaetognatha en la costa sur de Brasil, para presentar un diagnóstico biológico de las condiciones oceanográficas de invierno y verano. Los datos de densidad de las diferentes especies fueron analizados por técnicas de agrupamiento nodal y de ordenación, relacionando las asociaciones con la salinidad, temperatura y, consecuentemente, con las masas de agua presentes en cada período. Se observó que *Sagitta tenuis*, *Pleopsis polyphemoides* caracterizan el agua costera, que asociada a *Evadne nordmanni* y *Pleopsis schmackeri* diferencian las características térmicas de invierno y verano, respectivamente. El Agua Subantártica de Plataforma fue caracterizada por la asociación de *Sagitta tasmanica* y *Limacina retroversa* en invierno. El Agua Tropical de la corriente de Brasil presentó una diversidad de asociaciones, pudiendo ser de plataforma con la dominancia de *Penilia avirostris*, *Sagitta enflata* y *Creseis virgula*, así como el Agua Tropical oceánica caracterizada por *Sagitta serratodentata*, *Limacina trochiformis* y *Evadne spinifera*. El Agua Subtropical, típica de procesos de surgencias, estuvo caracterizada por la asociación de los quetognatos *Sagitta decipiens* y *Krohnitta subtilis* en invierno y en verano. Las asociaciones de especies definidas en este estudio están de acuerdo con otros realizados en áreas vecinas y en períodos anteriores, caracterizando la región como zona de transición sur.

Palabras clave: zooplancton, asociaciones de especies, indicadores hidrológicos, agua costera, sur de Brasil.

INTRODUCTION

Different water masses are characterized not only by physical and chemical properties, but also by the fact that they contain a typical biological community. These communities are normally observed in studies of associations of organisms, which form part of the diverse oceanographic indicators. Associations of zooplankton species have been studied frequently: by Dadon & Boltovskoy (1982) and Raymont (1983) for environments with a mixture of different water masses, and by Omori & Ikeda (1984) for monitoring hydrological events, eutrophication processes, pollution, and disturbances over time.

For the southwestern Atlantic, several works refer to the study of species associations and zoogeographic delimitations based on zooplankton organisms. Among these are the studies by Boltovskoy (1975) on the associations between Foraminifera, Chaetognatha, and Pteropoda; Ramirez (1977) on Copepoda, Euphausiacea, Polychaeta, Amphipoda, Ostracoda, and Cladocera; Dadon & Boltovskoy (1982) on associations between Pteropoda, Euphausiacea, and Chaetognatha; and Fernández-Aráoz *et al.* (1991) on Copepoda, Amphipoda, Euphausiacea, Cladocera, and Ostracoda.

However, for the southernmost coast of Brazil, a hydrologically complex area, no studies have yet been presented on the use of associations of zooplankton species as indicators of water masses and information about these associations in different strata of the water column is still rare.

The circulation pattern of the waters off southern Brazil, Uruguay, and northern Argentina is characterized by the confluence of two water masses with different origins: one tropical (Brazilian Current), which moves north to south, and one Sub-Antarctic (Falklands Current), which moves south to north (Castello & Möller Jr., 1977; Miranda, 1982). This confluence, known as the Western Boundary of the Sub-Tropical Convergence, also presents phenomena of meanders (Miranda, 1982) and eddies (Legeckis & Gordon, 1982; Godoi, 1982) as well as upwelling processes (Lima Jr., 1992). The limits of this convergence zone are not static, but vary between latitudes 35° and 40°S (Godoi, 1982) depending on the season of the year; they are farther north in winter and farther south in summer due to the intensities of the currents involved (Boltovskoy, 1981).

In the coastal region, the complexity is intensified due to the strong influence of continental inflow coming mainly from the La Plata River estuary, and to a lesser extent, from the Patos Lagoon estuary (Castello

& Möller Jr., 1977; Miranda, 1982). In response to these mixing processes, the biota presents marked peaks of seasonal production off the Brazilian coast. High values of phytoplanktonic biomass (Teixeira *et al.*, 1973; Hubold, 1980a, 1980b; Ciotti *et al.*, 1995) associated with high concentrations of nutrients (Hubold, 1980a, 1980b) were established in the mixed waters between the Sub-Antarctic Water and the Coastal Water for the southern region of Brazil. High zooplankton biomass values were also found for this area (Navas-Pereira, 1973; Hubold, 1980a, 1980b; Resgalla Jr. *et al.*, 2001).

During the oceanographic cruises carried out in winter 1988 and summer 1990, studies were conducted on the water masses that influence the continental shelf off the extreme south of Brazil. During the winter cruise, Soares & Möller Jr. (2001) found a high concentration of discharge from the La Plata River and the Patos Lagoon estuary in the formation of coastal water or shelf water. This same period was also strongly influenced by the Sub-Antarctic Shelf Water (SASW, salinity 33.4-33.7), which originate from the mixing of the Sub-Antarctic Water coming from the coast of Argentina and the discharge from the La Plata (Piola *et al.*, 2000). SASW was located on the shelf, bordered to the west by Coastal Water (CW, salinity < 33), and to the east by Tropical Water (TW, salinity > 36 and temperature > 20°C). The Central Water of the South Atlantic (CWSA), also known as Sub-Tropical Water (STW), originating from the mixing processes between the Sub-Antarctic Water (SAW, salinity 33.7-34.15 and temperature between 4-14°C) and the TW, was often located in the oceanic region and at shallower depths. The prevailing winds from the south quadrant (64.8%) favor convergence processes, limiting the La Plata discharge near the coast and transporting it northward.

In summer, the low discharge from the La Plata and Patos Lagoon estuaries does not allow for the formation of CW. The TW dominated the entire shelf and oceanic surface regions, and no pronounced gradients were observed in temperature or salinity. Due to the occurrence of winds from the north quadrant, the conditions favored (63.3%) upwelling processes, with the dispersion of water on the shelf to the oceanic region and the intrusion of CWSA on the shelf associated with strong vertical thermal gradients.

MATERIAL AND METHODS

The samples for this study were part of the integrated project "Estudo do Ecosistema Pelágico do Extremo Sul do Brasil" (Study of the Pelagic Ecosystem of the

Extreme South of Brazil) (ECOPEL-CIRM) in which two cruises carried out by the NOc. "Atlântico Sul" (FURG) were selected: September 1988 (ECOPEL II-late winter) and February 1990 (ECOPEL III-summer). The study area was delimited by 31°40'S and 34°45'S, reaching the 500 m isobath for the winter cruise and the 1000 m isobath for the summer cruise (Fig. 1). The sample plan consisted of profiles perpendicular to the coast, with oceanographic stations 20 n.m. apart. In all the stations, vertical zooplankton hauls, obtained both at night and during the day, were carried out in five strata with standardized depths (0-25 m, 25-50 m, 50-100 m, 100-200 m, and 200-500 m), using a WP-2 type net (150 µm mesh size, 60 cm diameter) equipped with a flowmeter and a closing device. A total of 72 samples were gathered for each cruise. After collection, all the samples were immediately fixed in formaldehyde solution at 4% and neutralized with Borax.

