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COPEPODA

Seasonal variability of copepod abundance in the Balearic region (Western Mediterranean) as an indicator of basin scale hydrological changes

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Abstract Spatial and temporal changes of the copepod community have been investigated and related to the environmental variability of the Balearic Sea (Western Mediterranean). The period studied spans from 1994 to 1999 during which we analyzed the abundance and structure copepod variability over a cross-shore transect. Results showed a close link between hydrological changes and the variations of copepod abundance. The synchronous variability of copepods and hydrography indicated the rapid response of this zooplankton group to the inflow of cold and warm water masses coming through the study area. Cluster analysis revealed four main copepod assemblages that distinguished the coastal from the oceanic species and those species with different water masses preference. The copepod assemblage composed of *Calanus helgolandicus*, *Clausocalanus arcuicornis*, *C. pergens*, *C. paululus, Calocalanus tenuis* and *Pleuromamma gracilis* was associated with cool salty waters, whereas the assemblage formed by *Temora stylifera*, *C. pavo*, *C. styliremis*, *Centropages bradyi* and *Acartia danae* was related to warmer less saline Mediterranean waters. Moreover, it is suggested that changes in sea water temperature and salinity are linked to large-scale changes likely occurring at a basin scale, which is reflected in the Western Mediterranean mesoscale hydrographic changes. Therefore, it is stressed that changes in the Balearic copepod community can be used as potential tracers of the western Mediterranean water masses.

Keywords Copepods · Hydrography · Interannual-changes · Balearic Sea · Western Mediterranean

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Introduction

The Mediterranean Sea is a mid-latitude semi-enclosed sea connected with the Atlantic Ocean via the strait of Gibraltar. Because of its geographical location, this area is exposed to the major processes acting upon the global climate system. Consequently, the Mediterranean Sea is one of the most sensitive areas to future climate change previsions (IPCC, 2001). In the western basin, the Balearic Sea is a hydrographical transition area where different water masses can be found, the cool and salty waters from the Gulf of Lions and warmer less saline from the Alboran Sea. The former are characterized by a longer residence time in the north Western Mediterranean (WM), which reach the Balearic area through the Northern Current, whereas the latter shows more recent waters from the Atlantic and milder weather conditions (Font et al., 1988; Pinot et al., 2002). The south of the Balearic Islands is less affected by the Northern Current processes. However, it is influenced by the instability of the Almeria-Oran front and by mesoscale structures detached from the Algerian Current (Millot, 1987). The geographic location of the Balearic islands (39–40° N; 1–4°30′ E) led this region to be influenced by a combined effect of atmospheric forces and mesoscale circulation governing the WM (Pinot et al., 1995; Schneider et al., 2005). In turn, the ocean–atmosphere coupled system may favour this area with complex interactions between resident waters in the north and more recent Atlantic Waters (AW), which may also vary seasonally (Garcia et al., 1994). Therefore, the Balearic Sea offers the possibility to investigate the variability of the two main surface water masses (0–150 m) characterizing the western basin and so their influence on the dynamics of the pelagic ecosystem.

Zooplankton, and particularly copepods, can be good indicators of water mass flows (Peterson et al., 2001; Edwards et al., 2002; Hwang & Wong, 2005). Particular assemblages are related to specific water masses, which could be useful to detect the interannual scale variations in hydrographic regimes. Furthermore, copepods are a key food item for fish larvae and may affect the biological productivity in marine ecosystems.

The interannual variability of plankton is high in relation to that of the environment and time-series are required to investigate the functional changes in the marine ecosystem (Colebrook, 1978, 1985). So far, these studies in the Mediterranean Sea are scarce, although they are fundamental to assess environmental health in the Mediterranean marine ecosystem (CIESM, 2003). In the Mediterranean basin, previous works have investigated the interannual variability of zooplankton in different sites, such as the Gulf of Lions (Razouls & Kowemberg, 1993), Marseille (Gaudy, 1985), Ligurian Sea (Licandro & Ibanez, 2000; Molinero et al., 2005a, b), the Saronikos Gulf (Christou, 1998), the Balearic region (Fernández de Puelles et al., 2003b, 2004b; Fernandez de Puelles & Molinero, 2007), Gulf of Naples (Mazzocchi and Ribera d'Alcala, 1995) and the Adriatic Sea (Baranovic et al., 1993; Cataletto et al., 1995; Kamburska & Fonda-Umani, 2006). However, most of these studies were focussed on total zooplankton of coastal waters, and therefore, we know little on the interannual variability of the copepod community of open oceanic waters. Furthermore, although global atmospheric forcing strongly drives the dynamics of the atmospheric variability in the Mediterranean basin (Hurrell, 1995; Redaway & Bigg, 1996), only a few studies have investigated the response of copepods to large-scale atmospheric oscillations (Fernández de Puelles et al., 2004a; Molinero et al., 2005a, b; Fernandez de Puelles & Molinero, 2007; Molinero et al., 2008).

In this work, we have investigated the seasonal and interannual variability of the copepod community in the Mallorca channel over a transect across the shelf. The sampled stations, located in the boundary area between different WM water masses, are under strong influence of open-ocean circulation. The region has no freshwater inputs from rivers or chemical industries. Our aim is to analyze the response of copepods to the variability of hydrographic conditions governing the Balearic Islands and to assess the possibility of using copepods as indicators of the water mass dynamics in the region of study.

