ZOOPLANKTON BIOMASS, ABUNDANCE AND DIVERSITY IN A SHELF AREA OF PORTUGAL (THE BERLENGA MARINE NATURAL RESERVE).

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During November 1997 and May 1998, zooplankton samples were collected with other environmental data along the shelf area of Berlenga marine natural reserve (MNR) (NW Portugal). Copepods contributed > 70 % to the total zooplankton community. In November the dominant species of copepods were *Paracalanus parvus*, *Temora stylifera* and *Centropages chierchiae* with larvaceans and the cladocerans *Penilia avirostris* also abundant. The meroplankton was dominated by echinoderms. In May the dominant species of copepods were *Pseudocalanus elongatus* and *Acartia clausi*, *Centropages typicus*, and *Calanus helgolandicus*, with barnacle larvae and the pisces larvae also abundant. The islands influence was represented in the results by the increase in diversity and meroplankton's relative importance at the sampling stations in the vicinity of the islands.

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INTRODUCTION

Marine Natural Reserves (MNR) are a way of conserving particularly important marine habitats and wildlife, and other features along the shore or on the seabed. A valuable contribution that an MNR can make to the protection of our seas is to create an awareness of the value and fragility of the natural marine heritage. It is also a place to monitor changes in the general "health" of the sea and thus give early warnings of serious threats.

The Berlenga MNR, established in 1981 in west Portugal, has an extraordinarily wide range of marine plants and animals within a comparatively small area. This gives the area particular value for study and education and creates many opportunities to give visitors and local people an understanding of the Reserves´ special interest and the importance of conserving its hidden wealth for the future. The Berlenga Archipelago is located 5.7 miles northwest of Cape Carvoeiro and comprises three groups of small islands: Berlenga Grande, Estelas and Farilhões. This geographical location gives singular characteristics to the archipelago, which enhanced the interest of ecological studies, because it is influenced by two different climatic conditions: the Atlantic, in the northern cliffs and the Mediterranean climate in the southern cliffs.

In this paper we analyse the distribution and composition of zooplankton during cruises in November 1997 and May 1998 from 19 stations along the Berlenga shelf area.

The first studies on the Portuguese shelf zooplankton begin with ALVARIÑO (1957) and BOUCHER et al. (1983) and to date the only studies on Berlenga MNR have been undertaken by AZEITEIRO et al. (1997).

Marine reserves are important in the protection of biodiversity and providing areas free from direct human disturbance, acting as reference areas for the study of natural processes in the environment. The objective of this work is to have a reference study for the natural reserve.

MATERIAL & METHODS

A series of stations were made in November 1997 and in May 1998 perpendicular to the coastline (between the Peniche coast and Berlenga islands) and both to the NW and South of the Berlenga MNR (Fig. 1). At each station (within a depth range of 11 to 200 m) hydrographical data (temperature, salinity, oxygen, transparency, phosphates, silica, ammonia, nitrates and nitrites) and biological data (chlorophyll a and zooplankton abundance and biomass) were collected. Zooplankton were sampled with a 200 and 335 μm mesh 60 cm opening Bongo net. The use of the two nets followed the methodology adopted by CUNHA (1993 a, b) studying the seasonal and spatial variation of the zooplankton biomass in relation to the hydrographic conditions of the Portuguese coast. The volume of the water strained for each net was determined using calibrated flowmeters. Samples were collected in standard oblique tows as described by SMITH & RICHARDSON (1977) and OMORI & IKEDA (1984). Each zooplankton sample was subsampled by taking aliquots that were sufficiently large to provide several hundred organisms for counting (*e.g.* OMORI & IKEDA 1984; KIMMERER et al. 1985; GAUGHAN & POTTER 1995). The numbers of each taxon were converted to densities, i.e. numbers m^{-3}. Total zooplankton biomass (AFDW gm^{-3}) was determined as described by EDMONDSON & WINBERG (1971). Organisms were identified to the species level when possible. Diversity was calculated using the Margalef diversity index (MAGURRAN 1988).

After the biological sampling, temperature, salinity, dissolved oxygen, Secchi transparency and pH were measured *in situ*. Seawater samples were collected for the measurements of nutrients and chlorophyll *a* according to the methods described by STRICKLAND & PARSONS (1968).