In order to cover all the water masses that have a seasonal influence on the continental shelf of the extreme south of Brazil, the zooplankton groups pteropod Thecosomata (oceanic), cladoceran (coastal-neritic), and chaetognaths (widely distributed) were selected and used for multivariate analyses, establishing associations of species as hydrological indicators. Information on the treatments, identifications, morphological variations, and vertical behavior of each group can be seen in Resgalla Jr. & Montú (1993, 1994, 1995). The species selected for the multivariate analyses (cluster and ordination) were those that presented a minimum frequency of occurrence of 10%, and the density data dealt only with adult organisms, with their logarithmic transformation. These selections were made in order to reduce data variations such as those caused by different behaviors during the development phases. Five pteropod species, six cladoceran species, and ten chaetognath species were used (Table 1).

Cluster analysis

The quantitative Bray-Curtis dissimilarity index (b_{jk}) was used:

$$b_{jk} = \frac{\sum |x_{ij} - x_{ik}|}{\sum (x_{ij} + x_{ik})} \quad (1)$$

where: X_{ij} is the value of attribute i (species or line) measured in object j (station or column) as well as for object k . This coefficient, also known as Czekanowski & Sorenson, varies from 0 to 1, where 0 is maximum similarity (Boesch, 1977; Pielou, 1984; Romesburg,

1984). The Flexible method ($\alpha = -0.25$) was the linking strategy used, which simulates the results of the UPGMA (non-weighted arithmetic mean) method and the compact extreme link (minimum similarity), according to Sneath & Sokal (1973). The analyses were carried out in both directions Q (stations) and R (species) for each cruise separately.

Nodal analysis

In order to link the species groups with the groups of stations resulting from the clusters, qualitative nodal analysis (Boesch, 1977) was used, with the characterization of ecological concepts of constancy and fidelity.

Constancy (C_{ij})

This is the percentage or proportion of the number of occurrence of the species of the group for the total possible number of occurrences. This index has a value of 1 when all the species occur at all the stations in the group and 0 when none of the species occur at the stations.

$$c_{ij} = \frac{a_{ij}}{(n_i n_j)} \quad (2)$$

where: a_{ij} is the number of occurrence of the members of the group of species i in the group of stations j . And n_i and n_j are the numbers of entities in the respective groups.

Fidelity (F_{ij})

This presents an indication of the degree to which the species "select" or are limited to collection stations. This index is an expression of the constancy of the species in a group of stations compared with the total constancy. When its value is 1, the constancy of a determined species group in a group of stations is equivalent to the constancy in all the groups; when higher than 1, the constancy in the group of stations is higher than the total and, when less than 1, the constancy is lower than the total. An index over 2 suggests a strong "preference" of the group of species for one group of stations. Values lower than 1 suggest negative fidelity, or that species of a determined group of stations are excluded from the group.

$$F_{ij} = \frac{(a_{ij} \sum n_j)}{(n_j \sum a_{ij})} \quad (3)$$

using the same terms as the constancy index.

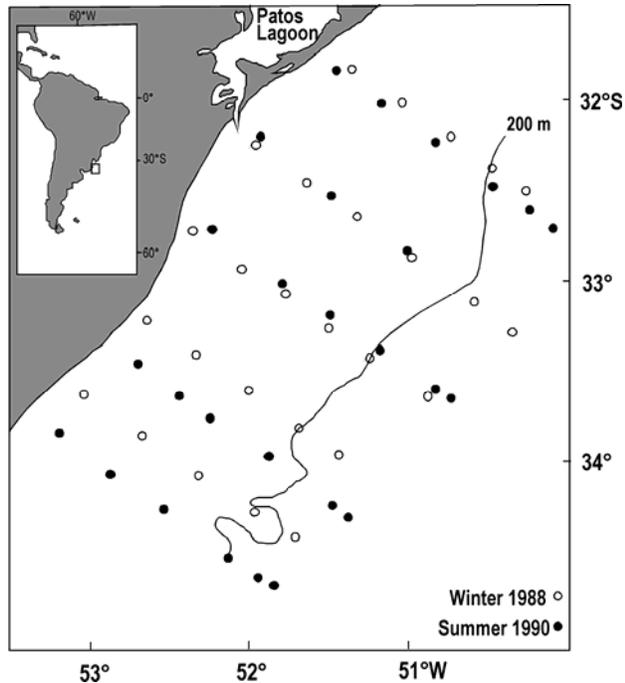


Figure 1. Study area and location of the oceanographic stations for winter 1988 and summer 1990 cruises off southern Brazil.

Figura 1. Área de estudio y ubicación de las estaciones oceanográficas en los cruceros de invierno de 1988 y verano de 1990 en el sur de Brasil.

Ordination analysis (Principal Components Analysis-PCA)

For this analysis, the density values of the species and abiotic variables (temperature and salinity) were centralized (average 0) and standardized (variance 1) as recommended by Pielou (1984). The abiotic variables (temperature and salinity) were obtained according to Ciotti *et al.* (1995) and the water masses were characterized according to Soares & Möller Jr. (2001). Water salinity was measured by a Kahlsico salinometer and temperature was measured using inversion thermometers attached to Nansen bottles. Water masses were determined using the T-S diagram.

RESULTS

The dendrograms of the cluster analyses for the winter and summer cruises are represented in figures 2 and 3. For the Q mode analyses (stations), and in both cruises, there were clear delimitations between the coastal and oceanographic groups (group I in relation to the others for the winter cruise; groups I and II in relation to groups III and IV for the summer cruise). In

general, four groups of stations were defined in both cruises, which can be summarized as follows:

- Groups I (winter) and IV (summer) – coastal stations.
- Groups IV (winter) and III (summer) – shelf stations.
- Groups III (winter) and I (summer) – oceanic surface stations.
- Group II (winter and summer) – deep ocean stations.

The groups defined in the R mode analysis can be characterized by their ecological affinities, preferential areas of occurrence, and origins, according to Resgalla Jr. & Montú (1993, 1994, 1995). These groups can be defined by the species with high densities registered in the samples, such as:

Winter:

- Group A: eurythermic and euryhaline coastal species such as the cladoceran *Pleopis polyphemoides* and the chaetognath *Sagitta tenuis*. *Evadne nordmanni*, typical of cold waters, was the second species in high densities among the cladocerans.
- Group B: Sub-Antarctic species represented by the pteropod *Limacina retroversa* and the chaetognath *Sagitta tasmanica*.
- Group C: comprised of tropical oceanic species, such as the chaetognaths *Sagitta serratodentata* and *S. minima*.
- Group D: comprised of the sub-tropical species chaetognaths *Krohnitta subtilis* and *Sagitta decipiens*.