Method

Physical and chemical data

From January 1994 to December 1999, three stations at 75-, 100- and 200-m depth (St. 1, St. 2 and St. 3, respectively), located along a transect reaching the shelf-break over the southern shelf of Mallorca, were visited monthly at the same time each day (09:30 am to 12:00 pm GTM + 1; Fig. 1). Water for nutrient

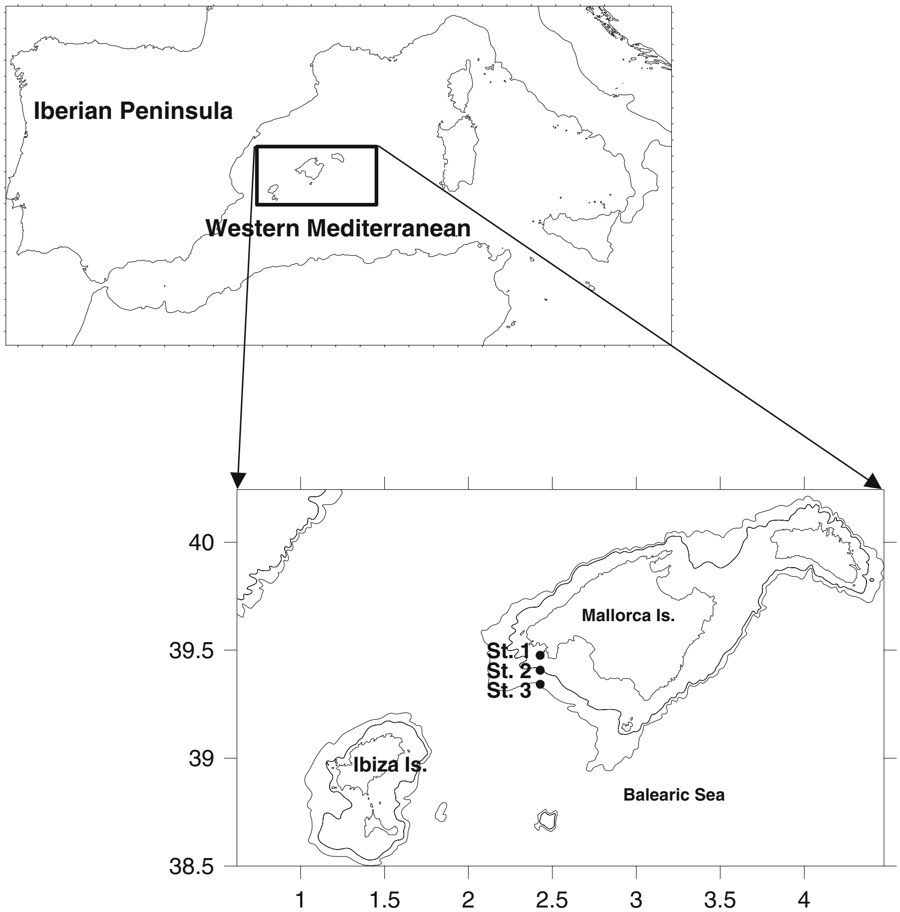

Fig. 1 Map of the Western Mediterranean indicating the location of the sampling stations at the south-west of Mallorca (Balearic Sea)

analysis and hydrography were collected at depths of 0, 5, 15, 25, 50, 75, 100, 125 and 200 m (if bottom depth was not shallower) with 5 l Niskin bottles. Nutrient samples were immediately frozen (−20°C) and later analyzed in the laboratory following Armstrong et al. (1967) recommendations. CTD data were recorded with a Seabird 19 probe.

Biological information

Zooplankton was sampled with a Bongo Plankton net, fitted with a mesh of 250-µm size, by means of oblique hauls from 100 m to the surface (from 75 m at St. 1). Samples were fixed in 4% neutralized formaldehyde buffered with borax. At least two subsamples were analyzed and the data given as ind. m^{-3} (for details see Fernández de Puelles et al., 2003a).

Statistical analysis

Oceanographic variables, i.e. standardized monthly averages of sea water temperature, salinity and nitrates were grouped using cluster analysis to identify hydrological similarities between years. Bray-Curtis similarity was used on squared root transformed oceanographic variables. The averaged hierarchical classification was carried out using the PRIMER program (Plymouth Marine Laboratory, UK).

At first, biological time series (38 copepod species more abundant and 72 monthly averages) were log-transformed and standardized to smooth the differences between species. Rare species that appeared in less than 10% of abundance values were not included. Groups of species with similar patterns in the interannual, seasonal and coastal-ocean gradients were then obtained by k-means following Hartigan & Wong (1979). In order to investigate the differences between groups, the average abundance per group was calculated and the differences in the group distribution were then inspected graphically.

We also investigated the temporal pattern of the eight most abundant species that encompassed more than 75% of the total abundance of copepods. Principal component analysis (PCA) was applied on a matrix Z_s (months as rows and standardized abundances of the eight top ranked species as columns). Pearson correlation was used to test the covariance of hydrographic factors and the main pattern of copepods' temporal variability as showed by the first principal component (49% of the total variance). The number of degrees of freedom was corrected to account for autocorrelation (Pyper & Peterman, 1998).

