Seasonal variability of pelagic copepod assemblages on the inner continental shelf off Paraná, Brazil.

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Abstract

The abundance and composition of pelagic copepod species were studied in relation to the hydrographic regime on the shallow inner continental shelf off Paraná State, Brazil, during a 1-year cycle (August 1997 to August 1998). Zooplankton samples were estimated analyzed monthly at each of 5 stations, from 3 to 28 nautical miles from shore, using vertical tows of a 200-µm mesh net. Changes in temperature and salinity were mainly associated with the influence of the South Atlantic Central Water (SACW) during summer, causing physical stratification of the water column. Copepods were more abundant in inshore waters under tidal influence. Forty-four species of Copepoda were identified, belonging to 29 genera. *Oncaea waldemari* was the most numerous species during summer, reaching 50% of the total; and in subsequent months the commonest species were *Paracalanus* spp. and *Temora* spp. Peaks of total abundance occurred in December, April, and August 1998. Two main copepod associations were defined by a cluster analysis (Pearson-1), one with: (i) a more "oceanic" species group present found in the outer areas, and (ii) another, a coastal group comprising species typical of inner-shelf areas. Regression analysis confirmed the influence of the SACW on copepod populations.

Key words: Copepods, composition, distribution, continental shelf, Brazil, South Atlantic

Introduction

The composition and distribution of pelagic copepods as related to large-scale hydrographic features have been studied in several areas of the southern Brazilian continental shelf since the pioneering work by Björnberg (1963). However, our knowledge of the seasonal variability of these assemblages is still far from conclusive. Milstein (1979) and Pinese (1982) were among the few to describe the temporal dynamics of inshore populations of calanoid copepods off São Paulo State based on monthly sampling schemes, but they focused on two dominant species only. More recently, Lopes (1997) and Abrahão (2000) showed that weekly to daily changes in the abundance of coastal copepods and other metazooplankton taxa collected at the mouth of Paranaguá Bay, under the influence of the adjacent sea, sometimes exceeded the range of seasonal variations. These results supported the view that monthly or even shorter sampling intervals are needed to better understand the seasonal fluctuations of pelagic copepods on the Brazilian shelf (Brandini *et al.*, 1997).

Inorganic nutrient concentrations and phytoplankton standing-stocks on the inner shelf off Paraná are under the influence of two three major hydrological processes that promote the injection of new nutrients into the euphotic zone: (i) the continental runoff from adjacent estuarine systems, (ii) the horizontal advection of cold subtropical waters from the Argentinean coast, and (iii) bottom intrusions of deep, nutrient-rich waters from beyond the continental slope (Brandini, 1990). Both these processes have a strong seasonal pulse related to prevailing meteorological conditions (Castro and Miranda, 1998; Lana *et al.*, 2000). Although the influences of such physical processes on the phytoplankton distribution and productivity are relatively well known for the Paraná shelf (Brandini, 1990; Fernandes, 1992), we still do not fully understand how changes in hydrography affect the seasonal dynamics of copepod assemblages in this area. The present study investigated the seasonal and cross-shelf variations in the composition and abundance of pelagic copepods over the inner shelf off Paraná State, in relation to basic hydrographical properties.

Material and Methods

Mesozooplankton was collected simultaneously with environmental data at five sampling stations located on a transect normal to the coast, between 7 and 69 km off Praia de Leste, Paraná (Table 1).

Table 1: Location and depth of sampling stations on the continental shelf off Paraná.

Station	South Lat.	West Long.	Distance from coast (Km)	Depth (m)
1	25 80'	48 40'	7	10
2	25 87'	48 25'	19	15
3	25 98'	48 05'	37	20
4	26 07'	47 80'	51	25
5	26 17'	47 62'	69	40

Samples were collected monthly from August 1997 to August 1998. Temperature and salinity were measured in vertical profiles with a Mini STD Sensordata 202A®. Stratification indexes of temperature and salinity were estimated as the differences between the highest and lowest values on each station. Rainfall data came from an automated meteorological station located in Pontal do Sul, at the mouth of Paranaguá Bay. Water transparency was measured with a Secchi disk, and chlorophyll-a concentrations were estimated from standard depths by fluorimetry (Parsons *et al.*, 1984). Zooplankton samples were collected by vertical hauls of a 0.30-m diameter conical net fitted with a 200-µm mesh. The volume of water filtered through the net was estimated assuming 100% filtration efficiency. Samples were immediately fixed in a 4% buffered formaldehyde solution. A minimum of 300 copepods were enumerated in aliquots taken with a 5-ml Stempel pipette (Frontier, 1981). Species identification was mainly based on the studies of Bowman (1971), Björnberg (1972, 1981), Rocha (1986), Björnberg *et al.* (1994), Vega-Pérez and Bowman (1992), Bersano and Boxshall (1994), Bradford-Grieve (1999), and Bradford-Grieve *et al.* (1999). Species nomenclature and classification were based on Bradford-Grieve *et al.* (1999).