Summer:

- Group A: similar to the winter cruise, dominated by *Pleopis polyphemoides* and *Sagitta tenuis* and by the cladoceran *P. schmackeri*, which is typical of warm waters.
- Group B: characterized by tropical species, but from the waters of the shelf with a predominance of the pteropod *Creseis virgula*, the cladoceran *Penilia avirostris*, and the chaetognaths *Sagitta enflata* and *S. hispida*.
- Group C: tropical oceanic species with a prevalence of the pteropod *Limacina trochiformis*, the cladoceran *Evadne spinifera*, and the chaetognath *Sagitta serratodentata*.

Table 1. Average density (AD) and frequency of occurrences (FO) for Pteropoda, Cladocera, and Chaetognatha species used to characterize the associations of species as indicators of water masses on the South Brazilian shelf in winter 1988 and summer 1990.

Tabla 1. Densidad media (AD) y frecuencia de ocurrencias (FO) de las especies de Pteropoda, Cladocera y Chaetognatha utilizadas para la caracterización de las asociaciones de especies indicadoras de masas de agua en la plataforma sur de Brasil de invierno de 1988 y verano de 1990.

Group/Species	Winter 1988		Summer 1990	
	AD (ind.m ⁻³)	FO (%)	AD (ind.m ⁻³)	FO (%)
Pteropoda				
<i>Creseis virgula</i>	-	-	1	40.7
<i>Hyalocylis striata</i>	-	-	< 1	25.9
<i>Limacina inflata</i>	< 1	14.8	< 1	22.2
<i>Limacina retroversa</i>	1	25.9	-	-
<i>Limacina trochiformis</i>	-	-	< 1	51.8
Cladocera				
<i>Evadne nordmanni</i>	10	48.2	-	-
<i>Evadne spinifera</i>	-	-	< 1	22.2
<i>Penilia avirostris</i>	-	-	48	70.4
<i>Pleopis polyphemoides</i>	122	59.3	11	22.2
<i>Pleopis schmackeri</i>	-	-	1	37.0
<i>Pseudevadne tergestina</i>	-	-	4	74.1
Chaetognatha				
<i>Krohnitta pacifica</i>	-	-	< 1	37.0
<i>Krohnitta subtilis</i>	< 1	25.9	< 1	18.5
<i>Pterosagitta draco</i>	< 1	22.2	< 1	33.3
<i>Sagitta decipiens</i>	< 1	22.2	< 1	14.8
<i>Sagitta enflata</i>	< 1	25.9	34	100.0
<i>Sagitta hispida</i>	-	-	6	85.2
<i>Sagitta minima</i>	1	44.4	1	44.4
<i>Sagitta serratodentata</i>	1	40.7	1	55.6
<i>Sagitta tasmanica</i>	< 1	29.6	< 1	3.7
<i>Sagitta tenuis</i>	15	88.9	8	51.8

- Group D: comprised of sub-tropical species (similar to group D of the winter cruise) with the chaetognaths *Krohnitta subtilis* and *Sagitta decipiens*.

According to the nodal analysis (Fig. 4), for the winter, a high fidelity and constancy were observed between the pairs of groups IV and B (Sub-Antarctic species in the shelf samples) and also between the groups II and D (sub-tropical species in deep ocean samples). In the summer, a greater homogeneity was observed between the groups obtained in the cluster analysis (for constancy) despite the high fidelity observed between the pairs of groups II and D (sub-tropical species in deep ocean samples) and the groups IV and A (coastal species in coastal samples).

By plotting the groups of stations on a T-S diagram (Fig. 5), it was possible to define the intervals of variance in temperature and salinity that comprise the tolerance limits for the species associations for each period and in relation to the water masses observed:

Winter:

- Group I: cold Coastal Water (11.12-13.47°C and salinity 30.13-33.44)
- Group II: Sub-Tropical Water (4.47-19.71°C and salinity 34.51-36.27)
- Group II: Tropical Water (9.99-19.82°C and salinity 33.23-36.07)

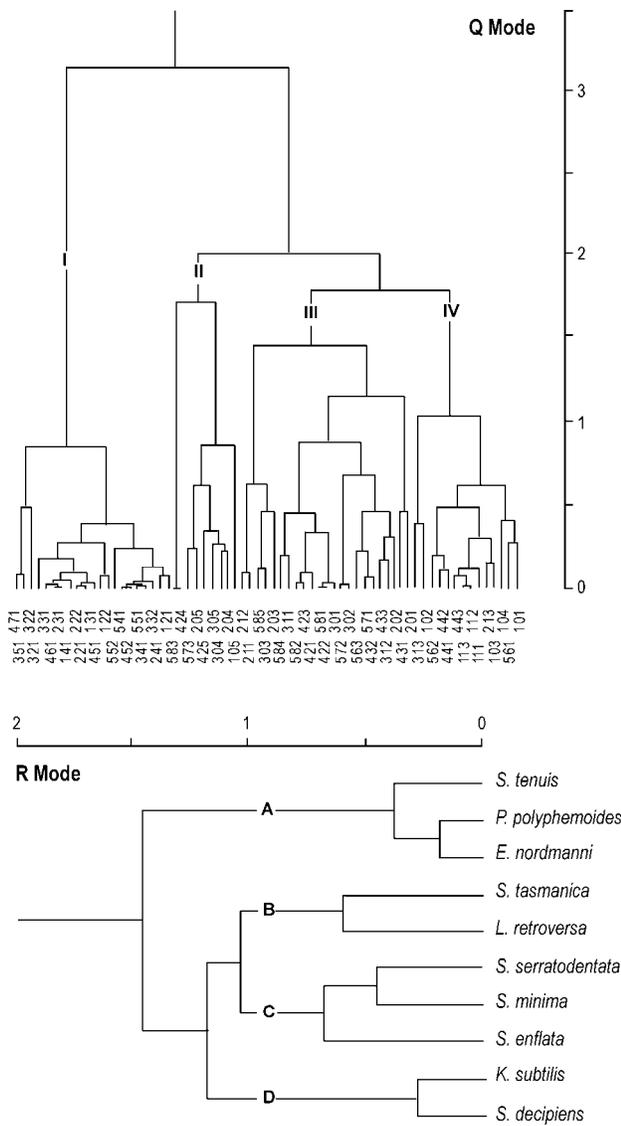


Figure 2. Dendrograms of the cluster analyses for the stations (Q Mode) and for the Pteropoda, Cladocera, and Chaetognatha species (R Mode) for the winter 1988 cruise. Roman numerals and letters indicate the denomination of the groups.

