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Acta Oecologica 24 (2003) S163–S173
ACTA OECOLOGICA
INTERNATIONAL JOURNAL OF ECOLOGY
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Original article

# Zooplankton distribution in a temperate estuary (Mondego estuary southern arm: Western Portugal)

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**Abstract**

The composition and spatio-temporal distribution of zooplankton abundance and diversity were studied monthly from July 1999 to June 2000 in the southern arm of the Mondego estuarine system (Western Portugal). Two sampling stations with different salinity conditions were selected. Zooplankton samples were obtained using 63 and 125 μm mesh nets. In both taxocenosis densities were higher in autumn and late spring-summer with copepodits and adult copepods among the most abundant zooplankters, representing more than 90.0% of the total densities. Abundance increased with increasing temperature, salinity and chlorophyll *a* values. The most abundant species were *Oithona nana*, *Acartia tonsa*, *Acartia clausi*, *Euterpina acutifrons*, *Oithona similis*, *Temora longicornis*, *Clausocalanus arcuicornis*, *Paracalanus parvus*, and *Acartia bifilosa* var. *inermis*. In the 63 μm taxocenosis, diversity was higher closest to the mouth of the estuary, during late spring and summer, and in the inner estuary, during autumn and winter. Cluster analysis showed that spatial distribution dominated over seasonal patterns, i.e. the similarities between the clusters grouping the samples of different months is high, which was also confirmed by ANOVA analysis.


*Keywords:* Zooplankton distribution; Seasonal changes; Mondego River estuary

## 1. Introduction

Life histories of zooplankters are related to environmental factors. Fluctuations of these factors are more pronounced and complex in estuaries, since there, the combination of land and ocean influences is stronger. Hence, the study of the spatial and temporal variability of estuarine zooplankton communities becomes important for a better understanding of the functioning of coastal ecosystems (Siokou-Frangou, 1996). This knowledge (variability of the zooplankton communities and the environmental preferences of its constituents) can help predict the effects of changes, whether man induced or not (Soetaert and Rijswijk, 1993). Recent studies in the Mondego southern arm estuarine system with respect to zooplankton only dealt with the spatial and seasonal distributions of meso- and macrozooplanktonic communities (Azeiteiro et al., 1999, 2000). It is essential to consider the smaller components of the planktonic food web, which comprise a substantial fraction in the aquatic systems, in order to understand their influence on the functioning of the planktonic aquatic food web (as a whole or when the different compartments are considered).

The aim of this study was to know the composition and estimate the abundance, diversity and distribution of the smaller components of zooplankton (63 and 125 μm taxocenosis assemblages), such as copepod nauplii and copepodits, in the Mondego southern arm of the estuary.

## 2. Materials and methods

### 2.1. Study site

The hydrological basin of the Mondego, with an area of 6670 km$^2$, provides an average discharge of $8.5 \times 10^9$m$^3$ s$^{-1}$. The estuary, located in the Portuguese west coast (40°08 N, 8°50 W), has an area of 3.3 km$^2$ and a volume of 0.0075 km$^3$. The circulation in the southern arm of the estuary (where the sampling stations were located) depends on the tides and, in much smaller amount on the freshwater discharge from a

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DOI: 10.1016/S1146-609X(03)00038-9

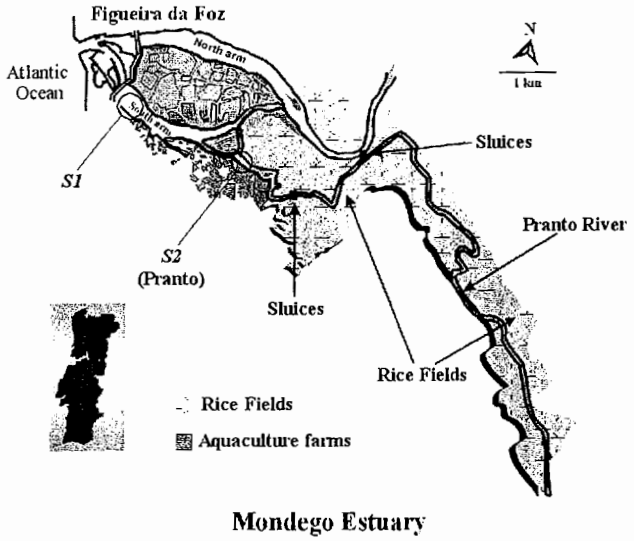


Fig. 1. Mondego River estuary, showing locations of sampling stations 1 ($S_1$) and 2 ($S_2$).

tributary—the Pranto River, controlled by a sluice (3 km from the confluence with the Mondego River) (Azeiteiro, 1999). Two stations were established, station 1 ($S_1$) nearer to the ocean and station 2 ($S_2$) in the Pranto River (Fig. 1).

### 2.2. Sampling programme

Samples were collected monthly at the two stations from July 1999 to June 2000, at the sub-surface level, during high spring tides, using 63 and 125 μm mesh size nets and preserved in 4% buffered formaldehyde. The quantitative tows were made at constant velocity (2 knots) for 1 and 2 min, respectively. Measurements of salinity, temperature, dissolved oxygen and pH were always taken. Water samples were collected for posterior determination of nitrite, nitrate, ammonia, phosphorus and chlorophyll *a* concentrations.

### 2.3. Laboratory procedures

In the laboratory, organisms were identified to species level, when possible, and counted; all the densities are presented as number of individuals per cubic meter (ind. $m^{-3}$). Nitrite, nitrate, ammonia, phosphorus and chlorophyll *a* concentrations were determined following the methods described by Strickland and Parsons (1972).

### 2.4. Data analysis

Multivariate regression analysis (Zar, 1984) was applied to find an explanatory model for the 63 and 125 μm taxocenosis distribution in relation to the environmental variables. A two-way analysis of variance (ANOVA) was used to test the differences between sampling stations and months of the year, for the most important *taxa*. All the samples collected in each sampling moment were considered replicates. Prior to analysis, data were subjected to a logarithmic transformation, in order to achieve parametric analysis requirements (Zar, 1984). Diversity ($H$) and evenness ($J$) were calculated using the Shannon-Wiener diversity index (Washington, 1984).

The biological data were analysed by cluster analysis of taxa performed by the UPGMA method, using Pearson's correlation coefficient (Legendre and Legendre, 1979).

## 3. Results

### 3.1. Environmental parameter distribution

The environmental parameters over the 11-month study (July 1999-June 2000) are shown in Table 1.

In sampling station 1, the average temperature was 16.1 °C, varying between 20.0 °C in August, 2000 and 11.8 °C in December, 1999. Salinity varied along the annual cycle between a minimum of 17.9‰ in December, 1999 and a maximum of 31.7‰ in April, 2000, with an annual average value of about 25.5‰. pH suffered a slight fluctuation during the year varying between a maximum of 7.5 and a minimum of 8.3, rounding off to an average of 7.9. The dissolved oxygen levels presented a minimum of 66.0% in June, 2000 and a maximum of 99.4% in February, 2000, with an annual average value of about 83.3%. $NO_2^-$ varied between 0.012 mg $l^{-1}$ in June, 2000 and 0.005 mg $l^{-1}$ in December, 1999 and January, 2000 with an average value of 0.007 mg $l^{-1}$. $NO_3^-$ varied between 0.178 mg $l^{-1}$ in May, 2000 and 0.051 mg $l^{-1}$ in September, 1999, with an average value of 0.102 mg $l^{-1}$.