A cluster analysis was applied to the abundance data to identify copepod assemblages. Multidimensional scaling (MDS) analysis was performed to explore the main trends of variability in copepod abundance. A multiple regression analysis was run using the environmental data (temperature, salinity, stratification indexes of temperature and salinity, chlorophyll-a, and Secchi disk readings) and the scores of MDS dimensions 1 and 2, to identify the factors which most influenced copepod distribution. In addition, a 1-way ANOVA test was performed to evaluate differences in the number of species and total copepod abundance, relative to stations and sampling periods. Copepod abundances were log-transformed (ln x +1), while raw values were used in the case of environmental data. For a complete list of raw data, see Sartori (2000).

Results

Rainfall and hydrography

Total monthly rainfall varied from < 10 (June) to 374 mm (March), with higher values (> 200 mm) during the warm season (October 1997 to March 1998). Cross-shelf, vertical, and seasonal gradients of water temperature and salinity are illustrated in Fig. 1. Water column stratification was observed from November 1997 to February 1998 for both temperature and salinity, suggesting the occurrence of bottom intrusions of the South Atlantic Central Water (SACW) during warmer months (Castro and Miranda, 1998). In November 1997, when thermal stratification began, differences between surface and near-bottom temperatures were around 3°C. The highest vertical range (10°C) occurred in December 1997 and January 1998, at stations 4 and 5 (Fig. 1). Colder months (August-October 1997 and March-October 1998) were a period of vertical homogeneity. Salinity showed similar vertical trends as compared to temperature. Water transparency was higher at the outer stations than inshore, but showed no clear seasonal pattern. Chlorophyll-a concentrations varied between 0.03 and 8.7 µg.l^{-1} during the study period, with higher values at the inner stations and during summer months.