RESULTS

Except for sampling stations S2 and S3 temperature values were always higher in November 1997 than in May 1998. The pattern of variation in salinity was the same for both months. Stations S1, S2 and S3 showed the lowest values. With the exception of sampling station S2 dissolved oxygen values were always higher in November 1997 than in May 1998. Secchi transparency measures exhibited the lowest values in stations S9, S11 and S18, North and South Berlenga islands and in May 1998. Phosphates showed the highest values for both months at the coastal stations. Except for sampling stations S6, S9 and S15 silica concentration was always higher in May 1998 than in November 1997. Ammonia presented higher concentration values in November 1997 than in May 1998. The two peaks in ammonia concentration occurred both North of the Berlenga and Farilhões islands (sampling stations S11 and S15). Nitrites showed the highest concentration values in the vicinity of the Berlengas islands and Peniche and both in May 1998. Nitrates presented the highest values at the vicinity of the coast and in May 1998. Without exception chorophyll *a* concentration values were higher in May 1998 than in November 1997 (Fig. 2).

The zooplankton abundance and biomass in November 1997 was high over a broad band (offshore) between the coastline and the Berlenga islands and offshore (Fig. 3). The zooplankton abundance and biomass pattern were not so clear for the > 335 μm fraction and > 200 μm fraction in May 1998. The abundance and biomass of the smaller organisms (> 200 μm fraction) was higher than the larger (> 335 μm fraction) for both months (Fig. 3). Zooplankton biomass exhibited a similar pattern to abundance.

In May 1998 the diversity index (Fig. 4) was higher than in November 1997 for both cruises. This index was highest at the 335 μm fraction. The diversity values peaked, generally, in the vicinity of the islands.

In November 1997 and May 1998, holoplankton averaged 90.44% and 86.83%, respectively, of the zooplankton sampled (Table 1). In November 1997 the meroplankton was dominated by echinoderms (echinopluteus and ophiopluteus). In May 1998 meroplankton was dominated by barnacle larvae (cyprid and nauplii), fish eggs and larvae. In both fractions holoplankton was more abundant than meroplankton (Table 1), and more abundant at the sampling stations immediately south of the

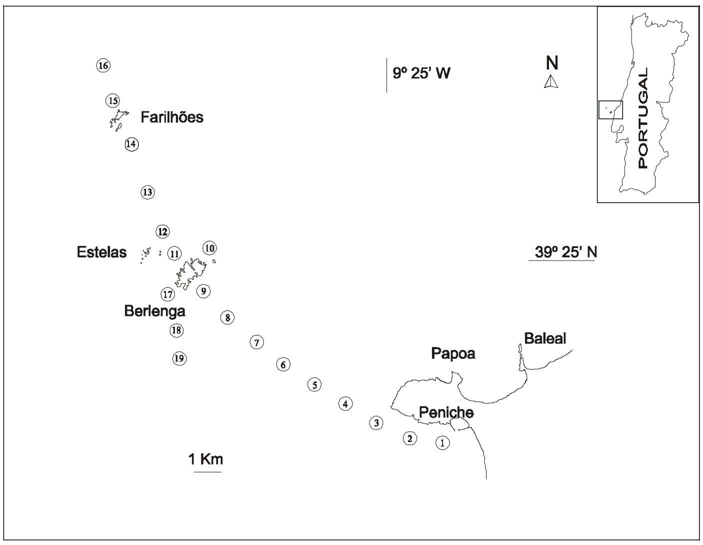

Fig. 1. Locations of sampling stations.