Table 1
Environmental data (temperature, salinity, pH, oxygen dissolved-saturation%, $NO_2^-$, $NO_3^-$, $NH_3$, $PO_4^{3-}$ and chlorophyll *a* values) from monthly annual sampling cycle in the southern arm of the Mondego estuary, in both sampling stations, between July 1999 and June 2000

| | July | | August | | September | | October | | November | | December | | January | | February | | March | | April | | May | | June | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $S_1$ | $S_2$ | $S_1$ | $S_2$ | $S_1$ | $S_2$ | $S_1$ | $S_2$ | $S_1$ | $S_2$ | $S_1$ | $S_2$ | $S_1$ | $S_2$ | $S_1$ | $S_2$ | $S_1$ | $S_2$ | $S_1$ | $S_2$ | $S_1$ | $S_2$ | $S_1$ | $S_2$ |
| Temperature (°C) | 18.9 | 23.6 | 20.0 | 25.0 | 19.1 | 20.7 | 16.9 | 19.6 | 16.8 | 16.6 | 11.8 | 13.2 | 11.9 | 11.0 | 14.1 | 14.1 | – | – | 14.2 | 14.0 | 15.8 | 18.3 | 18.0 | 22.3 |
| Salinity (‰) | 24.5 | 18.1 | 23.0 | 26.0 | 25.0 | 31.0 | 27.0 | 22.0 | 31.1 | 19.5 | 17.9 | 29.3 | 23.2 | 23.2 | 29.7 | 29.4 | – | – | 31.7 | 9.5 | 21.1 | 12.0 | 26.1 | 10.1 |
| pH | 8.2 | 7.9 | 8.1 | 7.6 | 8.3 | 8.3 | 7.6 | 8.3 | 7.9 | 7.5 | 7.8 | 8.4 | 7.8 | 7.9 | 7.9 | 7.6 | – | – | 7.5 | 7.6 | 7.7 | 7.6 | 8.2 | 8.3 |
| % $DO_2$ | 80.0 | 72.0 | 94.0 | 85.0 | 86.0 | 48.0 | 80.5 | 60.0 | 68.4 | 48.0 | 69.5 | 79.0 | 89.5 | 91.0 | 99.4 | 72.4 | – | – | 85.0 | 74.0 | 97.4 | 75.2 | 66.0 | 59.0 |
| $NO_2$(mg $l^{-1}$) | 0.006 | 0.007 | 0.006 | 0.016 | 0.006 | 0.026 | 0.009 | 0.036 | 0.007 | 0.048 | 0.005 | 0.060 | 0.005 | 0.006 | 0.008 | 0.055 | – | – | 0.008 | 0.042 | 0.007 | 0.028 | 0.012 | 0.071 |
| $NO_3$(mg $l^{-1}$) | 0.065 | 0.031 | 0.058 | 0.033 | 0.051 | 0.035 | 0.085 | 0.076 | 0.073 | 0.106 | 0.061 | 0.135 | 0.129 | 0.193 | 0.164 | 0.163 | – | – | 0.171 | 0.274 | 0.178 | 0.384 | 0.091 | 0.177 |
| $NH_3$(mg $l^{-1}$) | 0.002 | 0.113 | 0.008 | 0.173 | 0.015 | 0.233 | 0.003 | 0.181 | 0.007 | 0.172 | 0.010 | 0.163 | 0.032 | 0.034 | 0.045 | 0.188 | – | – | 0.040 | 0.189 | 0.034 | 0.191 | 0.093 | 0.370 |
| $PO_4$(mg $l^{-1}$) | 0.004 | 0.007 | 0.004 | 0.008 | 0.004 | 0.008 | 0.003 | 0.007 | 0.003 | 0.007 | 0.003 | 0.007 | 0.003 | 0.009 | 0.004 | 0.007 | – | – | 0.003 | 0.008 | 0.003 | 0.008 | 0.003 | 0.005 |
| Chlorophyll *a* | 0.605 | 1.445 | 0.415 | 2.275 | 0.250 | 2.270 | 1.080 | 1.620 | 0.670 | 1.390 | 0.260 | 1.160 | 0.190 | 0.810 | 0.340 | 2.040 | – | – | 0.810 | 1.300 | 0.740 | 2.730 | 0.620 | 2.180 |

Table 2
Mean density and percentage of the most abundant species collected in the Mondego river estuary during the sampling period

| | 63 μm net | | 125 μm net | |
|---|---|---|---|---|
| | Mean density (ind. $m^{-3}$) | Percentage | Mean density (ind. $m^{-3}$) | Percentage |
| Polychaeta larvae | 797 | 1.77 | | |
| Gastropoda larvae | 3213 | 9.10 | 1707 | 12.08 |
| Bivalvia larvae | 1734 | 3.51 | 473 | 3.59 |
| Cladocera n. id. | | | 29 | 2.93 |
| Copepoda nauplii | 2692 | 8.17 | 1784 | 9.02 |
| *Calanus* spp. copepodits | 1345 | 4.90 | 562 | 3.69 |
| *Calanus helgolandicus* | 756 | 1.07 | | |
| *Paracalanus parvus* | 598 | 0.84 | 344 | 2.78 |
| *Clausocalanus arcuicornis* | 730 | 1.62 | 433 | 2.85 |
| *Calanipeda aquaedulcis* | | | 12 | 1.21 |
| *Temora longicornis* | 502 | 1.42 | 1615 | 15.52 |
| *Acartia* spp. copepodits | 3976 | 14.49 | 1029 | 7.81 |
| *Acartia clausi* | 1559 | 6.31 | 253 | 2.04 |
| *Acartia bifilosa* var. *inermis* | 796 | 1.61 | 342 | 2.25 |
| *Acartia tonsa* | 2412 | 9.28 | 1121 | 11.34 |
| *Oithona* spp. copepodits | 2086 | 5.06 | | |
| *Oithona nana* | 3540 | 10.03 | 918 | 7.42 |
| *Oithona similis* | 1250 | 1.51 | 403 | 2.03 |
| *Oithona plumifera* | | | 468 | 1.18 |
| *Euterpina acutifrons* | 1543 | 4.99 | 409 | 3.52 |
| Harpacticoida n. id. | 1245 | 4.79 | 405 | 3.28 |
| Cirripedia larvae | 1830 | 4.81 | 324 | 1.8 |
| *Paragnathia formica* | | | 28 | 1.13 |
| Praniza *Paragnathia formica* | 2024 | 2.04 | | |
| *Zoae Crangon crangon* | | | 628 | 1.9 |
| Others | 937 | 2.70 | 1 | 0.63 |

$NH_3$ varied between 0.093 mg $l^{-1}$ in June, 2000 and 0.003 mg $l^{-1}$ in July, 1999, with an average value of 0.026 mg $l^{-1}$. The average $PO_4^{3-}$ concentration was 0.003 mg $l^{-1}$ and varied between a maximum of 0.004 mg $l^{-1}$ in July, August and September, 1999 and February, 2000 and a minimum of 0.003 mg $l^{-1}$ in the other months of the year. The average chlorophyll *a* concentration was 0.544 mg $l^{-1}$, with a maximum in October, 1999 (1.080 mg $l^{-1}$) and a minimum in January, 2000 (0.190 mg $l^{-1}$). In station 2, the average temperature was 18.0 °C, varying between 25.0 °C, in August, 1999 and 11.0 °C in January, 2000. The salinity varied throughout the year with a minimum of 2.0‰, in May, 2000, and a maximum of 31.0‰ in September, 1999, with an annual average value of 20.0‰. pH suffered a slight fluctuation during the study period, varying between a maximum of 8.4 in December, 1999 and a minimum of 8.3 in September, 1999, with an annual average of 7.1. Dissolved oxygen presented minimum values of 48.0% in September and November, 1999, a maximum value of 91.0% in January, 2000 and an annual average of 69.4%. $NO_2^-$ presented a variation between 0.071 mg $l^{-1}$, in June, 2000 and 0.006 mg $l^{-1}$, in January, 2000, with an annual average of 0.036 mg $l^{-1}$. $NO_3^-$ presented a variation between 0.384 mg $l^{-1}$ in May, 2000 and 0.031 mg $l^{-1}$ in July, 1999, with an annual average of 0.146 mg $l^{-1}$. The values for the $NH_3$ varied between 0.370 mg $l^{-1}$ in June, 2000 and 0.034 mg $l^{-1}$ in January, 2000, with an annual average of 0.182 mg $l^{-1}$. The average $PO_4^{3-}$ value was 0.007 mg $l^{-1}$ and varied from a maximum of 0.009 mg $l^{-1}$, in January, 2000 and a minimum of 0.005, in June, 2000. Chlorophyll *a* concentration presented high average values than those in station 1 (1.747 mg $l^{-1}$), with a maximum of 2.730 mg $l^{-1}$ in May, 2000, and a minimum of 0.810 mg $l^{-1}$ in January, 2000.

### 3.2. 63 μm taxocenosis—composition and distribution

A list of the most representative species collected with both nets is presented in Table 2, with reference to its mean abundances and contributing percentages to zooplankton composition. The variation of total zooplankton abundance during the period of study was bi-modal at both stations (Fig. 2). At station 1, peaks of abundance were observed in October (44 700 ind. $m^{-3}$) and May (30 602 ind. $m^{-3}$). At

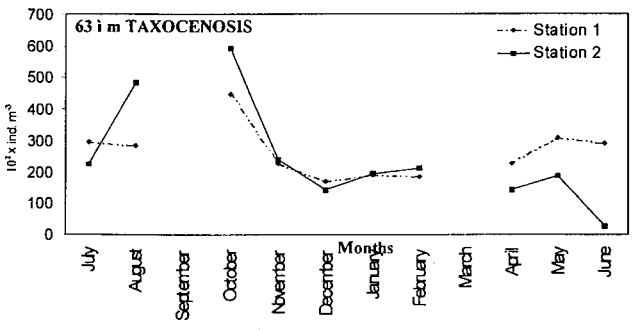


Fig. 2. Zooplankton seasonal abundance in 63 μm mesh size net, at both sampling stations.