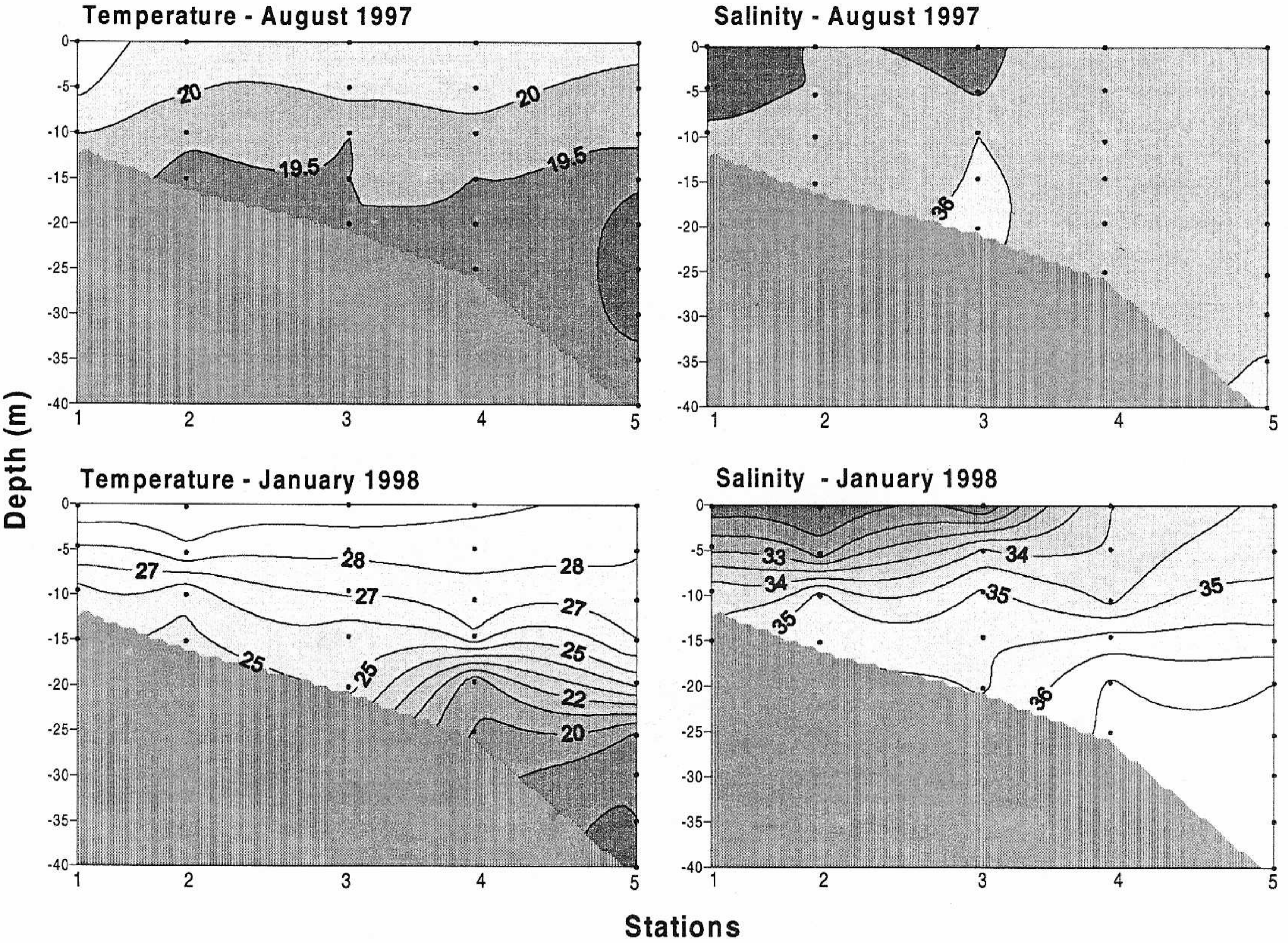

Figure 1: Vertical profiles of temperature and salinity during summer and winter over the inner continental shelf off Paraná, Brazil.

Copepod composition and abundance

We found 44 species of pelagic copepods, belonging to 4 orders and 29 genera (Table 2). Peak copepod abundances were usually found at the inner station (St. 1), with an annual maximum of 7,537 ind. m^{-3} occurring in December 1997 (Fig. 2). Lower abundances were recorded during colder months, with a minimum of 543 ind. m^{-3} at St. 2, in May 1998. The most frequent and abundant species during warm months were *Oncaea waldemari* Bersano and Boxshall, 1996; *Temora turbinata* (Dana, 1849), *Temora stylifera* (Dana, 1849), *Clausocalanus furcatus* Brady, 1883; and *Oithona plumifera* Baird, 1843. In colder months, dominant species were mainly *Parvocalanus crassirostris* (Dahl,1894); *Subeucalanus pileatus* (Giesbrecht, 1888); *Centropages velificatus* (Oliveira, 1947); and *Corycaeus amazonicus* F. Dahl, 1894. Some species, such as *Ctenocalanus vanus* Giesbrecht, 1888 and *Paracalanus quasimodo* Bowman, 1971, had a bimodal distribution, with maxima in both warm and cold months (Sartori, 2000).

Table 2: Copepod species recorded from August 1997 to August 1998 on the inner continental shelf off Paraná, Brazil; Abb. = code for each species.

Species	Abb.	Species	Abb.
Acartia danae Giesbrecht, 1889	Ada	*Macrosetella gracilis* (Dana, 1847)	Mgr
Acartia lilljeborgi Giesbrecht, 1889	Ali	*Mecynocera clausi* Thompson, 1888	Mcl
Acrocalanus longicornis Giesbrecht, 1888	Alo	*Microsetella* sp.	Msp
Calanopia americana F. Dahl, 1894	Came	*Monothula subtilis* (Giesbrecht, 1892)	Msb
Calocalanus contractus Farran, 1926	Cco	*Oithona hebes* Giesbrecht, 1891	Ohe
Calocalanus pavo (Dana, 1849)	Cpa	*Oithona nana* Giesbrecht, 1892	Ona
Calocalanus pavoninus Farran, 1936	Cpvn	*Oithona plumifera* Baird, 1843	Opl
Calocalanus styliremis Giesbrecht, 1888	Cst	*Oithona simplex* Farran, 1913	Osi
Candacia sp.	Cand	*Oncaea waldemari* Bersano and Boxshall, 1996	Owa
Centropages velificatus (Oliveira, 1947)	Cve	*Oncaea media* Giesbrecht, 1891	Ome
Clausocalanus furcatus (Brady, 1883)	Cfu	*Oncaea venusta venella* Farran, 1929	Ove
Clytemnestra rostrata (Brady, 1883)	Cro	*Paracalanus aculeatus* Giesbrecht, 1888	Pacl
Copilia mirabilis Dana, 1849	Cmi	*Paracalanus nanus* Sars, 1907	Pna
Corycaeus amazonicus F. Dahl, 1894	Cama	*Paracalanus quasimodo* Bowman, 1971	Pqu
Corycaeus giesbrechti F. Dahl, 1894	Cgi	*Paracalanus* sp.	Psp
Corycaeus speciosus Dana, 1849	Csp	*Parvocalanus crassirostris* (Dahl, 1894)	Pcr
Ctenocalanus vanus Giesbrecht, 1888	Cva	*Pontellopsis brevis* (Giesbrecht, 1889)	Pbr
Dolichocerea tenuis (Farran, 1936)	Dte	*Pseudodiaptomus acutus* (F. Dahl, 1894)	Pact
Subeucalanus pileatus (Giesbrecht, 1888)	Spi	*Sapphirina* sp.	Sap
Euterpina acutifrons (Dana, 1847)	Eac	*Temora stylifera* (Dana, 1849)	Tst
Farranula gracilis (Dana, 1853)	Fgr	*Temora turbinata* (Dana, 1849)	Ttu
Hemicyclops thalassius Vervoort and Ramírez, 1966	Hth	*Undinula vulgaris* (Dana, 1849)	Uvu