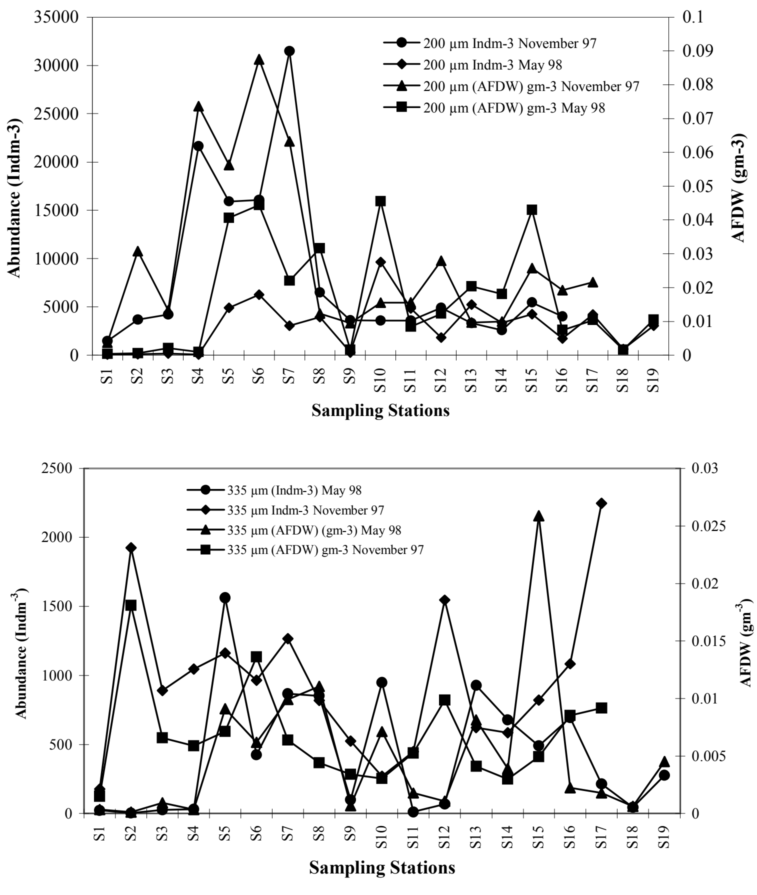

Fig. 3. Zooplankton density and biomass distribution in both fractions in the sampled area during both cruises.