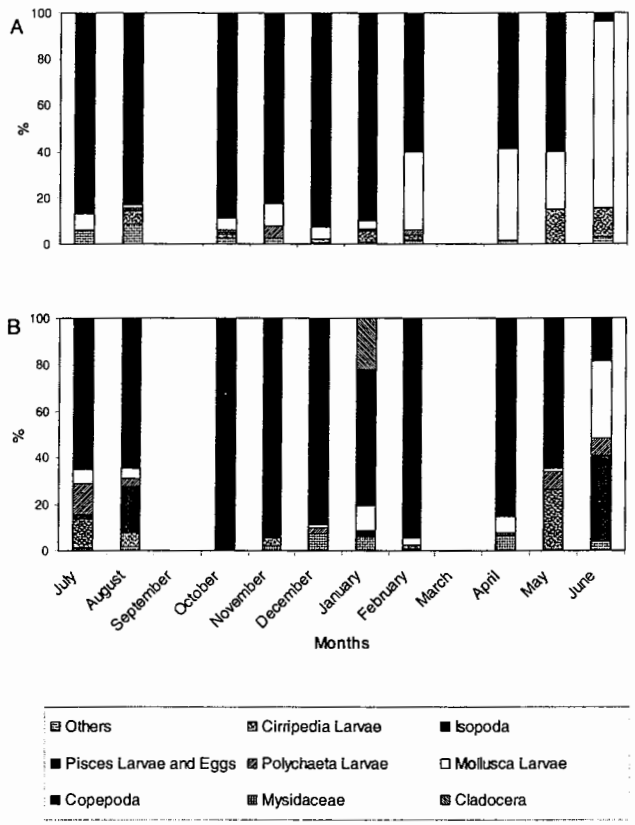


Fig. 3. Percentage of the main zooplanktonic groups in 63 μm mesh size net. (A) Sampling station 1; (B) sampling station 2.

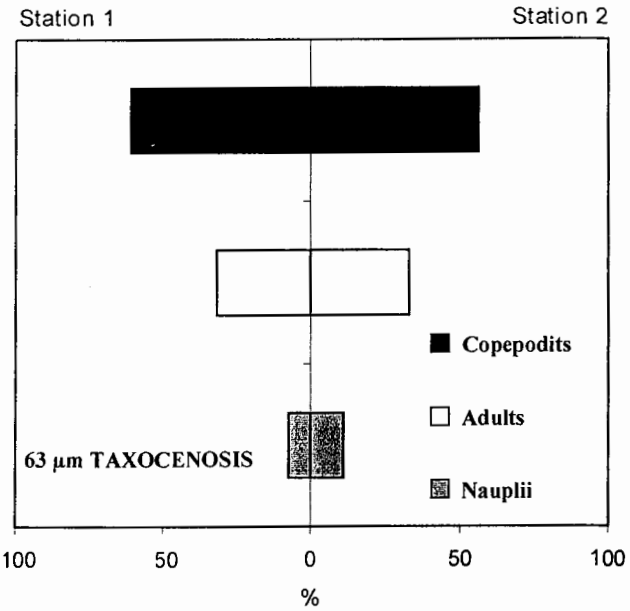


Fig. 4. Percentage of the three development stages of copepoda, in 63 μm mesh size, at both sampling stations.

station 2, high densities were observed in August (48 207 ind. $m^{-3}$) and October (59 200 ind. $m^{-3}$). Copepods dominate the zooplankton composition throughout the year at both stations (Fig. 3). At station 1, the highest contributions of copepoda abundance were observed from July until January, always being superior to 80.0% (Fig. 3A). At station 2, copepods highest contributions were observed from October until April, always being superior to 50.0% (Fig. 3B). During the spring period, Mollusca larvae also contributed, in important fractions, to the total zooplankton abundance, reaching 80.4% and 32.9%, at station 1 and station 2 in June, respectively. During this period, meroplanktonic forms, such as cirripedia larvae, Isopoda (praniza and adults of *Paragnathia formica*), Polychaeta larvae (metatrocofer *Spionidae*), and Decapod larvae (zoae *Crangon crangon*) and Hydromedusae (*Liriope tetraphyla*), presented important contributions. Among other holoplanktonic taxa, the most important in terms of absolute or relative abundance (> 1.0%) were Cladocera, Mysidacea (*Mesopodopsis slabberi*), Dinoflagelata (*Noctiluca scintillans*) and Appendiculata (*Oikopleura dioica*).

### 3.2.1. Copepoda community

The zooplankton community, in terms of species composition, was dominated by estuarine and estuarine/marine copepods, adults and copepodits, nominately *Oithona nana* (16.0%), *Acartia tonsa* (11.2%), *Acartia clausi* (10.0%), *Euterpina acutifrons* (8.0%), *Clausocalanus arcuicornis* (3.0%), *Acartia bifilosa* var. *inermis* (2.0%), *Temora longicornis* (1.9%), *Paracalanus parvus* (1.4%) and *Oithona similis* (1.0%). Regarding the copepoda community in itself, copepodits were in the most abundant stage of development at stations 1 and 2, contributing, respectively, with 61.0% and 56.0%, to the total abundances (Fig. 4). The copepodits' contributions, at station 1, with the exception of July, February and June were always superior to 50.0% (Fig. 5A) while at station 2, these contributions were relatively lower, but always superior to 40.0%, during almost the entire year (Fig. 5D). Adults showed, at station 1, an increase during autumn and spring, with high occurrences in February (89.1%) and June (90.0%). At station 2, the seasonal contributions of adults were similar to what was observed to the copepodits. The nauplii contributions to copepoda community registered higher values in July (34.4%), at station 1, and in June (62.0%), at station 2. Among the copepodit stage, the most abundant species were *Acartia* spp., *Oithona* spp., *Calanus* spp. and *Temora* spp. The copepodits of *Acartia* spp. registered, at station 1, high abundances from August until January, with peaks in August (2906 ind. $m^{-3}$) and October (6000 ind. $m^{-3}$) (Fig. 5B). At station 2, this species, presented high densities throughout the year, showing three peaks of abundance, in August (20 200 ind. $m^{-3}$), November (12 500 ind. $m^{-3}$) and February (14 600 ind. $m^{-3}$) (Fig. 5E). The copepodits of *Oithona* spp. were significantly more abundant at station 1 ($0.05 > P > 0.01$) (Table 3), peaks being observed in August (6130 ind. $m^{-3}$), and October (10 000 ind. $m^{-3}$). At station 2, *Oithona* spp. copepodits only presented important densities in May (2402 ind. $m^{-3}$). *Calanus* spp. copepodits occurred with very low densities during throughout the year, with high abundances, at station 1, in November (2380 ind. $m^{-3}$) and, at station 2, in October (3250 ind. $m^{-3}$) *Temora* spp. copepodits presented low abundance throughout the year, at