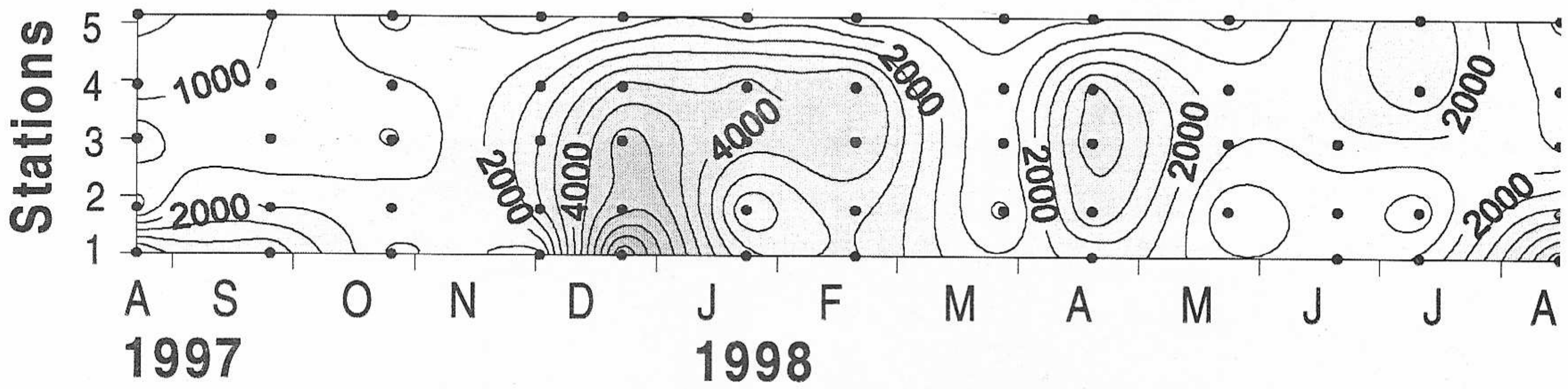

Figure 2: Total copepod abundance and distribution (ind.m-3) over the inner continental shelf off Paraná along the sampling stations between August 1997 and August 1998

Two major copepod assemblages were identified by cluster analysis, and further divided into subgroups according to their spatial and seasonal variability (Fig. 3). The abundance distribution of each subgroup along stations and months, calculated by adding each group abundance, is shown in Fig. 4. Group A combined oceanic and shelf-water species associated with the Tropical Water (TW) of the Brazil Current, and mixtures of TW, SACW, and Coastal Water (CW). Subgroups A1 and A2 were formed as a result of both seasonal and cross-shelf variabilities within the large group. *Acrocalanus longicornis* Giesbrecht, 1888; *Calocalanus contractus* Farran 1936; *Calocalanus pavo* (Dana, 1849), *Candacia* sp., *Pontellopsis brevis* (Oliveria, 1947), *Undinula vulgaris* (Dana, 1849), *Sapphirina* sp., and *Farranula gracilis* (Dana, 1853), (A1) were more abundant during warm months (November 1997 – March 1998) and at outer stations (Fig. 4). Subgroup A2 contained oceanic and shelf species which occurred in high numbers during cold months (Fig. 4), including *Monothula subtilis* (Giesbrecht, 1892) (see Böttger-Schnack and Huys, 2001); *Microsetella* sp.; *Corycaeus speciosus* Dana, 1849 and *Calocalanus pavoninus* Farran, 1936.