Results

Hydrography

The seasonal cycle in temperature was the most obvious signal detectable in the upper waters of the study area, characterized by winter cooling and summer warming as a typical thermic regime of these temperate latitudes. Strong stratification developed between May and October from 50- to 75-m depth and a well-mixed water column occurred during winter months (see St. 3 representing the area, Fig. 2a). During the six-year study, the sea surface temperature (SST) has ranged from 13.1°C in January (1994, 1996 and 1997) to 27.4°C in August 1998. The annual mean temperature of the upper waters (0–75 m) during the six years of the study was 17.1 (STD = 2.13). A sinking of the thermocline was observed during 1997 and 1998 (especially clear at 75-m depth). Conversely, salinity (annual mean 37.69; STD = 0.15) did not show a well-defined seasonality probably due to the influence of different water masses in the area (St. 3; Fig. 2b). Higher values were usually observed during winter (38.3) and lower ones during autumn (37). Monthly fluctuations dominated the signal particularly evident in the upper 50 m. The nutrients (represented here by nitrates) showed interannual variability and were also noticed to decrease from the beginning to the end of the study period (Fig. 2c). The average temperature for each year showed a slight increase, with a maximum annual mean in 1998 that exceeded the mean of all 6 years by more than 0.7°C. The year 1996, however, showed the minimum mean annual temperature (Fig. 3a). The annual means of salinity are indicative of the interannual signal modulating the mesoscale hydrographic fluctuations in the study region (Fig. 3b). The lowest salinity values of 1995 and 1998 suggested that these fresher water masses may be indicative of intrusion from the southwestern Mediterranean. Southwestern waters are also generally warmer, which explains the anomalous high waters in 1998. The annual concentration of nitrates showed low values during the warming period and during those years with low salinity (Fig. 3c).

Cluster analysis performed on sea temperature, salinity and nitrate data shows the interannual variation of hydrological properties during the study period (Fig. 4). The years 1994 and 1996 showed similar oceanographic conditions, i.e. high salinity and nutrient concentrations and low temperatures, suggesting the influence of northern WM waters. The year 1998 was particularly warm with low salinities and nitrate concentrations, indicative of more recent AW. On the other hand, the other years were characterized by a mixture of both water masses, which is usually the case in the Balearic Sea.

Copepod structure

Copepods dominated the zooplankton assemblage at the three stations (on average 54% of total zooplankton) and 10–15 species out of the 83 identified represented the bulk of copepod abundance (68–80% of total copepods). *Oithona* and *Clausocalanus* (*C. arcuicornis*, *C. furcatus*, *C. pergens* and *C. paulus*) were the most abundant copepods (52% of total copepods) followed by *Ctenocalanus vanus, Paracalanus parvus, Centropages typicus, Oncaea* spp., *Acartia clausi* and *Diaixis hibernica* (each one >2%). *Temora stylifera, Nannocalanus minor* (>1%), *Calanus helgolandicus* and *Neocalanus gracilis* (<1%) were less abundant.

Seasonal and interannual variability

Total abundance of copepods showed a cross-shelf gradient that decreased from the coast to offshore