Figura 2. Dendrogramas de los análisis de agrupamiento para las estaciones (Modo Q) y para las especies de Pteropoda, Cladocera y Chaetognatha (Modo R) referente al crucero de invierno de 1988. Los números romanos y las letras indican la denominación de los grupos.

- Group IV: Sub-Antarctic Shelf Water (9.35-13.24°C and salinity 32.99-35.00)

Summer:

- Group I: Tropical oceanic surface water (17.42-25.84°C and salinity 35.16-36.80)

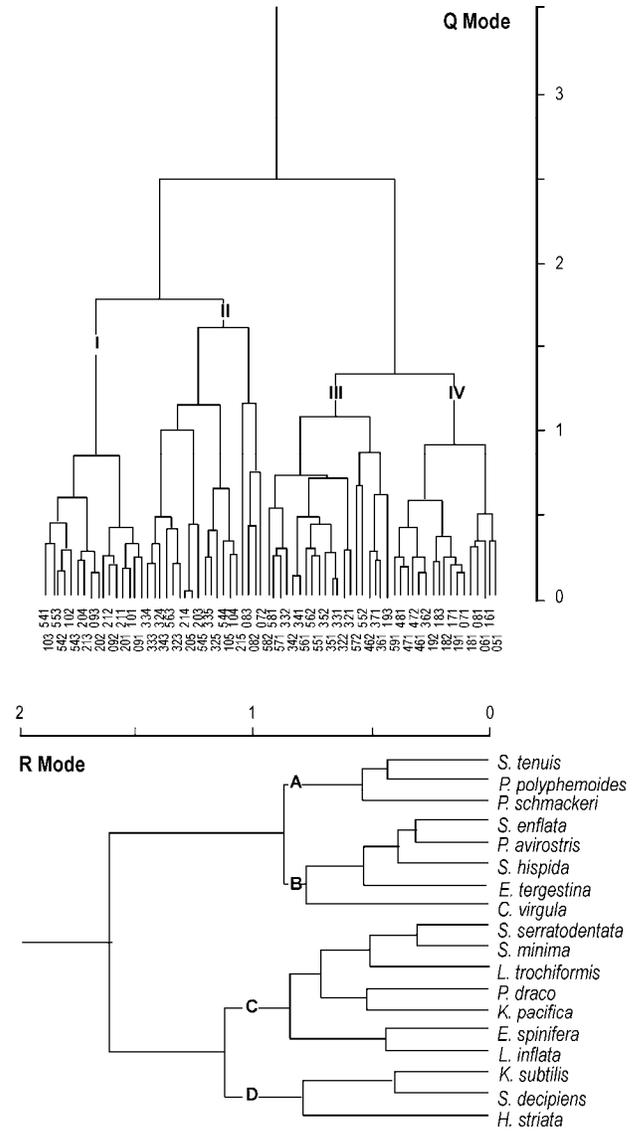


Figure 3. Dendrograms of the cluster analyses for the stations (Q Mode) and for the Pteropoda, Cladocera, and Chaetognatha species (R Mode) for the summer 1990 cruise. Roman numerals and letters indicate the denomination of the groups.

Figura 3. Dendrogramas de los análisis de agrupamiento para las estaciones (Modo Q) y para las especies de Pteropoda, Cladocera y Chaetognatha (Modo R) referente al crucero de verano de 1990. Los números romanos y las letras indican la denominación de los grupos.

- Group II: Sub-Tropical Water (11.63-22.52°C and salinity 34.03-36.54)
- Group IV: Tropical Shelf Water (14.98-24.53°C and salinity 34.24-36.45)
- Group II: Coastal Water (17.76-25.98°C and salinity 34.08-35.72)

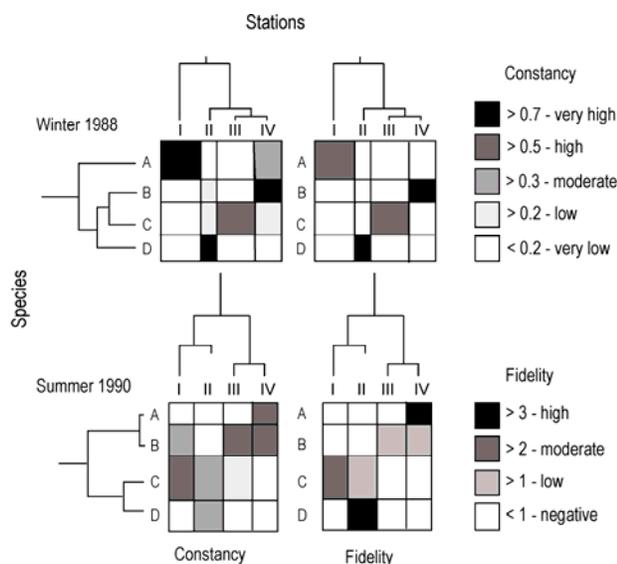


Figure 4. Nodal analysis (constancy and fidelity) according to the groups defined in the cluster analysis (winter 1988 and summer 1990).

Figura 4. Análisis Nodal (constancia y fidelidad) según los grupos definidos en el análisis de agrupamiento (invierno de 1988 y verano de 1990).

The delimitation of the groups at collection stations represented in the T-S diagram for the summer cruise was not clearly defined, as it was for the winter cruise, with a greater dispersion of the group IV (Coastal Tropical Water) occurring at the center of the diagram. Also, the points which characterize the Sub-Tropical Water (group II) are concentrated on the extreme right of the diagram for the winter cruise, with points scattered outside its axis in summer, indicating spatial and density variations.

This distribution can be better visualized by the classification of sample points for each oceanographic cruise (Fig. 6). In winter, the coastal species association was limited by the sub-antarctic and tropical species associations over the shelf. Despite a low definition between different tropical groups at the surface, the summer cruise was characterized by the intrusion of sub-tropical species on the shelf bottom.

DISCUSSION

Studies of fauna associations determine the species that present similar responses to variations in the natural properties of the environment (Omori & Ikeda, 1984). The characteristic biological history of a water mass is not controlled by temperature and salinity

alone, but also by biotic variables such as primary production, particle size, and characteristics of the food chain (Fager, 1963; Johnson & Brinton, 1963; Raymont, 1983; Boltovskoy, 1986) that can delimit the species associations. However, the relationships between the temperature and salinity pairs (T-S diagram) and groups of similar species normally give good results (Hida, 1957; Bary, 1959; Johnson & Brinton, 1963; Angel, 1979).