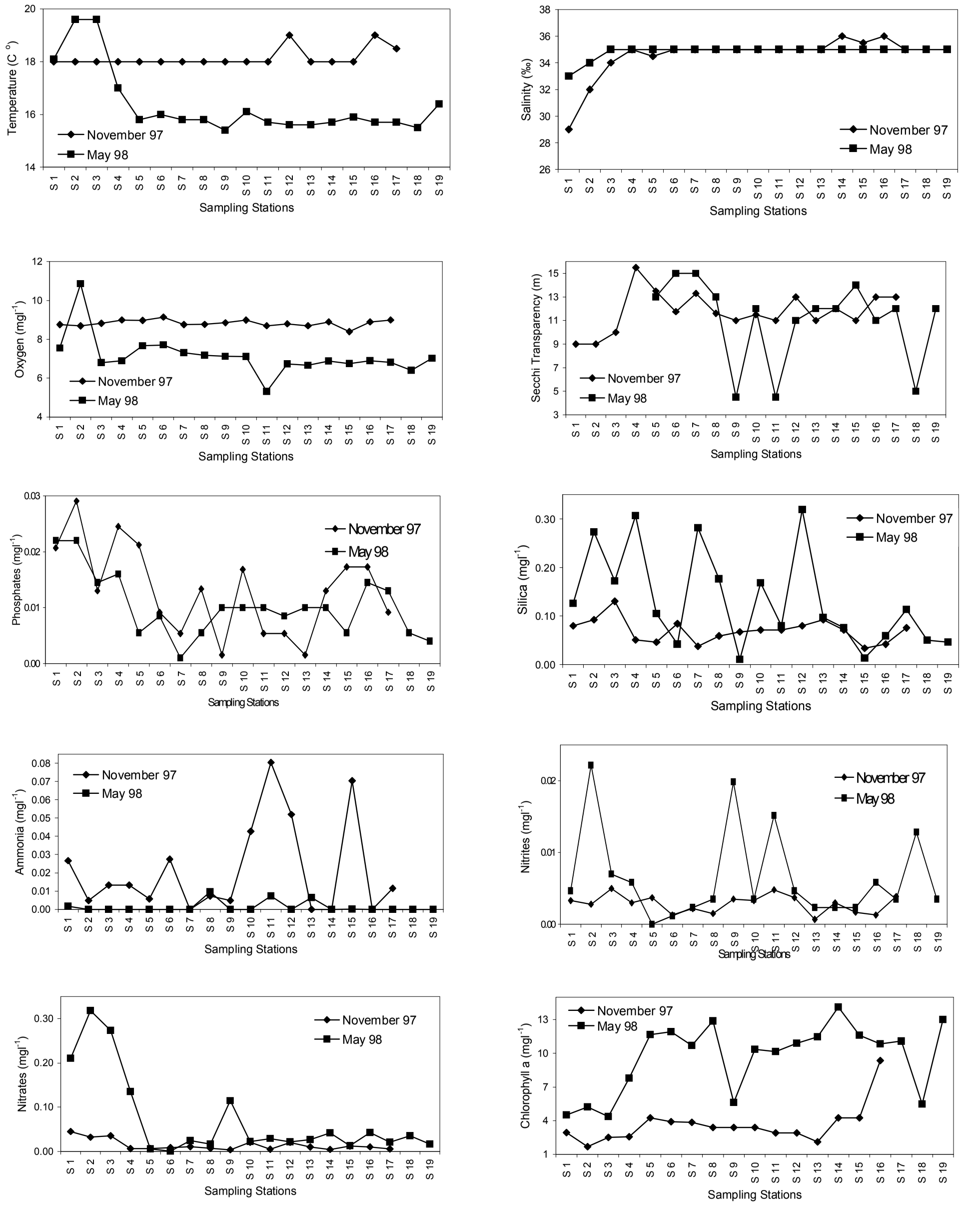

Fig. 2. Spatial variation of physical and chemical parameters for each period of sampling.

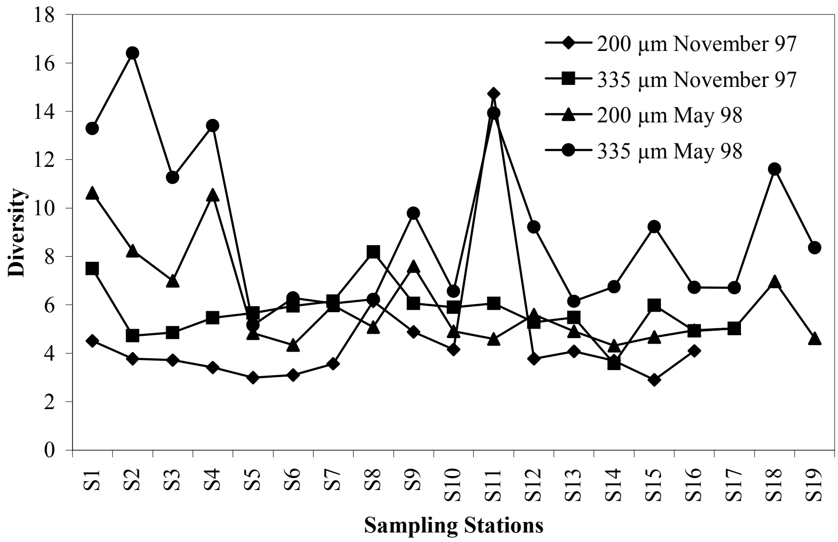

Fig. 4. Diversity index distribution in the sampled area for both cruises and both fractions.

islands. The contribution of the meroplanktonic forms was important mainly in the > 335 µm fraction (Table 1). Within the meroplankton we also found molluscs (gastropod and bivalve veliger and post-veliger), polychaetes (mainly Spionidae and crab zoeae (anomuran, *Pisidia longicornis*; brachyuran and others, mainly *Ebalia* sp.). Given the narrow time period for reproduction of the various benthic invertebrates, their presence in the meroplankton varied between November 1997 and May 1998. Echinoderm larvae, primarily distributed in the vicinity of the islands, were more abundant in November 1997 than in May 1998. In contrast, barnacle and fish larvae increased in numbers from November 1997 to May 1998 (Figs. 5 and 6). In November 1997 Copepoda and Cladocera were the most abundant groups (Fig. 5). In the copepods (Figs. 7 and 8), the most represented group, the species *Paracalanus parvus*, *Temora stylifera*, *Centropages chierchiae*, *Clausocalanus* sp. (*arcuicornis* c.f.), *Acartia clausi*, *Oithona* spp., and *Oncaea media* were present at all sampling stations. In the cladocerans the species *Penilia avirostris*, *Evadne spinifera* and *Podon* spp., were present at all sampling stations. The appendicularians (mainly *Oikopleura dioica*) and the chaetognaths (predominantly *Sagitta friderici*) were well represented groups. In May 1998, Copepoda and Cirripedia were the most abundant groups (Fig. 6). Among the copepods (Figs. 7 and 8), which was the most represented group, the species *Pseucalanus elongatus*, *Acartia clausi* and *Calanus helgolandicus* were present at all sampling stations.