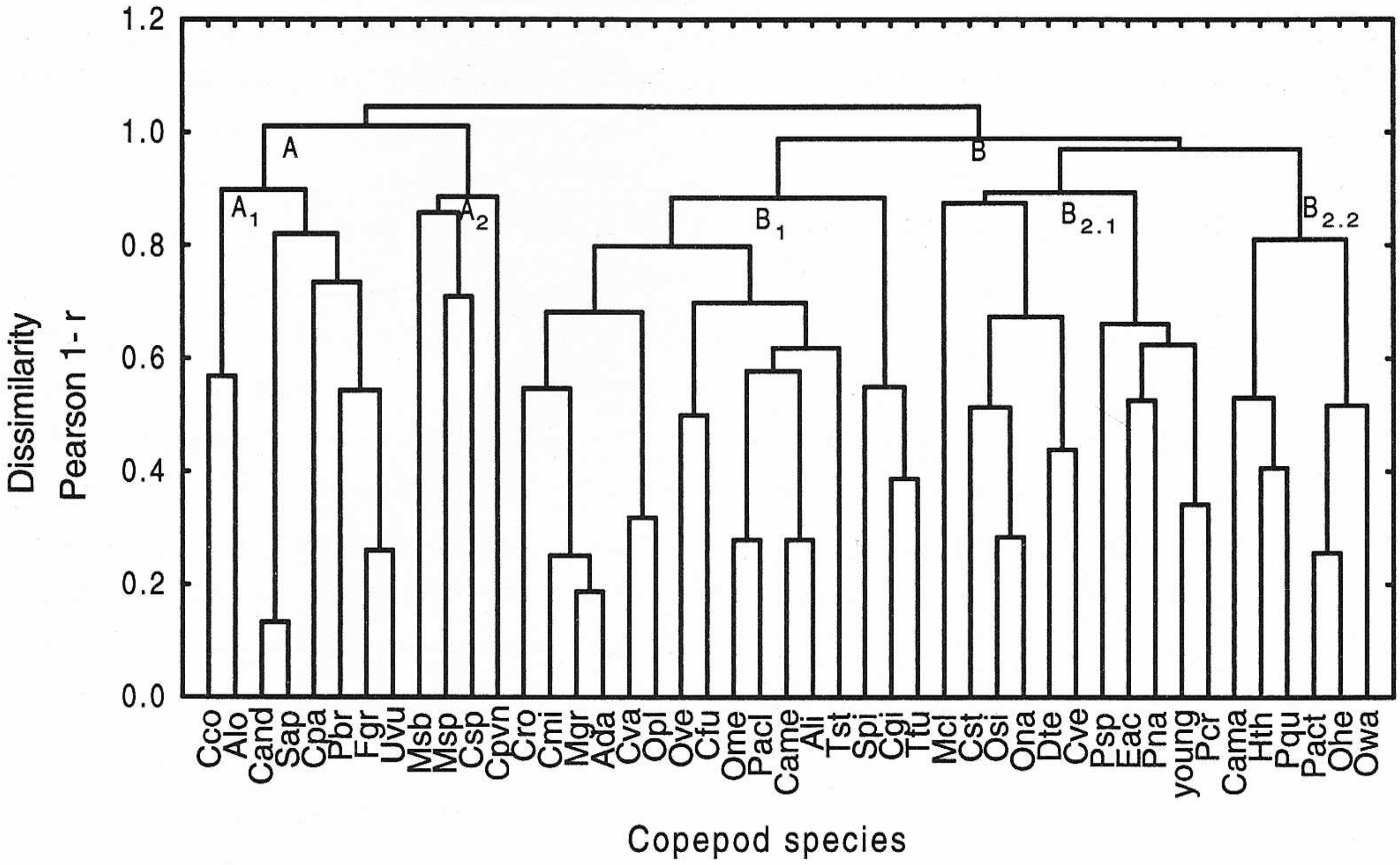

Figure 3: Dendrogram from cluster analysis (Pearson -1) of copepod species observed over the inner continental shelf off Paraná. Species codes shown in Table 2.