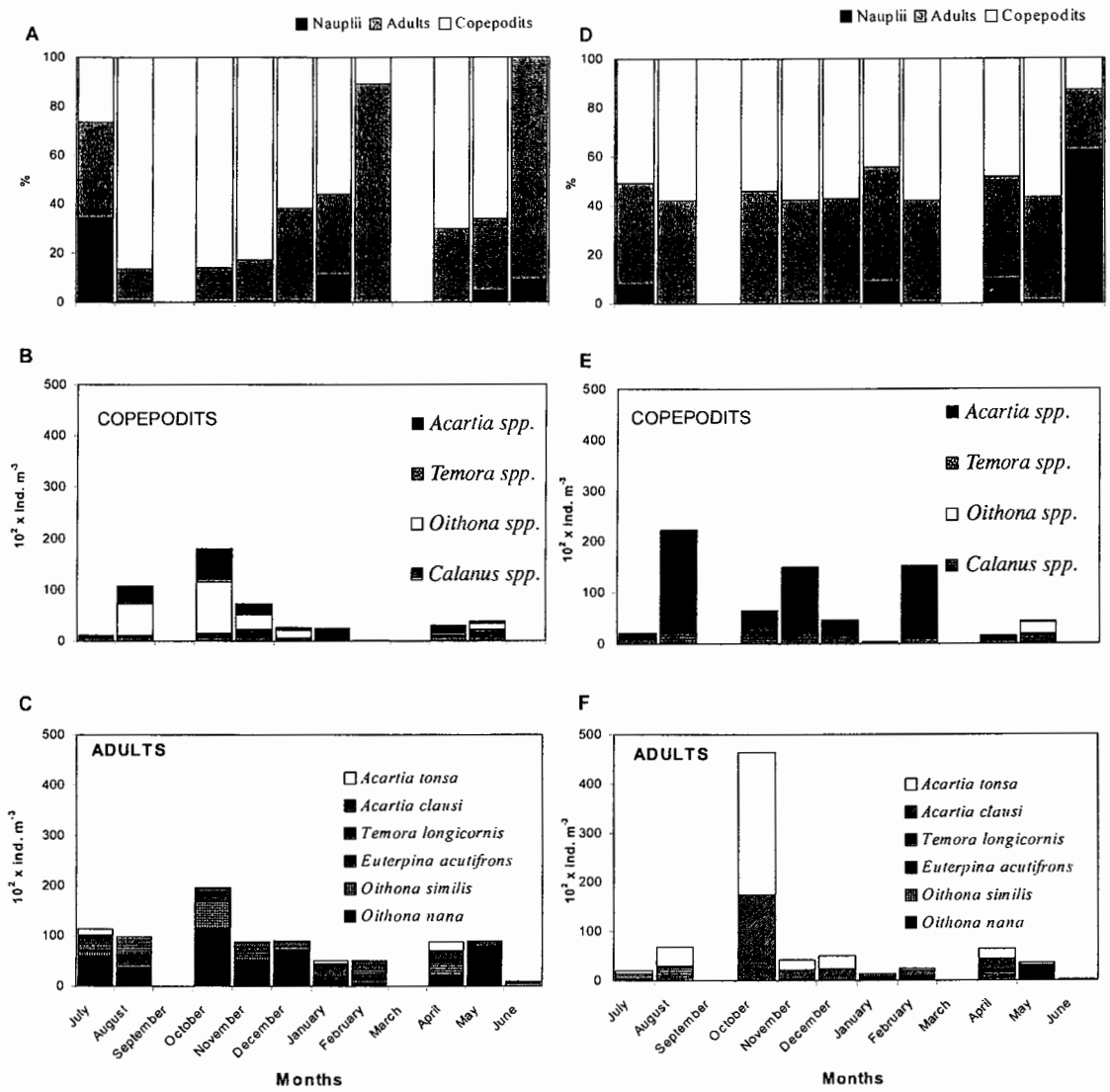


Fig. 5. Percentage and seasonal variation of copepoda community in 63 μm mesh size net. (A) and (D) Percentage of the three development stages of copepoda, in station 1 and station 2, respectively; (B) and (E) seasonal variation of copepodits in sampling stations 1 and 2, respectively; (C) and (F) seasonal variation of six most abundant adult copepoda species in sampling stations 1 and 2, respectively.

both stations, and registered peaks in August (405 ind. $m^{-3}$), at station 1, and in April (404 ind. $m^{-3}$), at station 2. In the adults, the most abundant species, at both stations, were *O. nana*, *A. tonsa*, *A. clausi*, *E. acutifrons*, *O. similis* and *T. longicornis* (Table 2). *O. nana* was significantly more abundant at station 1 ($P < 0.001$), registering peaks of abundance in October (11 400 ind. $m^{-3}$) and May (18 100 ind. $m^{-3}$) and also important densities in July (6000 ind. $m^{-3}$), November (11 400 ind. $m^{-3}$) and December (6830 ind. $m^{-3}$) (Table 3) (Fig. 5E). *A. tonsa* occurred with low densities throughout the year, at station 1, registering a peak in April (1860 ind. $m^{-3}$ ). At station 2, this species showed a peak in October (29 070 ind. $m^{-3}$) and important densities in August (3793 ind. $m^{-3}$), November (2121 ind. $m^{-3}$), December (2724 ind. $m^{-3}$) and April (1966 ind. $m^{-3}$) (Fig. 5F). *A. clausi* abundances showed significant differences of abundance throughout the seasons of the year ($0.05 > P > 0.01$), registered peaks in January (2331 ind. $m^{-3}$) and April (1623 ind. $m^{-3}$), at station 1 (Table 3), and in October (14 172 ind. $m^{-3}$), November (1810 ind. $m^{-3}$), December (2138 ind. $m^{-3}$) and April (2276 ind. $m^{-3}$), at station 2. *E. acutifrons* was significantly more abundant at station 1 ($0.05 > P > 0.01$), and registered a peak in August (4100 ind. $m^{-3}$) (Table 3). *O. similis* was significantly more abundant at station 1 ($0.01 > P > 0.001$), and registered a peak in October (5380 ind. $m^{-3}$) (Table 3). *T. longicornis* presented low densities throughout the year, at both stations, showing a peak in October (3207 ind. $m^{-3}$), at station 2 (Table 3).

### 3.2.2. Multiple regression analysis and diversity

Multiple regression analysis between physical and chemical parameters and zooplankton density showed that zooplankton density increases with increasing salinity, temperature and chlorophyll *a* ($r = 0.859$; $r^2 = 0.737$) (Table 4).

Diversity and evenness of 63 μm taxocenosis were higher during late spring and summer, at station 1, and during

Table 3
Two-way ANOVA results for biological parameters, at both sampling stations, during the period of study, in 63 μm mesh size. The null hypothesis is that when there are organisms in the water column, their average concentration does not differ across treatments. df, degrees of freedom; MS, mean square; Fs, test value; *P*, probability value; * $0.05 > P > 0.01$; ** $0.01 > P > 0.001$; *** $P < 0.001$; n.s. $P > 0.05$

| | Season | | | | | Sampling station | | | | | Season vs. sampling station | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | d.f. | MS | *F* | *P* | | d.f. | MS | *F* | *P* | | d.f. | MS | *F* | *P* | |
| Total 63 μm zooplankton | 3 | 0.068267 | 0.854719 | 0.490676 | n.s. | 1 | 0.056512 | 0.707549 | 0.416706 | n.s. | 3 | 0.038105 | 0.477084 | 0.704113 | n.s. |
| *Acartia bifilosa* var. *inermis* | 3 | 0.079763 | 0.393252 | 0.760145 | n.s. | 1 | 0.629191 | 3.102067 | 0.103627 | n.s. | 3 | 0.271206 | 0.202829 | 0.308364 | n.s. |
| *Acartia clausi* | 3 | 0.647365 | 0.139941 | 0.022609 | * | 1 | 0.066220 | 0.139941 | 0.473201 | n.s. | 3 | 0.343025 | 2.451207 | 0.113709 | n.s. |
| *Acartia tonsa* | 3 | 0.235530 | 0.730495 | 0.553385 | n.s. | 1 | 1.101137 | 3.415172 | 0.089384 | n.s. | 3 | 0.477597 | 1.481264 | 0.269272 | n.s. |
| *Acartia* spp. copepodits | 3 | 0.613303 | 1.182430 | 0.357483 | n.s. | 1 | 0.398358 | 0.768023 | 0.398034 | n.s. | 3 | 0.131604 | 0.253729 | 0.857202 | n.s. |
| *Calanus* spp. copepodits | 3 | 0.504867 | 2.343547 | 0.124545 | n.s. | 1 | 0.035412 | 0.164381 | 0.692290 | n.s. | 3 | 0.041935 | 0.194659 | 0.898013 | n.s. |
| *Oithona* spp. copepodits | 3 | 0.525371 | 1.821270 | 0.196934 | n.s. | 1 | 1.873553 | 6.494928 | 0.025535 | * | 3 | 0.569732 | 1.975054 | 0.171586 | n.s. |
| *Euterpina acutifrons* | 3 | 0.196169 | 0.686572 | 0.577317 | n.s. | 1 | 1.490685 | 5.217248 | 0.041368 | * | 3 | 0.261703 | 0.915935 | 0.462393 | n.s. |
| Copepoda Nauplii | 3 | 0.086166 | 0.126784 | 0.942405 | n.s. | 1 | 0.116946 | 0.172073 | 0.685596 | n.s. | 3 | 0.056754 | 0.083507 | 0.967739 | n.s. |
| *Oithona nana* | 3 | 0.510943 | 1.979510 | 0.170908 | n.s. | 1 | 5.363703 | 20.78026 | 0.000656 | *** | 3 | 0.403292 | 1.562450 | 0.249642 | n.s. |
| *Oithona similis* | 3 | 0.282486 | 2.656800 | 0.095870 | n.s. | 1 | 1.453878 | 13.67382 | 0.003048 | ** | 3 | 0.282486 | 2.656800 | 0.095870 | n.s. |
| *Temora longicornis* | 3 | 0.315688 | 1.861297 | 0.189953 | n.s. | 1 | 0.018164 | 0.107096 | 0.749113 | n.s. | 3 | 0.076242 | 0.449520 | 0.722252 | n.s. |

autumn and winter, at station 2. Diversity varied between 0.93 bits ind.$^{-1}$ (November 1999) and 1.50 bits ind.$^{-1}$ (June of 2000) at station 1, and between 0.96 bits ind.$^{-1}$ (April 2000) and 1.43 bits ind.$^{-1}$ (February of 2000), at station 2 (Fig. 6). The average diversity at station 2 (1.22 bits ind.$^{-1}$) was higher than that at station 1 (1.109 bits ind.$^{-1}$). Evenness, at station 1, varied between 0.214 (November 1999) and 0.342 (June of 2000), and between 0.219 (April of 2000) and 0.325 (February of 2000), at station 2. The average evenness at station 2 (0.278) was higher than that at station 1 (0.252) (Fig. 6).