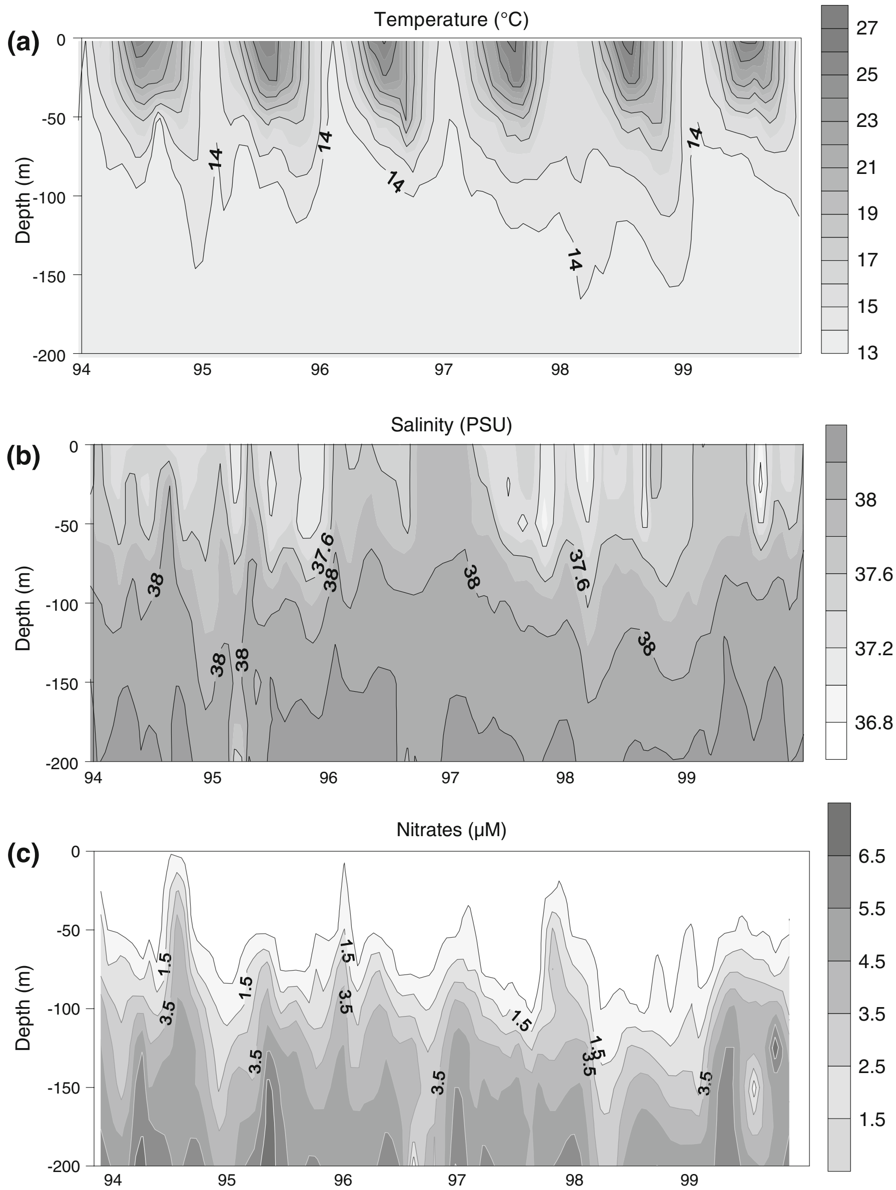

Fig. 2 Monthly time-series of (**a**) temperature (°C), (**b**) salinity (PSU) and (**c**) nitrates (μM) in the upper 200-m depth at station 3

(Fig. 5). The seasonal variability of coastal waters was characterized by three main peaks occurring in late winter, spring and at the end of summer, the spring peak being usually the highest. Going offshore, the winter peak becomes more important than the spring peak. Interannual variability was also observed during the 6-year period with a lower abundance during the last years of the study. Furthermore, it is worth mentioning that the seasonal and interannual variability of some species exhibited a clear pattern, while others were not so defined and almost present. For instance (Fig. 6), *C. typicus*, which was usually observed during spring, was more abundant during the last years of the study. In addition, *A. clausi*, which exhibited summer preference and more coastal presence, was particularly abundant during warmer years. *T. stylifera* was mainly recorded in autumn, showing similar abundance at the three stations. *Acartia danae* was another species exhibiting a higher abundance during autumn and in particular offshore during the warming period. Finally, among the *Calanidae*, *C. helgolandicus* was present only in winter during the first 3 years and it was absent afterwards. However, *N. minor* and

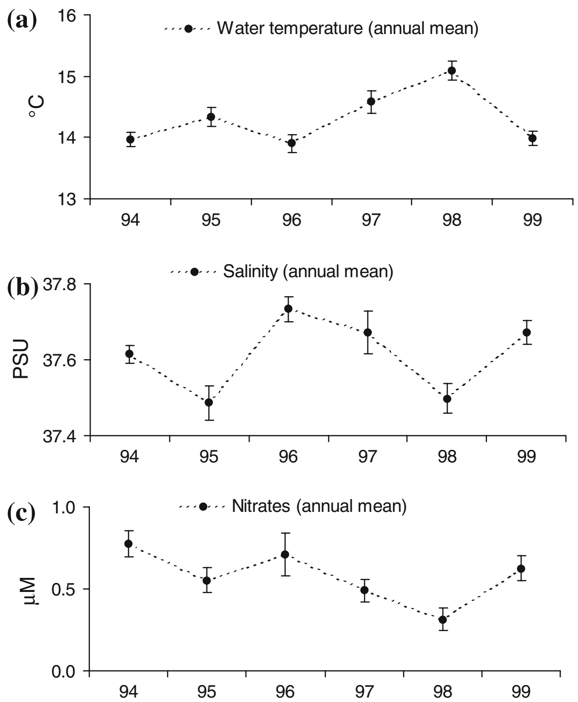

Fig. 3 Mean annual values of (**a**) sea water temperature (°C), (**b**) salinity (PSU) and (**c**) nitrates (µM) at 75-m depth (modified from Fernández de Puelles et al., 2003b) at station 2

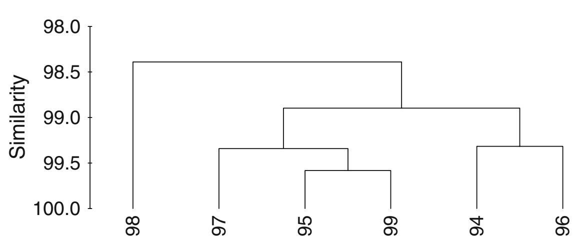

Fig. 4 Hierarchical classification of environmental conditions during the study period. Dendrogram considers water temperature, salinity and nitrates concentrations at the three stations, based on the Bray-Curtis similarity matrix and squared root data transformation (taken from Fernández de Puelles et al., 2003b)

N. gracilis, recorded in autumn and winter, respectively, did not show defined temporal variability.

Overall, copepods were grouped into four assemblages by the K-means analysis (Fig. 7). The first group (Group 1) was composed of *C. helgolandicus*, *C. arcuicornis*, *C. pergens* + *C. paululus*, *C. vanus*, *C. tenuis*, *Pleuromamma gracilis* and *Candacia* spp. These species were generally present at the three stations during the cold months, from winter to early spring. Pearson coefficients indicated a significant positive correlation between the abundance of copepods in this group and salinity ($r = 0.68$–0.78; $P < 0.05$) and an inverse correlation with temperature ($r = -0.85$–0.96, $P < 0.01$). *C. furcatus* was the most abundant species of the second assemblage (Group 2). This species, which had highest abundances in shallowest waters (St1 > St2 > St3; $P < 0.05$), together with the associated *P. parvus*, *C. typicus*, *A. clausi*, *Isias clavipes* and *D. hibernica*, was more abundant during warm months, from late spring to summer. Also, group 2 showed positive correlation with salinity and negative correlation with temperature ($r = -0.58$–0.70; $P < 0.05$), but the correlation coefficients were significant only in very shallow waters (St. 1, $r = 0.53$ and -0.64, $P < 0.05$ for salinity and temperature, respectively).