Table 1.
Percent abundances of holoplankton and meroplankton for both cruises and fractions.

	200 µm		335 µm	
	Holo	Mero	Holo	Mero
November 97	91.84	8.16	89.04	10.96
May 98	92.97	7.03	80.69	19.31

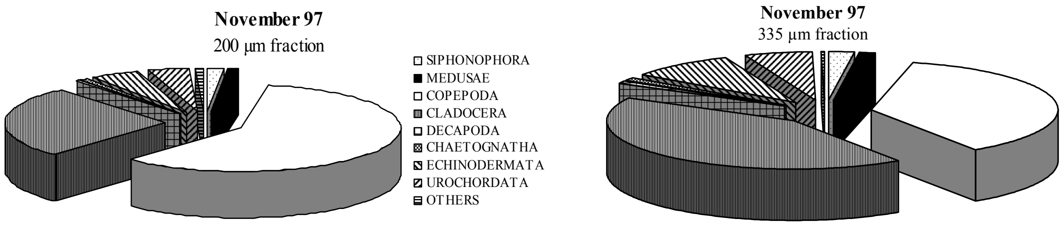

Fig. 5. Percent composition of zooplankton groups in November 97 cruise for both fractions.

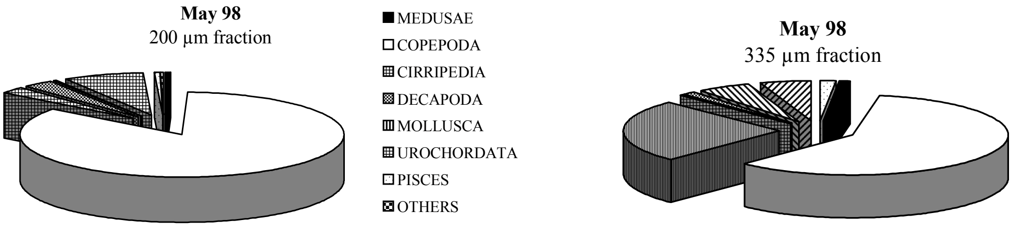

Fig. 6. Percent composition of zooplankton groups in May 98 cruise for both fractions.

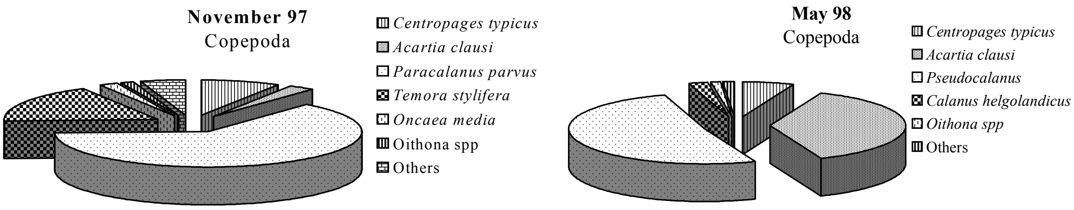

Fig. 7. Percent composition of the copepod group for both cruises.