### 3.3. 125 μm taxocenosis—composition and distribution

The variation of total zooplankton abundance during the period of study was bi-modal at station 1 and tri-modal at station 2. The zooplankton density showed significant differences between the seasons of the year ($0.01 > P > 0.001$) (Table 5), and registered, at station 1, peaks of abundance in November (12 530 ind. m$^{-3}$) and April (17 300 ind. m$^{-3}$), and, at station 2, in November (2120 ind. m$^{-3}$), January (17 600 ind. m$^{-3}$) and April (15 400 ind. m$^{-3}$) (Fig. 7). The copepods dominate the zooplankton composition almost all year round, with contributions always being superior to 40.0% at both stations (Fig. 8). Mollusca larvae and cirripedia larvae have also contributed, in some months, with important densities to the total zooplankton abundance. Mollusca larvae were abundant, in station 1, from February until June, reaching the highest contribution in June (90.5%) and cirripedia larvae in July (5.4%), August (5.0%) and October (4.3%), (Fig. 8A). At station 2 the contribution of meroplankton was higher, with important densities of mollusca larvae and isopods in August (13.3% and 76.0%, respectively) and June (61.0% and 20.0%, respectively), cirripedia larvae, in July (21.4%) and May (4.0%) and polychaeta larvae in July (3.0%) (Fig. 8B). Among other holoplanktonic taxa, the most important in terms of absolute or relative abundance (>1.0%) were Cladocera, Isopoda (adults and praniza of *P. formica*), Decapoda larvae (zoae *Palaemon serratus* and zoae *C. crangon*) and Apendiculata (*O. dioica*).

Table 4
Variables in the equation of multiple regression for the variation of the abundance of 63 μm net taxocenosis ; $r = 0.859$; $r^2 = 0.737$

| Variables | Regression coefficient | Standard deviation of the regression coefficient |
|---|---|---|
| $NO_3^-$ | 0.091 | 0.404 |
| $NO_3^-$ | –0.314 | 0.338 |
| $NH_3$ | –0.832 | 0.466 |
| $PO_3^{3-}$ | 0.213 | 0.252 |
| Chlorophyll *a* | 0.533 | 0.380 |
| Dissolved oxygen | –0.142 | 0.251 |
| PH | –0.391 | 0.165 |
| Salinity | 0.359 | 0.303 |
| Temperature | 0.205 | 0.315 |

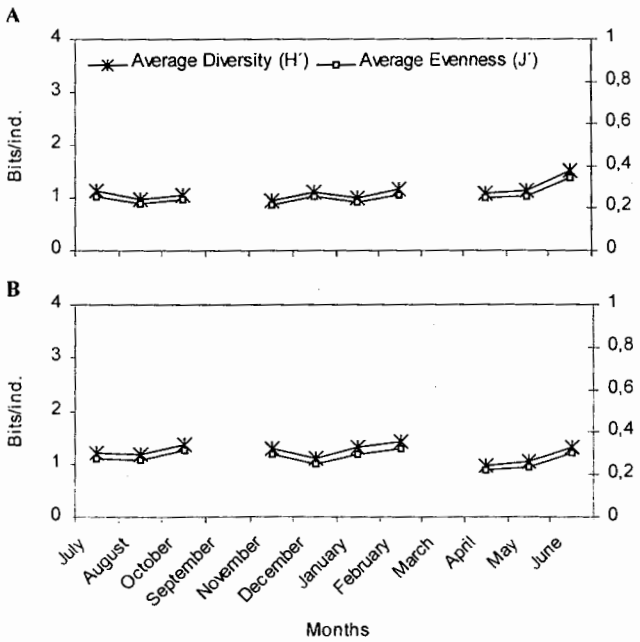


Fig. 6. Sixty-three micrometer taxocenosis monthly average diversity and evenness. (A) Sampling station 1; (B) sampling station 2.

Table 5
Two-way ANOVA results for biological parameters, at both sampling stations, during the period of study, in 125 µm mesh size. The null hypothesis is that when there are organisms in the water column, their average concentration does not differ across treatments. df, degrees of freedom; MS, mean square; Fs, test value; *P*, probability value; * $0.05 > P > 0.01$; ** $0.01 > P > 0.001$; *** $P < 0.001$; n.s. $P > 0.05$

| | Season | | | | | Sampling station | | | | | Season vs. sampling station | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | d.f. | MS | F | P | | d.f. | MS | F | P | | d.f. | MS | F | P | |
| Total 125 µm zooplankton | 3 | 0.316656 | 5.32051 | 0.014555 | ** | 1 | 0.004523 | 0.076000 | 0.787483 | n.s. | 3 | 0.058438 | 0.981889 | 0.433761 | n.s. |
| *Acartia bifilosa* var. *inermis* | 3 | 0.075455 | 0.449663 | 0.722157 | n.s. | 1 | 0.226578 | 0.135203 | 0.719501 | n.s. | 3 | 0.200362 | 1.194037 | 0.353527 | n.s. |
| *Acartia clausi* | 3 | 0.228578 | 2.791295 | 0.085936 | n.s. | 1 | 0.022960 | 0.280380 | 0.606110 | n.s. | 3 | 0.043636 | 0.532859 | 0.668379 | n.s. |
| *Acartia tonsa* | 3 | 0.679351 | 7.075000 | 0.005406 | ** | 1 | 1.031489 | 10.742300 | 0.006610 | ** | 3 | 0.423865 | 0.096021 | 0.026023 | * |
| *Acartia* spp. copepodits | 3 | 0.734380 | 3.191004 | 0.062710 | n.s. | 1 | 0.664259 | 2.886316 | 0.115088 | n.s. | 3 | 0.116830 | 0.507645 | 0.684367 | n.s. |
| *Calanus* spp. copepodits | 3 | 0.438568 | 2.523706 | 0.107017 | n.s. | 1 | 0.162919 | 0.937503 | 0.352031 | n.s. | 3 | 0.015454 | 0.088926 | 0.964757 | n.s. |
| *Euterpina acutifrons* | 3 | 0.028532 | 0.254653 | 0.856557 | n.s. | 1 | 0.731019 | 6.524561 | 0.025264 | * | 3 | 0.041214 | 0.367848 | 0.777578 | n.s. |
| Copepoda nauplii | 3 | 0.449253 | 1.410795 | 0.287694 | n.s. | 1 | 2.023637 | 6.354853 | 0.026866 | * | 3 | 0.193095 | 0.606380 | 0.623421 | n.s. |
| *Oithona nana* | 3 | 0.183727 | 0.904207 | 0.467682 | n.s. | 1 | 1.540053 | 7.579319 | 0.027503 | * | 3 | 0.304824 | 1.500181 | 0.264550 | n.s. |
| *Oithona similis* | 3 | 0.196541 | 2.422482 | 0.116491 | n.s. | 1 | 0.562863 | 6.937620 | 0.021817 | * | 3 | 0.145086 | 1.788278 | 0.202905 | n.s. |
| *Temora longicornis* | 3 | 1.115566 | 4.486279 | 0.024799 | * | 1 | 0.084717 | 0.340691 | 0.570240 | n.s. | 3 | 0.207523 | 0.834561 | 0.500361 | n.s. |