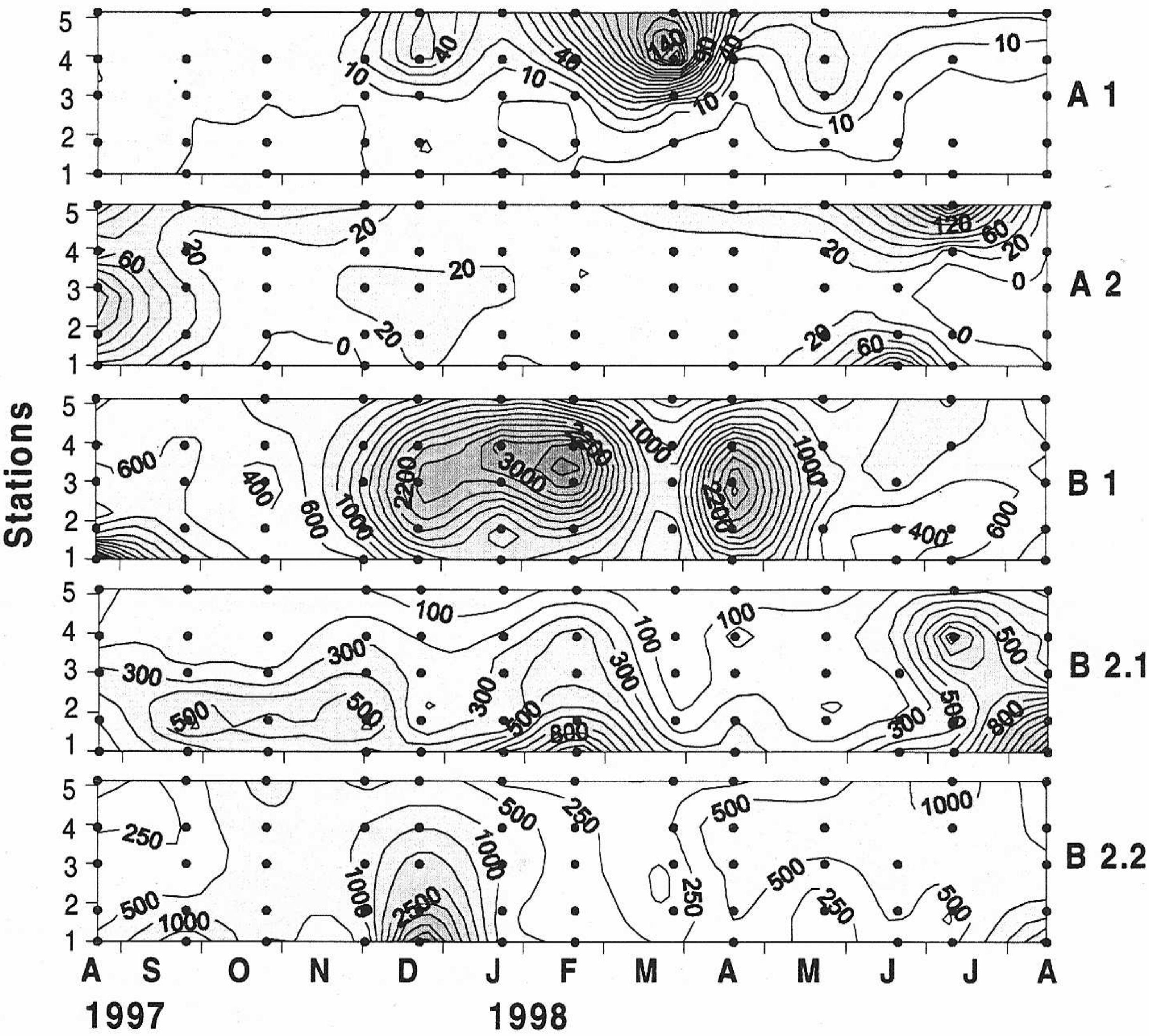

Figure 4: Distribution of the copepod groups formed on cluster analysis, along the stations over the inner continental shelf off Paraná.

Group B includes shelf and coastal (euryhaline) species, which dominated mainly at intermediate and inner stations. Subgroup B1 comprised a long list of thermophilic species which occurred mainly at intermediate stations (St. 3 - 4) during warmer months. This was the case of *Acartia danae* Giesbrecht, 1889; *C. furcatus*; *Paracalanus aculeatus* Giesbrecht, 1888; *Clytemnestra rostrata* (Brady, 1883); *Macrosetella gracilis* (Dana, 1847); *O. plumifera*; *Oncaea venusta venella* Farran, 1929; *Oncaea media* Giesbrecht, 1891 and *Copilia mirabilis* Dana, 1849, among others (Figs. 3 and 4). Subgroup B2 contained mainly coastal euryhaline species, and was further split into two additional subgroups. Subgroup B2.1 included coastal species such as *C. velificatus*; *P. crassirostris*; *Oithona nana* Giesbrecht, 1892, and *Euterpina acutifrons* (Dana,1894), which were more abundant at the inner stations. Subgroup B2.2 comprised marine-euryhaline species found throughout the transect, but with their maxima at inner stations 1 and 2. The species *P. quasimodo; Pseudodiaptomus acutus* (F. Dahl, 1894); *Oithona hebes* Giesbrech, 1891; *Corycaeus amazonicus; Hemicyclops thalassius* Vervoort and Ramirez, 1966, and *O. waldemari* belong to this subgroup. The latter was the dominant species at St. 1, in December 1997, when peak abundances were recorded for subgroup B2.2 (Fig. 4).

The cross-shelf and seasonal gradients in copepod distribution were confirmed by the results of MDS analysis (Fig. 5). Inner stations formed a separate patch on the right section of Dimension 1 (D1), whereas the observations from outer stations appeared mainly on the opposite side (Fig. 5a). The horizontal variability in species composition and distribution, as represented by D1, is depicted in Fig. 5b. The arrangement of data scores on Dimension 2 (D2) corresponds to the seasonal variability of copepod assemblages. Observations from warmer months appear on the top, and from colder months on the bottom of the panel (Fig. 5a). Species dominating in summer and winter are shown along the vertical plane (D2) of Fig. 5b.