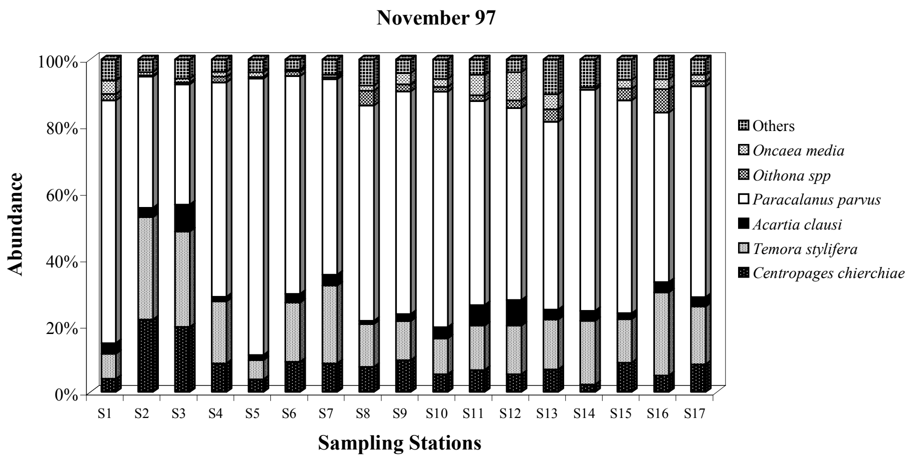

Fig. 8. Percent composition of copepod assemblages in the sampled area during both cruises.

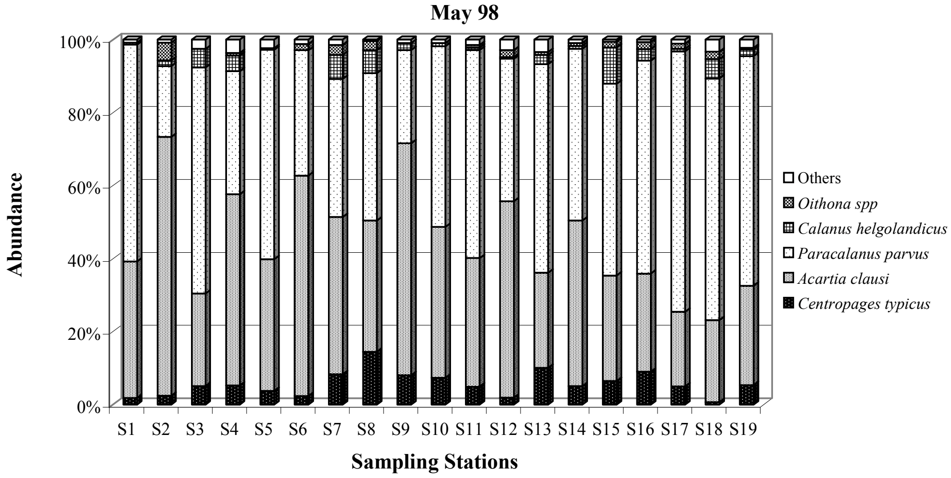

Fig. 8 (cont). Percent composition of copepod assemblages in the sampled area during both cruises.

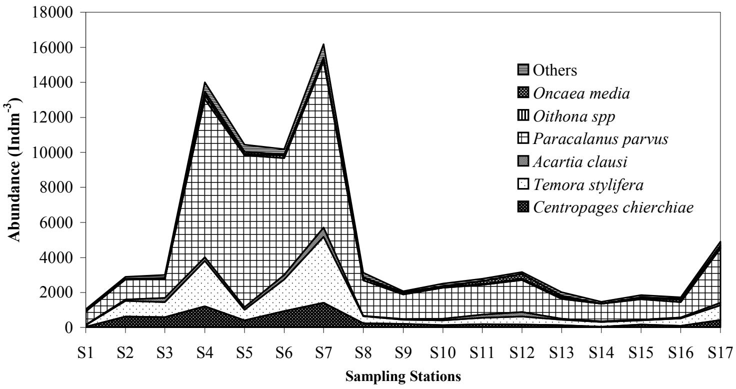

Fig. 9. Abundance of copepod assemblages in the sampled area in November 1997.