### 3.3.1. *Copepoda community*

The copepoda community, in terms of species composition, was dominated by estuarine and estuarine/marine species (adults and copepodits), including *T. longicornis* (23.6%), *A. tonsa* (17.3%), *O. nana* (11.0%), *E. acutifrons* (5.3%), *C. arcuicornis* (5.0%), *P. parvus* (4.2%), *A. bifilosa* var. *inermis* (3.4%), *A. clausi* (3.2%) and *O. similis* (3.0%). In the copepoda community, copepodits were the most abundant stage of development at station 1 and 2, contributing, respectively, with 54.0% and 49.0% to the total copepoda abundances (Fig. 9). During the study period, copepodits presented contributions always superior to 60.0% and 50.0% at station 1 and 2, respectively, although at this station, the adults also contributed with important densities in August (52.0%), December (69.0%) and June (99.0%) (Fig. 10A). At station 2, adults were not so abundant during the period of study, but registered important contributions in January (99.0%), April (55.0%) and June (99.0%) (Fig. 10D). Copepod nauplii were significantly more abundant in station 2 ($0.05 > P > 0.01$) (Table 5), showing the largest contributions in July (22.0%), November, (18.2%) and December (33.3%). Among the copepodits, the most abundant species were *Acartia* spp., *Calanus* spp. and *Temora* spp. The copepodits of *Acartia* spp. and *Calanus* spp. dominated at both stations. At station 1, *Acartia* spp. copepodits registered high densities in October (17 920 ind. $m^{-3}$), January (4800 ind. $m^{-3}$) and May (5760 ind. $m^{-3}$), *Calanus* spp. copepodits in October (5440 ind. $m^{-3}$), November (6400 ind. $m^{-3}$), January (5040 ind. $m^{-3}$) and April (5700 ind. $m^{-3}$) and *Temora* spp. copepodits in April (960 ind. $m^{-3}$) (Fig. 10B). At station 2, the *Acartia* spp. copepodits registered high densities in October (14 700 ind. $m^{-3}$), November (7080 ind. $m^{-3}$) and February (7200 ind. $m^{-3}$) (Fig. 10E), and the *Calanus* spp. copepodits in November (7200 ind. $m^{-3}$). At this station, the *Temora* spp.

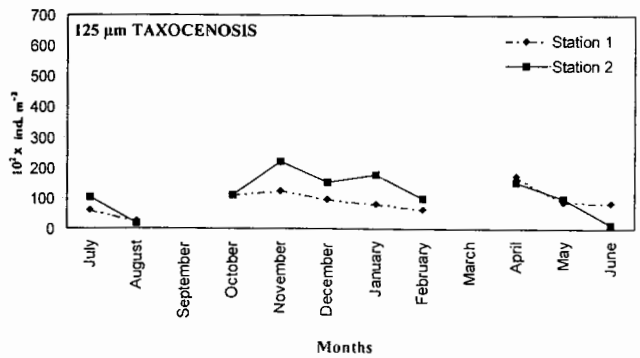


Fig. 7. Zooplankton seasonal abundance in 125 µm mesh size net at both sampling stations.

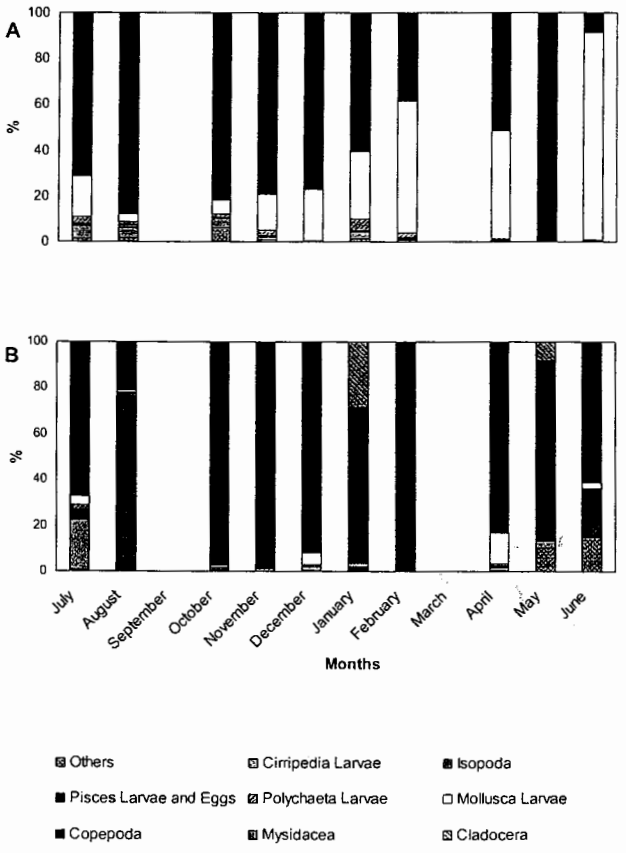


Fig. 8. Percentage of the main zooplanktonic groups in 125 µm mesh size net, at both sampling stations.

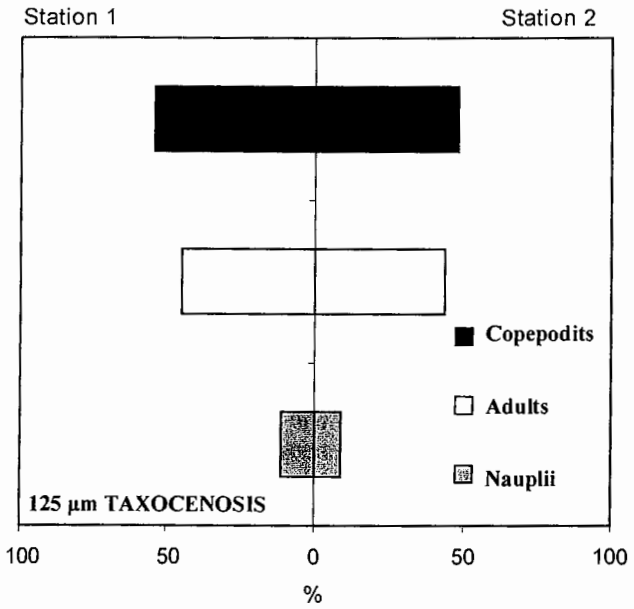


Fig. 9. Percentage of the three development stages of copepoda, in 125 µm mesh size, at both sampling stations.

copepodits presented important densities, in December (2100 ind. $m^{-3}$) and April (3120 ind. $m^{-3}$). In the adults, the most abundant species, at both stations, were *T. longicornis*, *A. tonsa*, *O. nana*, *E. acutifrons*, *A. clausi* and *O. similis* (Table 2). *T. longicornis* showed significant differences of abundance throughout the seasons of the year ($0.05 > P > 0.01$), registering a peak, at station 1, in May (7400 ind. $m^{-3}$) (Table 5). At station 2, *T. longicornis* was abundant from December until May, reaching high values in January (6600 ind. $m^{-3}$), August (4400 ind. $m^{-3}$) and May (7400 ind. $m^{-3}$) (Fig. 10F). *A. tonsa* densities were significantly affected by the interaction between the seasons of the year and the sampling stations ($0.05 > P > 0.01$) (Table 5). At station 1, they showed high abundances in April (1680 ind. $m^{-3}$) and May (840 ind. $m^{-3}$). At station 2, they showed peaks in November (6520 ind. $m^{-3}$) and February (3500 ind. $m^{-3}$), and significant densities in October (1650 ind. $m^{-3}$), December (2960 ind. $m^{-3}$) and April (2520 ind. $m^{-3}$). *O. nana* was significantly more abundant at station 1 ($0.05 > P > 0.01$), registering three peaks, in October (4100 ind. $m^{-3}$), November, (2400 ind. $m^{-3}$) and December (2802 ind. $m^{-3}$)