The coastal groups (I in winter and IV in summer) present an association of similar species, the majority of which are constant or have high fidelity. Morphometric differences in *Sagitta tenuis* (larger size in winter) and reproductive differences in *Pleopsis polyphemoides* (higher number of embryos per female in summer) presented by Resgalla Jr. & Montú (1993, 1995) distinguish these populations seasonally. These, when combined with the alternated occurrences of *Evadne nordmanni* and *Pleopsis schmackeri*, constitute thermal indicators of each group (Onbé, 1999). Both the species and the station groups were well defined in the winter cruise (cluster and nodal analyses), and highly similar to the Argentina coastal region (Boltovskoy, 1981), which presents limited diversity for chaetognaths, total prevalence of a taxon such as cladocerans, and an absence of pteropods. There is also a fauna similarity of cladoceran species associations at the mouth of the La Plata River presented by Fernández-Aráoz *et al.* (1991), showing a strong influence of water from the Argentine shelf in winter (Piola *et al.*, 2000; Soares & Möller Jr., 2001). For the summer cruise, the most represented group of coastal species was in the south of the study area, the site of the lowest salinity values for Tropical Water (Fig. 6).

Likewise, group IV of the stations was characterized by Sub-Antarctic species that tend to live on the coast. Occurrences of *Sagitta tasmanica* have already been pointed out in Sub-Antarctic waters with a mixture of coastal waters by Bary (1959), Boltovskoy (1975, 1981), and Dadon & Boltovskoy (1982), as has accentuated eurythermia for *Limacina retroversa* (Boltovskoy, 1981, 1979), which is characteristic of the coastal branch of the Falklands Current (Van der Spoel & Dadon, 1999). The point of dispersion of this water would be to the south on the shelf-break and slope, due to the occurrence of high densities and the joint presence of adults and juveniles in both species (Resgalla Jr. & Montú, 1994, 1995) (Fig. 6). Associated with this, the Sub-Antarctic Water, according to the nodal analysis, presents a strong influence of cold coastal species, which agrees with the definition of Sub-Antarctic Shelf Water presented by Piola *et al.* (2000).

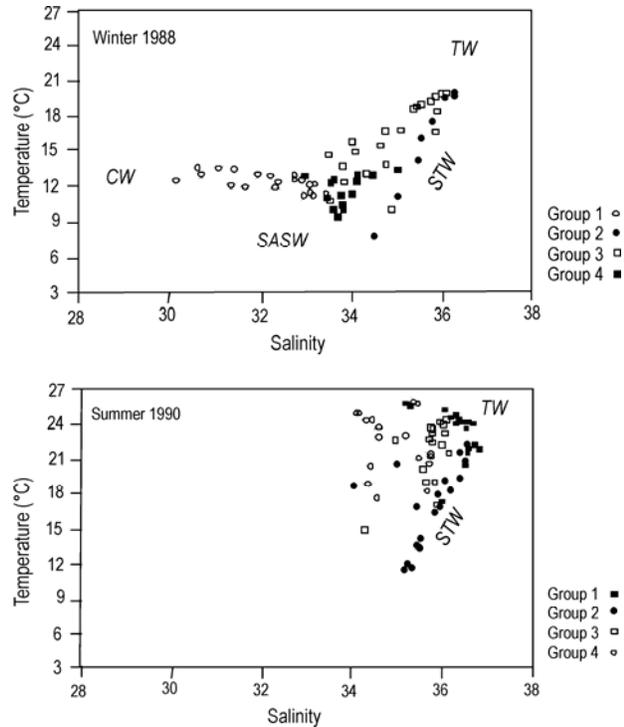


Figure 5. Plotting of the groups of stations defined in the cluster analysis in a T-S diagram for winter 1988 and summer 1990. Water mass are: CW: Coastal Water, TW: Tropical Water, STW: Sub-Tropical Water, SASW: Sub-Antarctic Shelf Water.

Figura 5. Ploteo de los grupos de estaciones definidas en el análisis de agrupamiento en un diagrama T-S para invierno de 1988 y verano de 1990. Las masas de agua son: CW: Aguas Costeras, TW: Agua Tropical, STW: Agua Sub-Tropical, SASW: Agua de la Plataforma Sub-antártica.

Winter group III (tropical species) was characterized by winter populations of *Sagitta serratodentata* and *Sagitta minima*. *S. minima*, in particular, is considered an indicator of mixed waters between the neritic and oceanic region, and between Sub-Antarctic and Tropical Waters (Hida, 1957; Johnson & Brinton, 1963; Tokioka, 1979; Raymont, 1983). Therefore, this group would not be a good indicator of Tropical Water, since typical species such as *Pterosagitta draco* and *Sagitta hexaptera* (Crelie & Daponte, 2004) do not present the minimum occurrences for inclusion in the analysis. The oceanographic stations associated with this group of species probably delimit a transition zone between the cold waters of the Sub-Antarctic Shelf Water and the warm waters of the Tropical Water. In summer, group I, with the same species (*S. serratodentata* and *S. minima*), presented a different fauna association which, together with the morphometric variations (larger specimens in winter for

both species) (Resgalla Jr. & Montú, 1995), could, in fact, characterize the Brazil Current (Tropical Water).

In the summer cruise, the delimitation of the tropical associations of shelf and oceanic waters (groups III and I) were observed in a study of Siphonophorae associations on the South Brazilian shelf by Cordeiro & Montú (1991). The point of dispersion of the group of tropical shelf species is to the north of the area, where high densities of *Penilia avirostris* and juvenile and adult *Creseis virgula* were both highlighted by Resgalla Jr. & Montú (1993, 1994).

During both cruises, the species in group II were characterized by the sub-tropical species *S. decipiens* and *K. subtilis*, which are cited as indicators of upwelling (Alvariño, 1967, 1968; Nair, 1977; O'Brien & Rock, 1978; Casanova, 1999). In summer, despite the homogeneity of surface water masses, upwelling processes on the shelf break are common (Soares & Möller Jr., 2001). Due to the greater detailing of the associations presented by the zooplankton, it was possible to observe a tendency of dislocation of the tropical-shelf groups to the open sea in the center of the area. In the same profiles and at depths, the sub-tropical group entered, spreading throughout the shelf break (Fig. 6), confirming the use of these two chaetognath species as indicators of the upwelling in the south of Brazil.