DISCUSSION

The evolution of the zooplankton biomass strained by the 200 µm and 335 µm sieves shows that the biomass strained by the 200 µm sieve was always higher than that retained by the 335 µm: this means that the contribution of the smaller species, which in general are herbivore or omnivore, is higher. The zooplankton production cycle of the Portuguese coast is characterised by the maintenance of relatively high production levels during spring and autumn months only diminishing in the winter months (CUNHA 1993 a, b). The holoplankton dominated over the meroplankton. The holoplankton copepods, and cladocerans were the dominant groups in November 1997. Copepods and cladocerans normally dominate the zooplankton assemblages (OMORI & IKEDA 1984). The meroplankton was dominated by different meroplanktonic species in November 1997 and May 1998. The November high abundances of echinoderms were replaced by the May high abundances of barnacle larvae. This temporal distribution reflects the life cycles of the different species (NETO 1999; METELO 2000). The use of the 335 µm net allowed a better characterization of the meroplanktonic fraction and explains the differences in biomass, abundance and diversity between the sampling nets. The differences in nutritional conditions and the differences in temporal variation of the meroplankton contribute to explain the differences in biomass, abundance and diversity between November 1997 and May 1998. Holoplankton and meroplankton distribution was comparable to other Atlantic studies (WILLIAMS & COLLINS 1986; VALDES et al. 1990). Also, the relationship between the diversity index values distribution pattern and meroplankton abundance was comparable to other studies (VALDES et al. 1990).

The Portuguese coast hydrography and pelagic ecology are seasonal and influenced by the coastal morphology and shelf topography. Upwelling patterns of Portugal coast are also determined by the coastal morphology and the shelf/upper slope topography. Winds along the Portuguese coast are monsoonal. During winter (November-February) the winds are most frequently from the Southwest, while in summer (March-October) they are mainly upwelling producing winds from the north. Winter winds from the Southwest, which produce surface flow from the south and toward the shore, alternate with summer winds from the north, which produce flow from the north and away from shore, generating coastal upwelling from March-April through October-November. During this period, Ekman transport is offshore and the upper layer flow to the south. These seasonal changes in the currents flowing along the Portuguese coast and the different upwelling patterns originated by differences in the shelf topography may cause changes in phytoplankton and zooplankton species and standing crops. In this study we have found seasonal composition differences in the species assemblages that can be explained by the differences in nutritional conditions and with the annual development of main predators, suggesting direct evidence of food limitation and a possible control of the zooplankton by predator pressure. A certain regulation of omnivorous zooplankton by carnivorous zooplankton has been reported in inshore areas (LUCAS et al. 1997). Fish populations have also been implied in order to explain changes in the composition of zooplankton (FULTON 1984). The differences in meroplankton can be explained by the different life cycles of the species. Given the narrow time period for reproduction of the various benthic invertebrates, their presence in the meroplankton varied between November 1997 and May 1998 (NETO 1999; METELO 2000). There was a difference in total zooplankton abundance between the sampling stations. It is likely that the horizontal distribution of zooplankton is related to the coast hydrography. Plotting the copepod species assemblages in November 1997, the high abundance in stations 4 to 8 was due to the presence of *Centropages* spp., *Temora* spp., and *Paracalanus parvus* (Fig. 9). We hope to clarify this ecological preference in further studies.

The ecological and biogeographical distribution of the species is in accordance with other studies (VALIELA 1995). The majority of species observed in the area were typical constituents of the North Atlantic zooplankton: *Temora longicornis*, *T. spinifera*, *Acartia clausi*, *Pseudocalanus elongatus*, *Centropages* spp, *Paracalanus parvus*, *Oithona* spp., *Calanus helgolandicus*, *Podon* spp. *Evadne* spp., *Penilia avirostris*, *Oikopleura dioica*, *Sagitta* spp. (FRANSZ et al. 1991). In terms of geographical distribution, the dominant species, mainly neritic, have been recorded from subtropical or warm temperate areas, in the Mediterranean basin (LAKKIS 1971, 1990), on the Atlantic Coast of USA (MALLIN 1991) and in the Atlantic (ALVAREZ-OSSÓRIO 1984; VALDES et al. 1990; D`ELBÉE 1993; AZEITEIRO et al. 1997).

We can compare the copepod species assemblages in this study with earlier works from the Atlantic (ALVAREZ-OSSORIO 1984; VALDES et al. 1990). The more abundant species from our samples were comparable to these studies.

The zooplankton cycle, best illustrated by the dominance of *Paracalanus parvus* and the occurrence of *Temora stylifera* and *Oncaea media* in November 1997 and the dominance of *Pseudocalanus elongatus* and *Acartia clausi* and the occurrence of *Calanus helgolandicus* in May 1998, with some variation, can be seen in other areas (ROFF et al. 1988).

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