The third group (Group 3) consisted of oceanic species, *N. gracilis*, *N. minor*, *Mecynocera clausi*, *Pleuromamma abdominalis*, *Lucicutia flavicornis* and *Farranula rostrata*. The species of Group 3 were more abundant at low temperatures (St. 3, $r = -0.77$; $P < 0.05$), while a negative correlation with salinity was observed only in St. 1 ($r = -0.70$; $P < 0.05$).

The fourth group (Group 4) was dominated by *Oithona* spp. that with *Calocalanus pavo*, *C. styliremis*, *C. plumulosus*, *T. stylifera*, *Centropages bradyi* and *A. danae* showed the annual maximum during the autumn. This group did not show differences amongst stations. Group 4 was the only assemblage positively correlated with temperature ($r = 0.50$–0.58; $P < 0.05$).

The interannual changes of the main copepods and their link with hydrographic properties were also investigated, performing a PCA on the most abundant species or genera (Table 1). The contribution of each species to the first axis of the PCA (49% of the total variance) is indicated in Table 1. The significant correlation between the first axis of the PCA and the environmental factors (temperature $r = -0.48$; $P < 0.03$; salinity $r = 0.74$; $P < 0.001$) suggest that around Mallorca, the bulk of the copepod community is significantly related to the hydrographic patterns of the area. The close relationship between the temporal pattern of the most abundant copepods and environmental factors (Fig. 8) suggests the possibility of using this association to track hydrographic changes in the Balearic Sea.

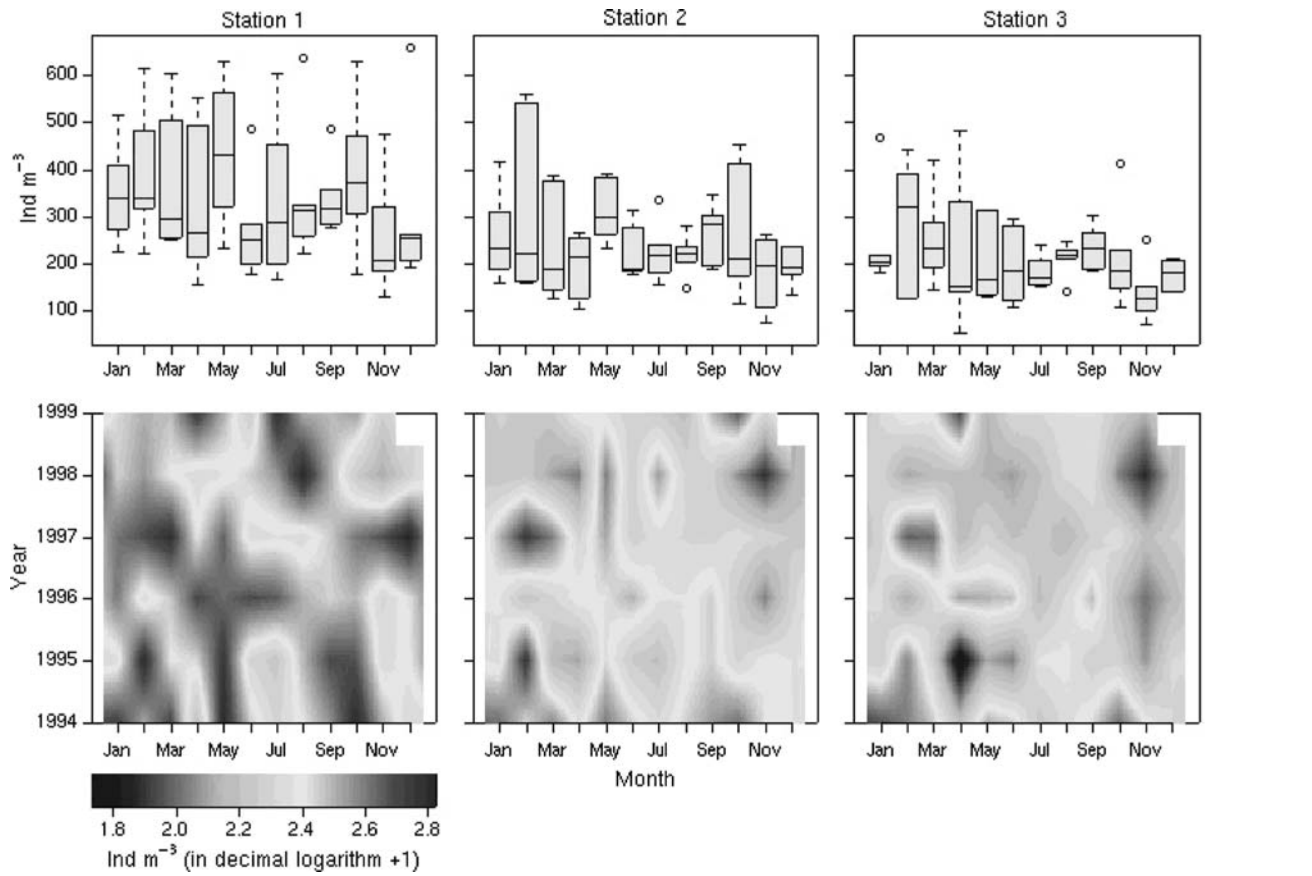

Fig. 5 Seasonal (upper panel) and interannual (lower panel) distribution of total copepods (as ind. m^{-3}) during the study at the three stations