As primary validation (Romesburg, 1984), the principal components analysis (PCA) confirms the groups defined by the cluster analysis (Figs. 7 and 8). The PCA presents the advantage of linking the various groups to some of the possible abiotic gradients (temperature and salinity). It was observed that, in the two cruises, the salinity was positively correlated with the first axis, resulting in differences between the neritic and oceanic conditions, with temperature remaining negatively correlated with the second dispersion axis of the points (delimiting surface waters and deeper waters). These characteristics are logical when dealt with for coastal environments, whereas, in the oceanic environments, the main controlling factor is temperature (Boltovskoy, 1988). However, in winter, 56.7% of the variance was related to the thermohaline gradients; this was 44.2% for the summer cruise. Fager (1963) indicated that, as the variation in the abiotic components decreases, their biotic strength increases, but without any of them effectively ceasing to be active. The biotic factors are more pronounced in summer, resulting in a larger similarity among the groups of oceanographic stations observed in the cluster analysis.

The associations of species obtained in this study are similar to those found in studies based on historic data carried out by Boltovskoy (1975) and Dadon &

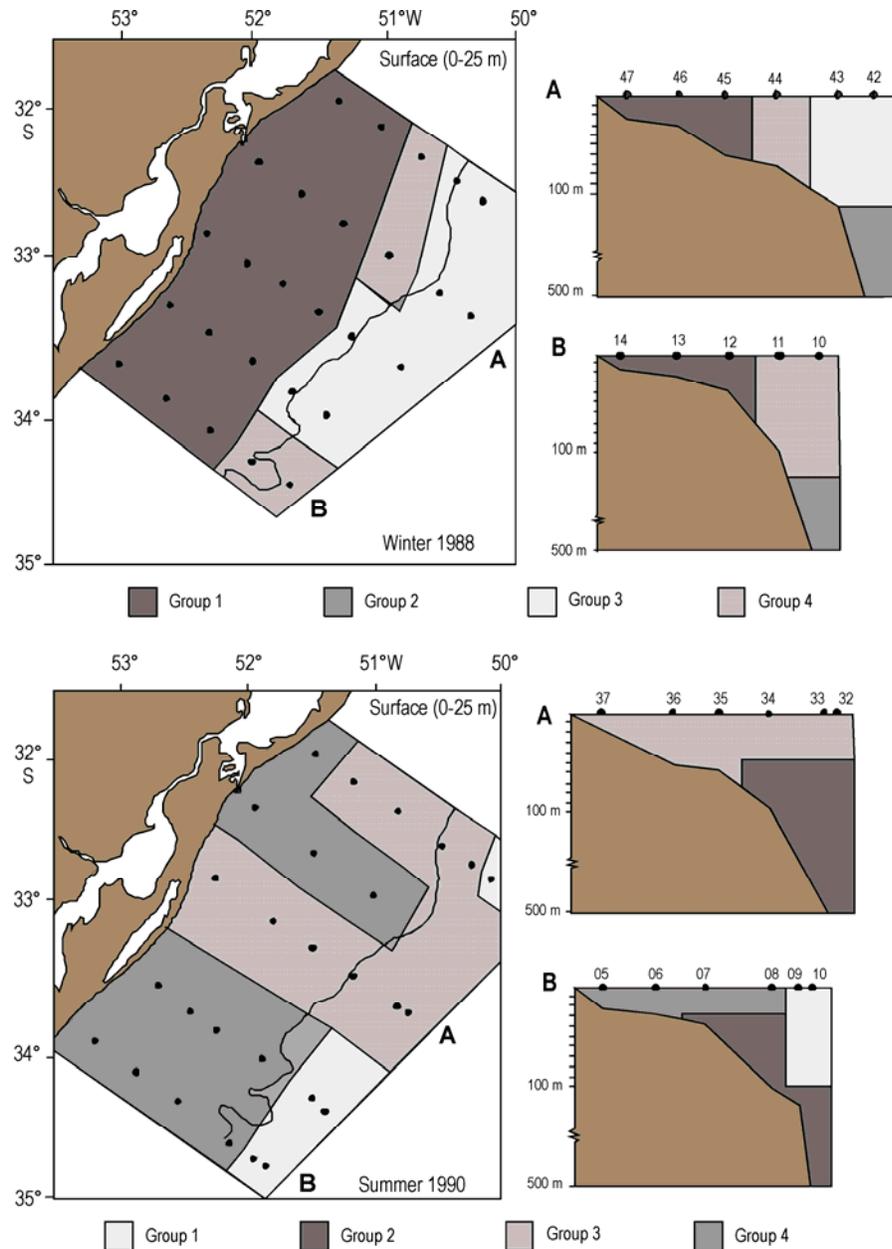


Figure 6. Study area with horizontal distribution of the groups of stations defined in the cluster analysis for winter 1998 and summer 1990. Vertical distribution was represented in the profiles A and B.

Figura 6. Área de estudio y distribución horizontal de los grupos de estaciones definidos en los análisis de agrupamiento, para invierno de 1988 y verano de 1990. La distribución vertical fue representada en los perfiles A y B.

Boltovskoy (1982), classifying the study area as a southern transition zone. Crelier & Daponte (2004) presented chaetognath associations sampled during the same period off the northern coast of Argentina, whereas Coelho (1993) carried out a study based on samples obtained 10 years earlier off the south of Bra-

zil. The similarities observed among the studies on species associations highlight the existence of past data that might be used in the future to assess the changes in fauna that are observed today and that are attributed to climate changes resulting from global warming.

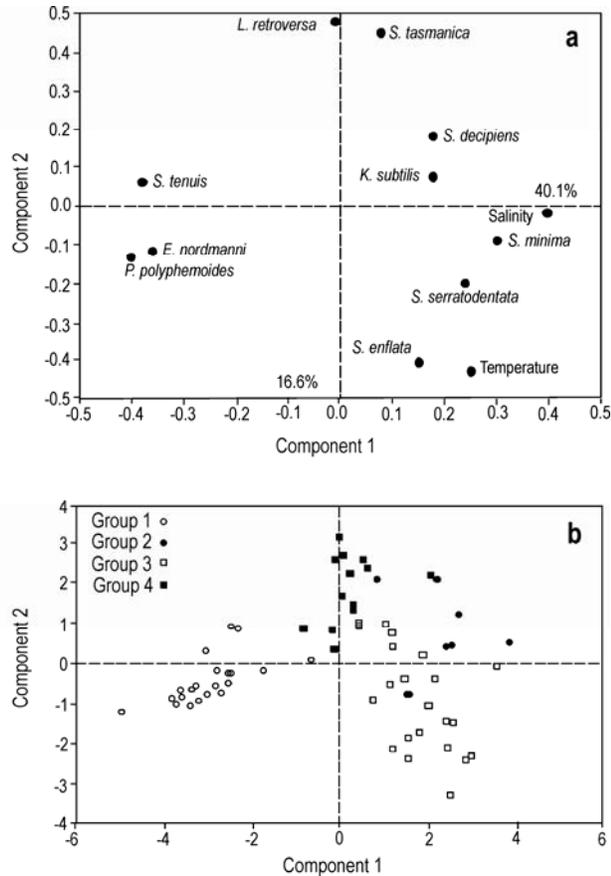


Figure 7. First and second axes of the principal components analysis (PCA) for winter 1988. a) Eigenvalues, and b) eigenvectors with the identification of the groups defined in the cluster analysis.