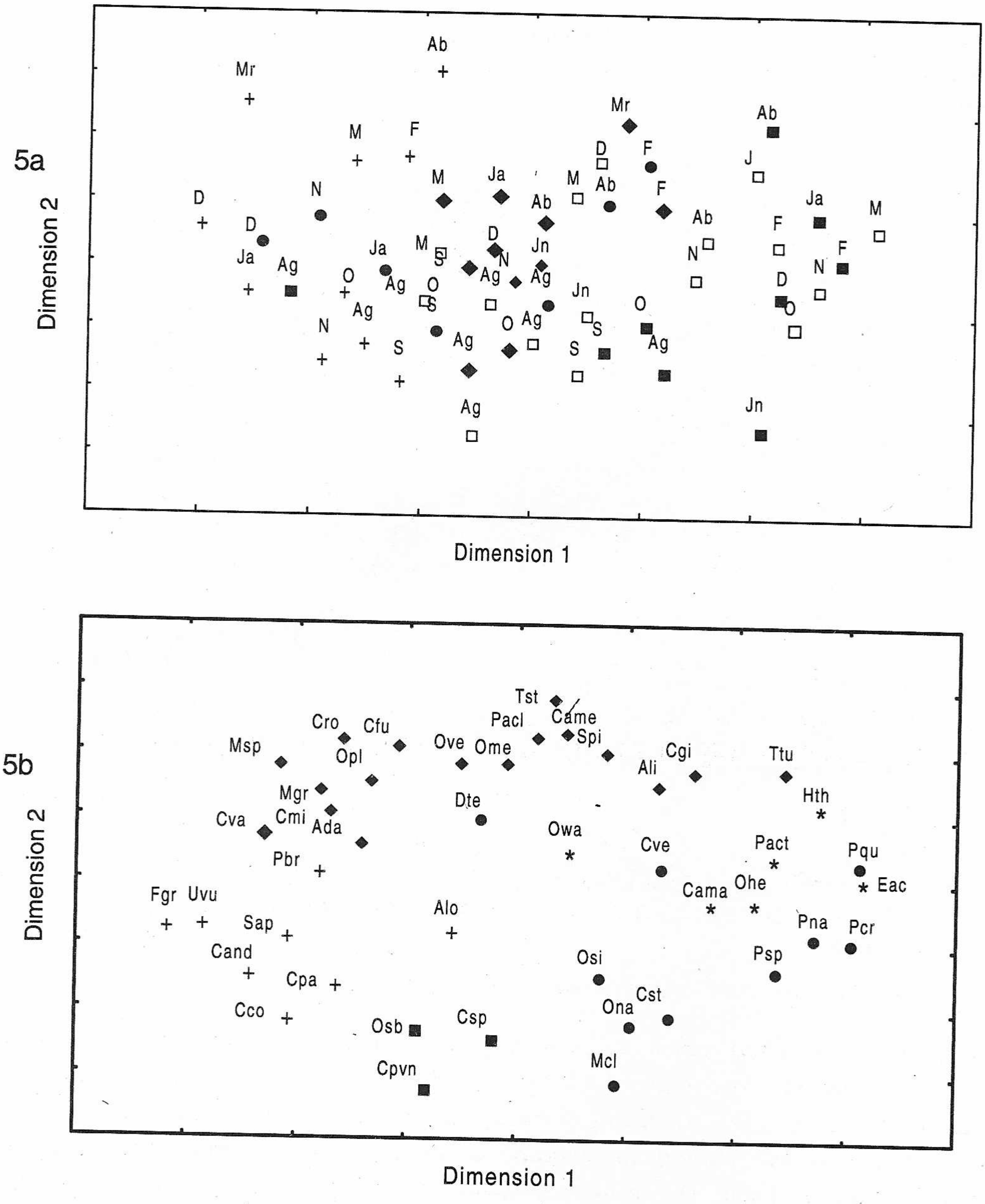

Figure 5: a) MDS analysis of sampling stations based on copepod abundance data. Symbols representing the stations- St. 1 (n); St. 2 (o); St. 3 (u); St. 4 (l); St. 5 (+); and b) MDS analysis of copepod species. Symbols representing the groups of species- A1 (+); A2 (n); B1 (u); B2.1 (l); B2.2 (*). Species codes as in Table 2.

By applying a multiple regression analysis between the MDS scores for the observations (Fig. 5a) and the available environmental data, the following picture emerges (Table 3): (i) copepod abundances at the inner stations (i.e., D1, right side of panel) were positively related to water temperature; (ii) salinity, the stratification index of temperature and salinity, as well as water transparency, were positively related to the "oceanic" copepod assemblages, from outer stations (D1, left side of panel); (iii) water temperature and transparency were positively related to the warm-water copepod assemblages (D2, upper part of panel); and (iv) the temperature stratification index was negatively related to the warm-water copepod assemblages. On an annual basis, total copepod abundance was statistically different among stations and sampling dates (Table 4). Stations 1 – 4 shared similar abundances, and only the outer station (St. 5) differed from them. Finally, two distinct seasonal periods of total copepod abundance were distinguished: warmer (December 1997, January, February, and April 1998) and colder (August – November 1997, and May – Aug 1998). Total abundances recorded in March 1998 did not fit well into any of these patterns, probably because of the entrainment of oceanic species (subgroup A1) towards St. 2 during this month (Fig. 4), which resulted in lowered copepod abundances throughout the transect (Fig. 2). Species richness did not differ either spatially or seasonally (Table 4).