Discussion

During the period from 1994 to 1999, we have analyzed annual changes of the copepod community in relation to the environmental variability in the Mallorca channel (Balearic Sea). This is considered a boundary area into the WM between the northern Mediterranean waters with longer residence time, getting salty and cooler from the Gulf of Lions and more recent AW from the Alboran Sea, warmer and less saline (Pinot et al., 2002). Our results highlight the strong hydrological changes that the area experiences, i.e. saltier and cooler waters noticed in 1996, and an increase in temperature observed during 1998 and 1999. These changes appeared to be important drivers of the interannual and seasonal variability of the copepod community in the Balearic region. Moreover, the close covariation between copepods and hydrography suggests a rapid response of copepods to the environmental changes, i.e. inputs of different water masses coming through the study area. These results also suggest the possibility of using pelagic copepods as indicators of hydrological regimes, as has also been reported in the Northeast Atlantic (Edwards et al., 2002; Beaugrand et al., 2002; Beaugrand, 2003), the California current (Peterson et al., 2001; Rebstock, 2002), the China current (Hwang & Wong, 2005) and the North Pacific (Mackas et al., 2001).

Hydrography is likely to have a substantial influence on the overall zooplankton distribution at coarse and mesoscale (Boucher, 1984; Peterson et al., 1979), which is in turn linked to large scale atmospheric forcing. A clear cross-shelf gradient was observed in the copepod abundance as in other areas of the WM Sea (Estrada et al., 1985). Such gradient is particularly evident in the Balearic Sea, where the shelf is