Figura 7. Primer y segundo eje del análisis de componentes principal (PCA) durante invierno de 1988. a) Autovalores, y b) Autovectores con la identificación de los grupos definida en el análisis del agrupamiento.

REFERENCES

- Alvariño, A. 1967. Bathymetric distribution of Chaetognatha, Siphonophorae, Medusae, and Ctenophorae off San Diego, California. *Pac. Sci.*, 21: 474-485.
- Alvariño, A. 1968. Los quetognatos, sifonoforos y medusas en la región del Atlántico ecuatorial bajo la influencia del Amazonas. *Anales del Instituto de Biología, Universidad Nacional Autónoma de México*. 39, Ser. Cienc. Mar Limnol., 1: 41-76.
- Angel, M.V. 1979. Zoogeography of the Atlantic ocean. In: S. Van der Spoel & A.C. Pierrot-Bults (eds.). *Zoogeography and diversity in plankton*. Bunge Science Publishers Utrecht, pp. 144-167.
- Bary, B.M. 1959. Species of zooplankton as a means of identifying different surface waters and demonstrating their movements and mixing. *Pac. Sci.*, 13: 14-54.

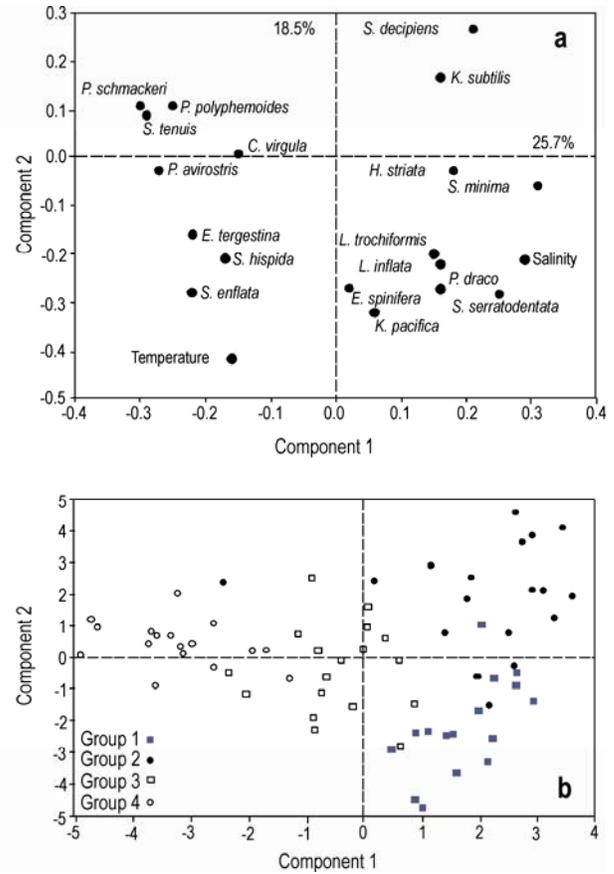


Figure 8. First and second axes of the principal components analysis (PCA) for summer 1990. a) Eigenvalues, and b) eigenvectors with the identification of the groups defined in the cluster analysis.

Figura 8. Primer y segundo eje del análisis de los componentes principal (PCA) durante verano de 1990. a) Autovalores, y b) Autovectores con la identificación de los grupos definida en el análisis del agrupamiento.

- Boesch, D.F. 1977. Application of numerical classification in ecological investigation of water pollution. Virginia Institute of Marine Science, Special Scientific Report, 77: 114 pp.
- Boltovskoy, D. 1975. Ecological aspects of zooplankton (Foraminifera, Pteropoda and Chaetognatha) of the southwestern Atlantic Ocean. *The Veliger*, 18(2): 203-216.
- Boltovskoy, D. 1979. Zooplankton of the south-western Atlantic. *South Afr. J. Sci.*, 75: 541-544.
- Boltovskoy, D. 1981. Características biológicas del Atlántico sudoccidental. In: D. Boltovskoy (ed.). *Atlas del zooplancton del Atlántico sudoccidental y métodos de trabajo con el zooplancton marino*. Publicación especial INIDEP, Mar del Plata, 239-251.