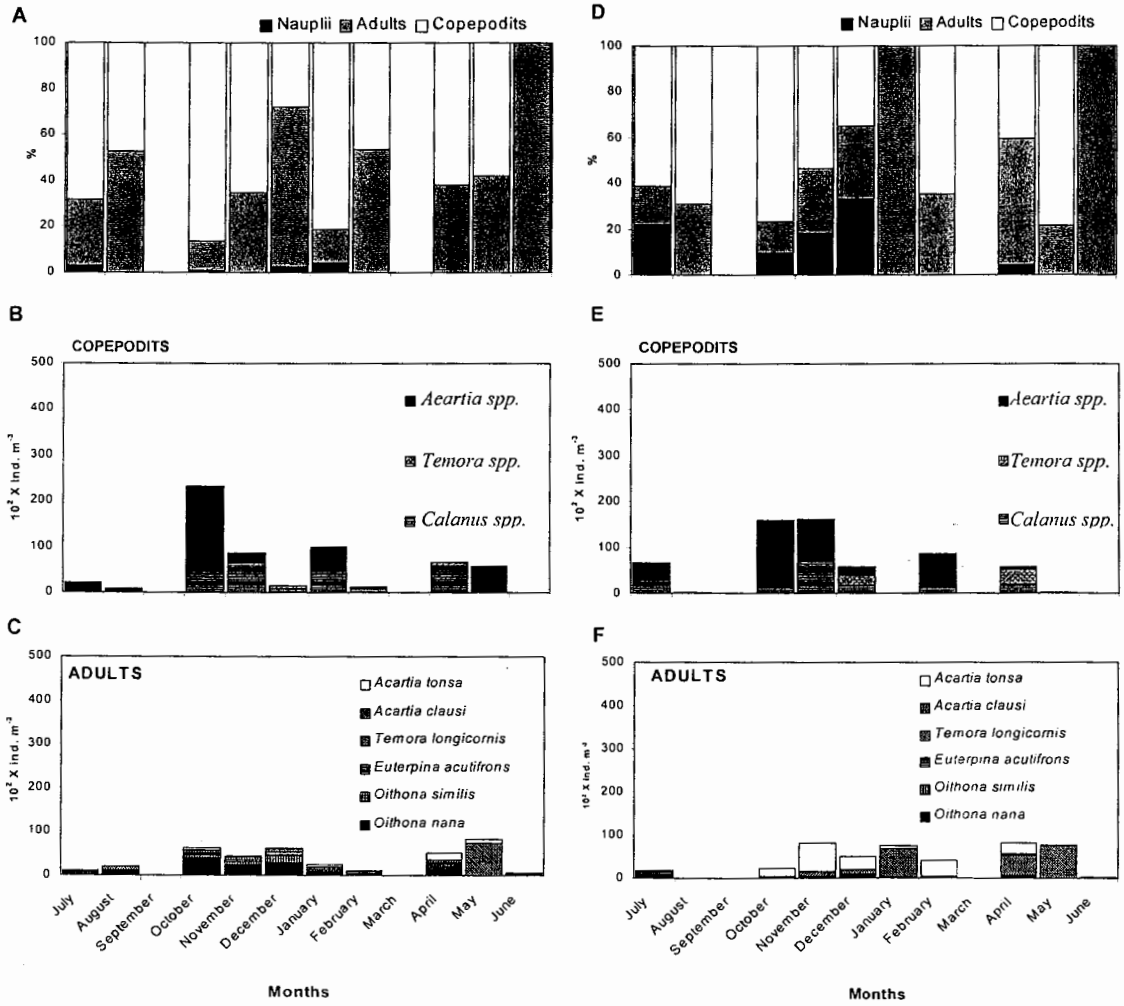


Fig. 10. Percentage and seasonal variation of copepoda community in 125 µm mesh size net. (A) and (D) Percentage of the three development stages of copepoda, in stations 1 and 2, respectively; (B) and (E) seasonal variation of copepodits in sampling stations 1 and 2, respectively: (C) and (F) seasonal variation of six most abundant adult copepoda species in sampling stations 1 and 2, respectively.

Table 6
Variables in the equation of multiple regression for the variation of the abundance of 125 μm net taxocenosis ; $r = 0.868$; $r^2 = 0.754$

| Variables | Regression coefficient | Standard deviation of the regression coefficient |
|---|---|---|
| $NO_3^-$ | 0.761 | 0.393 |
| $NO_2^-$ | 0.182 | 0.357 |
| $NH_3$ | −1.287 | 0.463 |
| $PO_4^{3-}$ | 0.452 | 0.245 |
| Chlorophyll *a* | 0.113 | 0.369 |
| Dissolved oxygen | −0.808 | 0.260 |
| pH | −0.022 | 0.200 |
| Salinity | 0.404 | 0.304 |
| Temperature | −0.186 | 0.305 |

(Fig. 10C) (Table 5). *E. acutifrons* was significantly more abundant at station 1 ($0.05 > P > 0.01$), registering a peak in April (1920 ind. $m^{-3}$) (Table 5). *A. clausi* presented low abundances all year round, registering a peak in April (560 ind. $m^{-3}$), at station 1, and in November (1160 ind. $m^{-3}$), at station 2. *O. similis* was significantly more abundant at station 1 ($0.05 > P > 0.01$), registering a peak in December (1700 ind. $m^{-3}$) (Table 5).

### 3.3.2. Multiple regression analysis and diversity

Multiple regression analysis between physical and chemical parameters and zooplankton density showed that zooplankton density increases with increasing chlorophyll *a* and salinity ($r = 0.868$; $r^2 = 0.754$) (Table 6).

The diversity of 125 μm taxocenosis, at station 1 and 2, was higher during late spring and summer. The diversity varied between 0.94 bits ind.$^{-1}$ (January 2000) and 1.75 bits ind.$^{-1}$ (May of 2000), at station 1, and between 1.31 bits ind.$^{-1}$ (January 2000) and 1.71 bits ind.$^{-1}$ (May of 2000), at station 2 (Fig. 11). The average diversity at station 2 (1.26 bits ind.$^{-1}$) was higher than that at station 1 (1.24 bits ind.$^{-1}$). Evenness, at station 1, varied between 0.205 (January of 2000) and 0.381 (May of 2000) and between 0.225 (July of 1999) and 0.373 (May of 2000), at station 2. The average evenness at station 2 (0.274) was higher than that at station 1 (0.270) (Fig. 11).

### 3.4. Cluster analysis

After a cluster analysis of the 63 μm taxocenosis, the dendrogram showed two main groups according to spatial occurrence (Fig. 12). A group (A) with high occurrences in station 2, composed of *A. bifilosa* var. *inermis*, *A. tonsa*, *A. clausi*, *Acartia* spp. copepodits, *Calanus* spp. copepodits and *T. longicornis*. This group can be divided into three sub-groups, according to seasonal occurrence. A first sub-group (A1), with high abundances in autumn, composed of *T. longicornis*, a second sub-group (A2), with high abundances in autumn-winter and late spring periods, composed of *Acartia* spp. copepodits and *Calanus* spp. copepodits and a third sub-group (A3), with high abundances in autumn, late spring and summer periods, composed of *Acartia* spp. copepodits, *A. clausi* and *A. bifilosa* var. *inermis*. A group (B) with high occurrences in station 1, composed of *Calanus helgolandicus*, *P. parvus*, Bivalvia larvae, Cirripedia larvae, *C. arcuicornis*, *Oithona* spp. copepodits, *O. nana*, *O. similis*, *E. acutifrons*, Gastropoda larvae, Polychaeta larvae and Copepoda nauplii. This group can be divided in five sub-groups, according to seasonal occurrence. The first sub-group (B1), with high abundances in early spring-summer-autumn period, composed of Copepoda nauplii and Polychaeta larvae, the second sub-group (B2), with high abundances in summer-autumn period, composed of *E. acutifrons* and Gastropoda larvae. The third sub-group (B3), with high abundances in autumn and early winter periods, composed of *O. similis*, *O. nana* and *Oithona* spp. copepodits. The fourth sub-group (B4), with high abundances in early summer period, composed of Bivalvia larvae and Cirripedia larvae. A fifth sub-group (B5), with high abundances in the spring period, composed of *C. helgolandicus* and *P. parvus*.

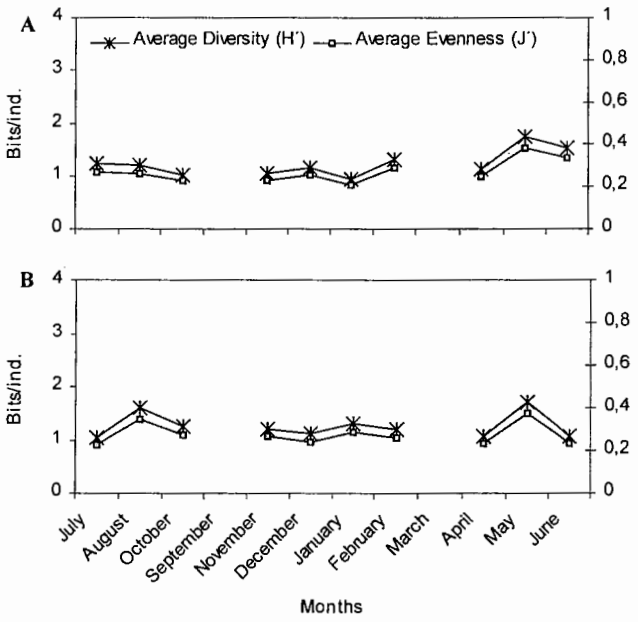


Fig. 11. One hundred and twenty-five micrometer taxocenosis monthly average diversity and evenness. (A) Sampling station 1; (B) sampling station 2.

After a cluster analysis of the 125 μm taxocenosis, the dendrogram showed two main groups according to spatial occurrence (Fig. 13). A group (A), with high occurrences at station 2, composed of, *A. clausi*, *Calanus* spp. copepodits, *A. tonsa*, *Acartia* spp. copepodits, Copepoda *nauplii*, *C. arcuicornis* and *P. parvus*. This group can be divided into two sub-groups, according to seasonal occurrence. A first sub-group (A1), with high abundances in autumn and spring and early summer periods, composed of *A. bifilosa* var. *inermis*, *A. clausi*, *A. tonsa*, *Calanus* spp. copepodits, *Acartia* spp. copepodits and Copepoda nauplii, and a second sub-group (A2), with high abundances in autumn-winter period, composed of *C. arcuicornis* and *P. parvus*. A group (B) with higher occurrences at station 1, composed of *E. acutifrons*, Gastropoda larvae, *O. nana*, *O. similis* and Bivalvia larvae.