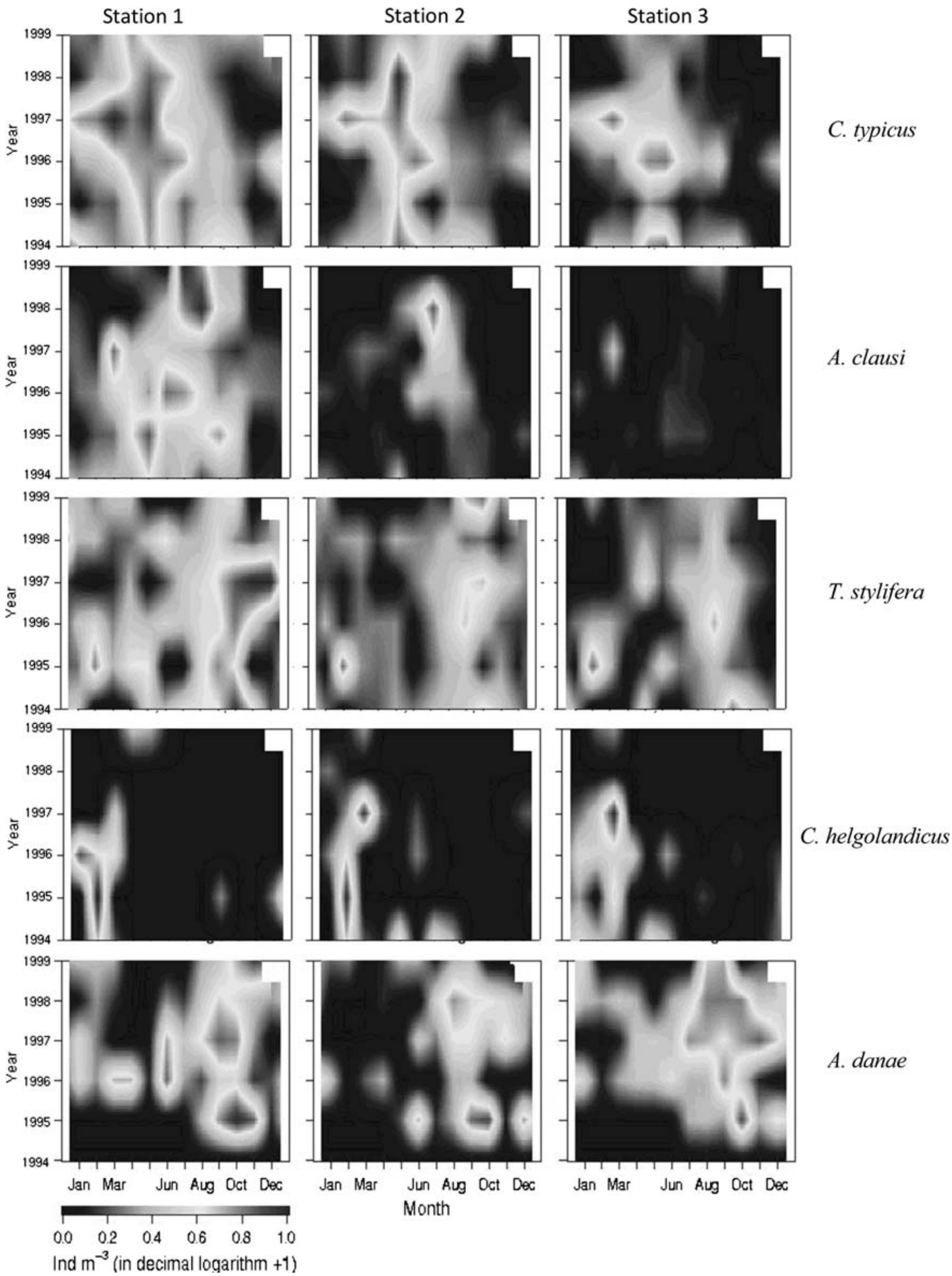

Fig. 6 Seasonal and interannual distribution pattern of *Centropages typicus*, *Acartia clausi*, *Temora stylifera*, *Calanus helgolandicus* and *Acartia danae*

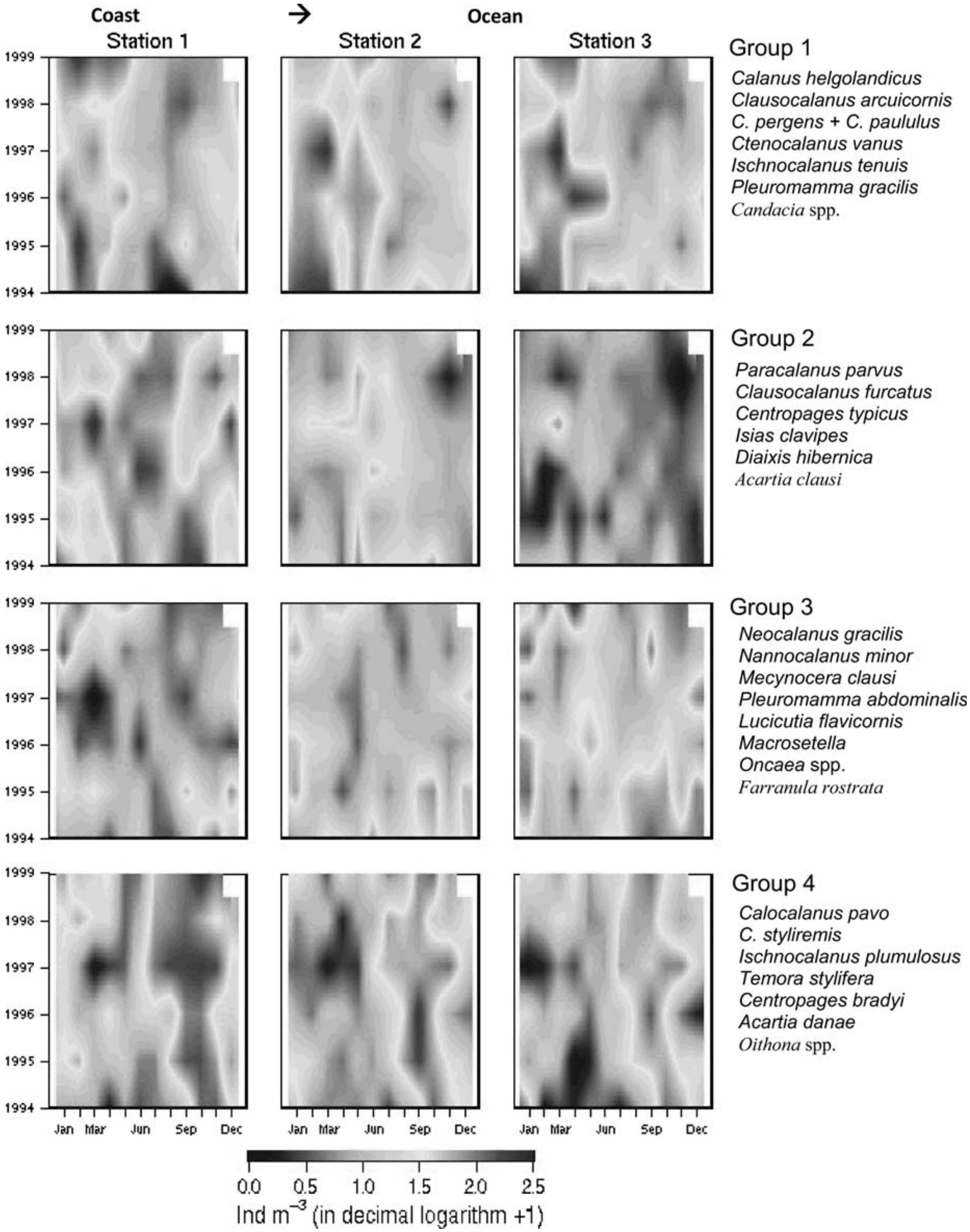

Fig. 7 Seasonal and interannual patterns on the four copepod assemblages identified by the k-means cluster analysis

Table 1 List of the eight top ranked copepod species and their contribution on the first principal component analysis