- Boltovskoy, D. 1982. Variación latitudinal de la diversidad zooplanctónica en el Atlántico sudoccidental. *Physis*, Secc. A, 41(100): 1-6.
- Boltovskoy, D. 1986. Biogeography of the southwestern Atlantic, overview, current. Problems and Prospects. In: A.C. Pierrot-Bults, S. Van der Spoel, J.B. Zahuranc & R.K. Johnson (eds.). Pelagic biogeography. Proc. Intern. Conf. Unesco, Techn. Pap. Mar. Sci., pp. 14-24.
- Boltovskoy, D. 1988. Las zonas de transición en la pelagial: biogeografía y paleobiogeografía, In: F.P. Brandini (ed.). Mem. III Enc. Brasileiro Plâncton, pp. 10-24.
- Casanova, J.P. 1999. Chaetognatha. In: D. Boltovskoy (ed.). South Atlantic zooplankton. Backhuys Publishers Leiden, The Netherlands, pp. 1353-1374.
- Castello, J.P. & O.O. Möller Jr. 1977. Sobre as condições oceanográficas no Rio Grande do Sul. *Atlântica*, 2(2): 25-110.
- Ciotti, A.M., C. Odebrecht, G. Fillmann & O.O. Möller Jr. 1995. Freshwater outflow and sub-tropical convergence influence on the phytoplankton biomass on the Southern Brazilian Continental Shelf. *Cont. Shelf Res.*, 15(14): 1737-1756.
- Coelho, M.J. 1993. Zooplâncton do Atlântico sudoeste (27°59'S a 39°59'S, 44°53'W a 56°56'W), com especial referência aos Chaetognatha. MSc. Dissertation, Universidade de São Paulo (IBUSP), 63 pp.
- Cordeiro, T.A. & M. Montú. 1991. Distribuição dos Siphonophorae: Calycophorae (Cnidaria) em relação as massas de água ao largo dos estados do Paraná e Santa Catarina, Brasil (28°S-31°S). *Nerítica*, 6(1-2): 107-126.
- Crelier, A.M. & M.C. Daponte. 2004. Chaetognatha of the Brazil-Malvinas (Falkland) confluence: distribution and associations. *Iheringia, Sér. Zool.*, 94(4): 403-412.
- Dadon, J.R. & D. Boltovskoy. 1982. Zooplankton recurrent groups (Pteropoda, Euphausiacea, Chaetognatha) in the southwestern Atlantic Ocean. *Physis*, Secc.A., 41(100): 63-83.
- Fager, E.W. 1963. Communities of organisms. In: M.N. Hill (ed.). *The Sea*. 2. Interscience Publishers John Wiley & Sons, New York, pp. 415-437.
- Fernández-Aráoz, N.C., G.M. Pérez-Seijas, M.D. Viñas & R. Reta. 1991. Asociaciones zooplanctónicas de la zona común de pesca Argentino-Uruguay en relación con parámetros ambientales. *Primavera* 1986. *Frente Mar*, 8(A): 85-99.
- Godoi, S.S. 1982. Estudos das variações sazonais da frente oceânica entre a Corrente do Brasil e a Corrente das Malvinas, utilizando dados oceanográficos e dados do satélite SMS-2. MSc. Dissertation. Inst. Pesq. Espaciais, 132 pp.
- Hida, T.S. 1957. Chaetognaths and Pteropods as biological indicators in the north Pacific. *Special Scientific Report: Fisheries*, 215:1-13.
- Hubold, G. 1980a. Hidrography and plankton off southern Brazil and Rio de la Plata. August-November 1977. *Atlântica*, 4: 1-22.
- Hubold, G. 1980b. Second report on hidrography and plankton off southern Brazil and Rio de la Plata, Autumn cruise: April- June 1978. *Atlântica*, 4: 23-42.
- Johnson, M.W. & E. Brinton. 1963. Biological species, water-masses and currents. In: M.N. Hill (ed.) *The Sea*. 2. Interscience Publishers John Wiley & Sons, New York, pp. 381-414.
- Legeckis, R. & A.L. Gordon. 1982. Satellite observations of the Brazil and Falkland Currents - 1975 to 1976 and 1978. *Deep-Sea Res.*, 29(3A): 375-401.
- Lima Jr., I.D. 1992. Distribuição e abundância de anchaita (*Engraulis anchoita*) em relação aos processos oceanográficos na plataforma continental do sul do Brasil. MSc. Dissertation. Fund. Univ. Rio Grande, 66 pp.
- Miranda, L.D. 1982. Análise de massa de água de plataforma continental e da região oceânica adjacente: Cabo de São Tomé (RJ) à ilha de São Sebastião (SP). PhD Thesis, Universidade de São Paulo, 123 pp.
- Nair, V.R. 1977. Chaetognaths of Indian Ocean. Proceedings of Symposium of Warm Water Zooplankton. Special Publication of the National Institute of Oceanography, Goa, pp. 168-195.
- Navas-Pereira, D. 1973. Análise qualitativa e quantitativa do zooplâncton. Relatório sobre a segunda pesquisa oceanográfica e pesqueira do Atlântico Sul entre Torres e Maldonado (Lat 29°-35°S). Programa Rio Grande do Sul II. GEDIP e Instituto Oceanográfico, Univ. São Paulo. Publicação Especial, 3(1): 29-92.
- O'Brien, F.I. & N.J. Rock. 1978. An interpretation of the Chaetognatha in Galway Bay during october 1973 using multivariate techniques. *Proceedings of the Royal Irish Academy*, 78B(14): 213-232.
- Omori, M. & T. Ikeda. 1984. Methods in marine zooplankton ecology. John Wiley & Sons, New York, 332 pp.
- Onbé, T. 1999. Ctenopoda and Onychopoda (Cladocera). In: D. Boltovskoy, (ed.). South Atlantic zooplankton. Backhuys Publishers Leiden, The Netherlands, pp. 797-813.
- Pielou, E.C. 1984. The interpretation of ecological data. A primer on classification and ordination. Wiley Intersci. Publ. John Wiley & Sons, New York, 263 pp.
- Piola, A.R., E.J.D. Campos, O.O. Möller Jr., M. Charo & C. Martinez. 2000. Sub-tropical shelf front off eastern south America. *J. Geophys. Res.*, 105(C3): 6565-6578.

- Ramirez, F.C. 1977. Planktonic indicators of Argentine shelf and adjacent areas. Proceedings of Symposium of Warm Water Zooplankton. Special Publication of the National Institute of Oceanography, Goa, pp. 65-68.
- Raymont, J.E.G. 1983. Plankton and productivity in the oceans. Vol. 2. Zooplankton. Pergamon Press, Oxford, 824 pp.
- Resgalla Jr., C. & M. Montu. 1993. Cladoceros marinhos da plataforma continental do Rio Grande do Sul-Brasil. Nauplius, 1: 63-79.
- Resgalla Jr., C. & M. Montu. 1994. Ocorrência espacial e temporal de Pteropoda Eutecosomata (Mollusca: Gastropoda) na plataforma do sul do Brasil. Atlântica, 16: 99-123.
- Resgalla Jr., C. & M. Montu. 1995. Quetognatos de la plataforma continental del sur de Brasil. Invest. Mar. CICIMAR, 10(1-2): 23-41.
- Resgalla Jr., C., M. Montu & C.L.L. Rocha. 2001. The influence of Ekman transport on zooplankton biomass variability off southern Brazil. J. Plankton Res., 23(1): 1191-1216.
- Romesburg, H.C. 1984. Cluster analysis for researchers. Lifetime Learning Publishers, London, 334 pp.
- Sneath, P.H.A. & R.R. Sokal. 1973. Numerical taxonomy. The principles and practice of numerical classification. W.H. Freeman and Company, San Francisco, 573 pp.
- Soares, I.D. & O.O. Möller Jr. 2001. Low-frequency currents and water mass spatial distribution on the southern Brazilian shelf. Cont. Shelf Res., 21: 1785-1814.
- Texeira, C., E. Aidar & R.M. Fernandez. 1973. Estudo preliminar sobre a distribuição de clorofila-a e potencial de produção primária. Relatório sobre a Segunda Pesquisa Oceanográfica e Pesqueira do Atlântico Sul entre Torres e Maldonado (Lat 29°S-35°S). Programa Rio Grande do Sul II. GEDIP e Inst. Oceanogr. Univ. São Paulo. Publ. Esp., 3(1): 1-27.
- Tokioka, T. 1979. Neritic and oceanic plankton. In: S. Van der Spoel & A.C. Pierrot-Bults (eds.). Zoogeography and diversity of plankton. Bunge Science, Publishers, Utrecht, pp. 126-143.
- Van der Spoel, S. & J.R. Dadon. 1999. Pteropoda. In: D. Boltovskoy (ed.). South Atlantic zooplankton. Backhuys Publishers Leiden, The Netherlands, pp. 649-706.

Received: 3 April 2008; Accepted: 25 August 2008