Table 4: Summary of ANOVA results, comparing total copepod abundance and species richness among stations and months. §: not significant

	Stations			Months		
	F	*P*	LSD test	F	*P*	LSD test
Abundance	3.33	0.017	St.1 = St.2 = St.3 = St.4 > St.5	2.90	0.005	Aug97=Sep=Oct=Nov<Dec=Jan=Feb>Mar<Apr>May=Jun=Jul=Aug98
Richness	1.00	0.413	§	1.40	0.200	§

Discussion

Most copepod species reported here have been routinely found in other neritic and oceanic areas of the Southern Brazilian Bight (SBB) (*e.g.*, Björnberg, 1981; Vega-Pérez, 1993; Lopes *et al.*, 1999), except for *O. waldemari* and *O. v. venella* which were reported only recently in the region (Bersano and Boxshall, 1994). The number of copepod species (44 recorded) on the inner shelf off Paraná was lower than reported in other studies carried out in nearby, deeper areas (e.g., Vega-Pérez, 1993; Montú *et al.*, 1999). This is because the core of the Brazil Current occurs further offshore than the position of our outer station (Castro and Miranda, 1998), and rare and even subdominant copepod species belonging to the tropical oceanic assemblages (Björnberg, 1981) were not detected in our samples. Therefore, our "oceanic" assemblage (Group A of cluster analysis) actually represents a transitional group, as reported by Oliveira (1999) for the same shelf area.

The fine-scale interval among stations along the transect allowed us to identify two major copepod assemblages with affinities for oceanic/transitional areas (Group A, St. 4 – 5) and coastal environments (Group B, St. 1 – 3). Species belonging to the coastal assemblage (Group B) reached higher abundances than Group A. This cross-shelf gradient in copepod composition and abundance has been well documented for the SBB (e.g., Campaner, 1985; Vega-Pérez, 1993; Dias, 1995; Lopes *et al.*, 1999), and closely follows the hydrographical contrasts between the Coastal Water (CW) inshore, and the Tropical Water (TW) of the Brazil Current offshore. The TW supports a regenerative plankton community with low biomass levels of both phytoplankton (Brandini, 1990) and zooplankton (Hubold, 1980). On the other hand, the CW carries high plankton standing-stocks thanks to the nutrient input from estuarine systems, such as Paranaguá Bay (Brandini *et al.*, 1988). Tidal pumping and other physical mechanisms may allow coastal copepod populations to remain within food-rich, shallow environments, while transitional (mid-shelf) populations such as those reported here (Group A) probably suffer high advective losses from offshore transport.

In addition to the cross-shelf gradients, our results confirmed previous findings that temporal changes in copepod distribution are strongly regulated by seasonal meteorological and circulation processes. Total copepod abundances were usually higher during warm than in colder periods, but secondary abundance peaks also occurred in winter (Figs. 1 and 3). During warm months, coastal assemblages reached peak numbers, a likely result of the enhanced nutrient load (and hence high primary productivity) from adjacent estuarine systems due to the heavy summer rains (Lopes *et al.*, 1998). Meanwhile, copepod populations from the outer stations seemed to benefit from bottom intrusions of the nutrient-rich SACW, which are more frequent during summer (Castro and Miranda, 1998), as found here as well (Fig. 1). The relationship between stratification indexes and "transitional" assemblages in outer stations during warm periods, as shown by regression analysis, further confirms the influence of the SACW on copepod populations. The abundance peaks found in wintertime might be attributed to another enrichment process, i.e., the advection of subtropical coastal waters from the La Plata estuarine area towards the Paraná shelf. This water mass contains high nutrient levels and may be responsible for increased chlorophyll concentrations in the southern sectors of the SBB during winter (Brandini, 1990; Brandini *et al.*, 1997).

In summary, the present study reports strong cross-shelf and seasonal variations in copepod composition and abundance during a one-year cycle off Paraná State, a shelf area belonging to the SBB domain. The opportunity to follow a monthly sampling schedule along a transect representative of inner- and mid-shelf conditions, allowed us to unravel some basic seasonal patterns in copepod distribution, such as the following: (i) the abundance maxima recorded during the warm season, associated with thermophilic species (group B, and especially subgroup B1), remain stable for at least 3 months (December – February); (ii) short-term changes in copepod abundance may be associated with advection processes (e.g., the entrainment of "transitional" species towards the inner shelf during March 1998); (iii) copepod assemblages from the southern area of the SBB are likely influenced by a bimodal pulse in nutrient enrichment and biological production events, related to the bottom intrusions of SACW (together with the enhanced continental drainage) during warm periods, and the advection of cold waters from the coast of Uruguay and Argentina during winter (Brandini, 1990).

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