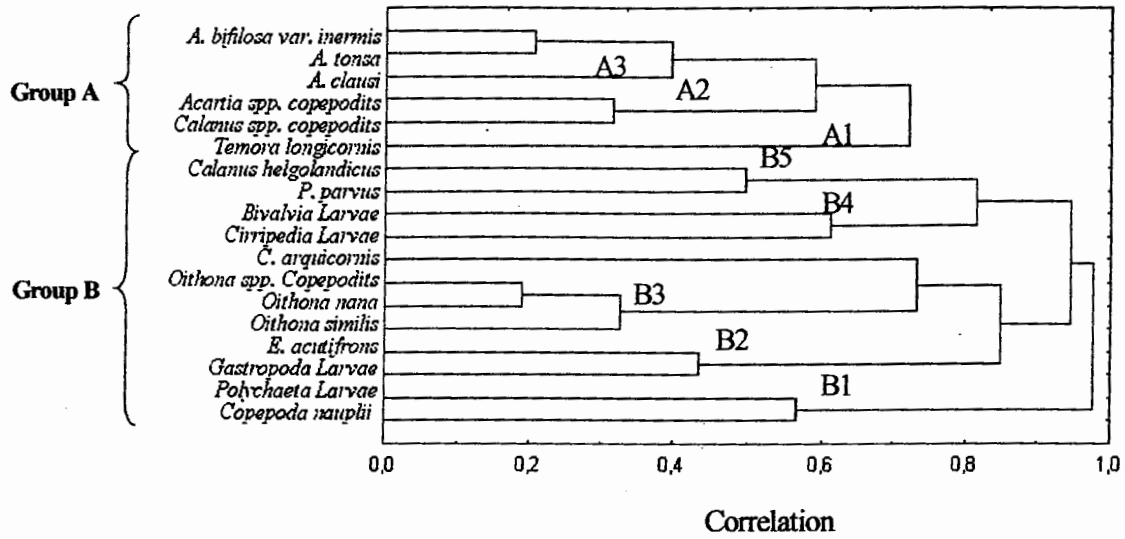


Fig. 12. Dendrogram (Pearson correlation coefficient) of the most abundant species, 63 μm mesh size, at both stations during the period of sampling.

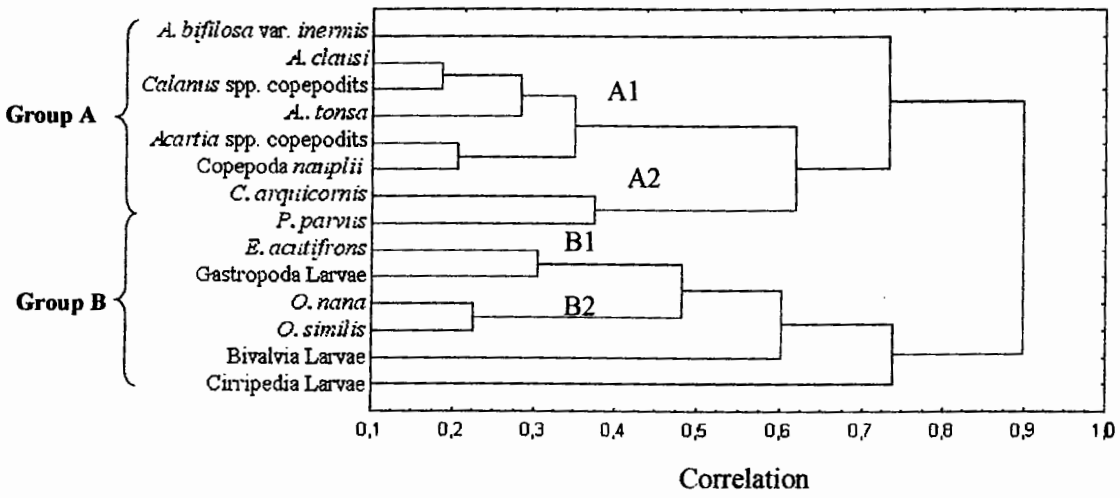


Fig. 13. Dendrogram (Pearson correlation coefficient) of the most abundant species, 125 μm mesh size, at both stations during the period of sampling.

This group can be divided into two sub-groups, according to seasonal occurrence. A first sub-group (B1), with high abundances in spring period, composed of *E. acutifrons* and Gastropoda larvae, and a second sub-group (B2), with high abundances in autumn and early winter periods, composed of *O. similis* and *O. nana*.

## 4. Discussion

The 63 and 125 μm taxocenosis distribution were determined by salinity, temperature and chlorophyll *a*. The 200 and 335 μm taxocenosis present in the system had already demonstrated this pattern (Azeiteiro et al., 1999, 2000). This trend is corroborated by a wider picture indicating that in estuaries, the potential range of a zooplankter is mainly determined by salinity, temperature (Fragopoulu and Lykakis, 1990) and food availability (Castro et al., 1991; Giske et al., 1990).

The evolution of the zooplankton biomass strained by the 63 and 125 μm mesh size nets showed that the biomass corresponding to the 63 μm sieve was always higher than that retained by the 125 μm sieve: this means that the contribution of the smaller individuals (adult specimens, copepodits and naupliar forms) was higher. The abundance patterns of the zooplankton showed significant variations during the year, with bi-modal and tri-modal patterns of distribution, which are typical of many temperate estuaries. The majority of species observed were typical constituents of the European estuaries (Azeiteiro, 1999; Azeiteiro et al., 1999, 2000; Morgado, 1997; Soetaert and Rijswijk, 1993; Villate, 1991a,b).

Copepods and Mollusca larvae were the most important components of the plankton in the southern arm of the Mondego estuary, as they are in other shallow temperate estuaries. Mollusca larvae, cirripedia larvae and polychaeta larvae dominated the meroplankton in the Mondego estuary, during spring and summer, mainly in the station located upstream (S2); a pattern verified in many other estuaries (Castel and Courties, 1982; Williams and Collins, 1986; Siokou-Frangou, 1996; Sprung, 1994; Wickstead, 1976). In

the Mollusca larvae, the gastropods *Hidrobia ulvae*, a typical estuarine organism (Bachelet and Yacine-Kassab, 1987; Fish and Fish, 1974) resident in the estuary (Baptista, 1996) with meroplanktonic larvae (Azeiteiro et al., 1999; Bachelet and Yacine-Kassab, 1987) together with the Bivalvia veligers were responsible for the peaks observed in the meroplankton in both taxocenosis.

Estuarine copepods typically reach very high densities and tend to dominate the fauna of estuaries, even if only for part of the year. Despite the domination of copepods as a group, only *Oithona nana*, *Acartia tonsa*, *Acartia clausi*, *Euterpina acutifrons*, *Oithona similis*, *Temora longicornis*, *Clausocalanus arcuicornis*, *Paracalanus parvus*, and *Acartia bifilosa* var. *inermis* species were common, and *Oithona nana*, *Acartia tonsa* and *Acartia clausi* were by far the most abundant.

In the Mondego estuary, the copepodits' stage dominance indicated the significant contribution of the smaller components to the annual zooplankton production in this area. Schneider and Lenz (1987), claimed that the neritic and estuarine plankton differ from the oceanic by the smaller dimension of the organisms and by the higher abundance of the larval stages, estimated by Wickstead (1976) to be 100 times superior. The data presented in this study also point to the, till now unknown, importance of the microzooplankton taxocenosis in estuaries and, particularly, in the Mondego estuary.

The genus *Acartia* represented by the species *A. clausi*, *A. bifilosa* and *A. tonsa* showed a distribution pattern in the system consistent with previous published information regarding the zooplanktonic taxocenosis (Azeiteiro et al., 2000). The species *A. tonsa* distribution pattern showed a significant spatial separation (although not evident in the cluster analysis) and *A. clausi* distribution pattern showed a significant temporal segregation (evident in the cluster analysis). This pattern is coincident with the knowledge of the *Acartia* congeneric species (Alcaraz, 1983).

The cluster analysis showed that in the zooplankton ecology, the spatial structure dominated over the seasonal patterns, i.e. similarities between clusters grouping the samples of different months are high. The main reason for this is the fact that the spatial gradient in species composition in estuaries is very steep: the communities of the zones of marine and brackish influence are composed of eminently different species.

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