	PC1 (49% variance)
Oithona spp.	−0.3179
Clausocalanus arcuicornis	0.2308
C. pergens & *C. paululus*	0.8832
Paracalanus parvus	0.6593
Ctenocalanus vanus	0.4511
Centropages typicus	0.7417
Clausocalanus furcatus	0.7166
Oncaea spp.	0.0742

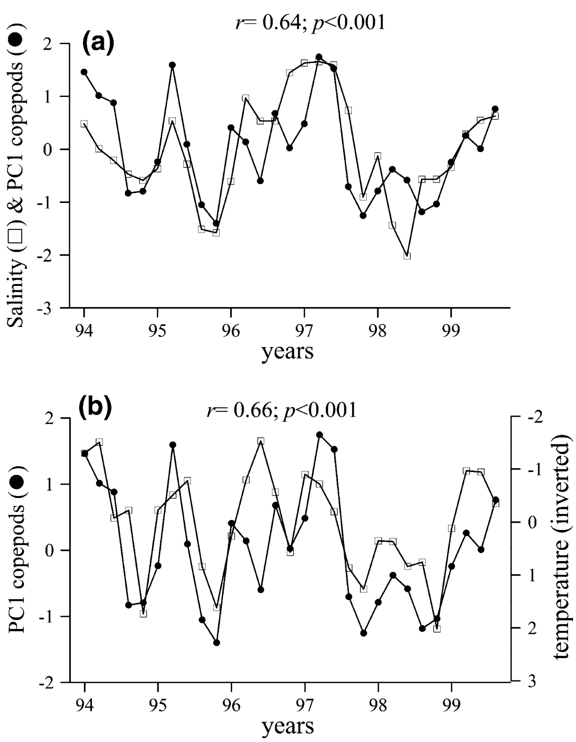

Fig. 8 First principal component (PC1) of the interannual variability of the eight most abundant copepods in relation to (**a**) salinity and (**b**) temperature (°C)

very short compared to other coastal areas of the Iberian mainland.

The four copepod species assemblages identified in the Balearic Sea are associated to different seasons and water masses. The first assemblage included the dominant species *C. arcuicornis*, *C. pergens*, *C. paululus*, and *C. vanus*, and the less abundant *C. helgolandicus* showed a closer distribution at the three stations and winter months presence. Moreover, their positive relation with salinity could be associated to northern Mediterranean waters rather than waters from the Alboran basin (Hopkins, 1985; Pinot et al., 2002). The second assemblage (Group 2), grouped *P. parvus*, *C. furcatus*, *C. typicus*, *A. clausi* and *D. hibernica*, showed the highest abundance in the coastal region during spring–summer. Group 3, i.e. *N. minor*, *N. gracilis*, *P. abdominalis* and *M. clausi,* mainly characterized the offshore waters. The preference for low salinity waters suggests that high abundance of the species in this group may be related to intrusions of waters from the Atlantic. The species assembled in Group 4, i.e. *C. pavo* and *C. styliremis*, *C. plumulosus*, *C. bradyi*, *A. danae*, *T. stylifera* and *Oithona* spp., were less abundant but they showed a clear seasonal maximum during autumn months. All the copepods mentioned above represent 85% of the total copepod community, and therefore, are indicative of changes in mesozooplankton standing stock in relation to the hydrographic conditions in the Balearic area. Although information on coastal species has been extensively documented in many areas of the Mediterranean (Vives, 1966; Mazzocchi & Ribera d'Alcala, 1995; Siokou-Frangou, 1996; Christou, 1998; Mazzocchi et al., 2007), less information exists for oceanic species, particularly in relation to hydrography (Mazzocchi et al., 1997) or in offshore waters (Scotto di Carlo & Ianora, 1983). In this framework, our work provides information on the temporal variability of pelagic copepods associated with hydrography in open waters of the Balearic Sea. Some species exhibited higher abundances during the cooler season (e.g. *C. helgolandicus*) but others during the warmer months (e.g. *N. minor*). The presence of *C. helgolandicus* during the cooler first 3 years of study and its absence afterwards could indicate the preference of this species for cool and saline WM waters (<15°C; >37.5°C). Nevertheless, we have to take into account the biological cycle of *C. helgolandicus* and its preference for deeper waters (Vives, 1978; Bonnet et al., 2005), which may indicate the input of deeper waters in the upper layers of the WM. Moreover, a higher abundance of *C. helgolandicus* has been mentioned in waters of the Ligurian Sea (Boucher et al., 1987; Licandro & Ibanez, 2000) rather than the Alboran Sea (Seguin et al., 1993), which is in accordance with the present study. *N. minor* and *N. gracilis*, however, showed a preference for milder conditions and less saline oceanic waters. The pelagic and subsuperficial distribution of these species has been already noted by different authors (Vives, 1978; Furnestin, 1979), but they did not find a clear distribution in the WM waters. In the Balearic Sea, *N. minor, F. rostrata, C. plumulosus* and *M. clausi* were found associated to the AW (Fernandez de Puelles et al., 2004b). According to Giron (1963) and Greze et al. (1985), 37 copepod species were considered as AW indicators in which *C. pavo*, *C. styliremis*, *M. clausi*, *P. abdominalis* and *A. danae* were also found in our study. Later studies in the front Almeria Oran (Seguin et al., 1993) indicated that the bulk of copepods was present in almost the whole area and very few poorly abundant species were found as indicators of Atlantic influence in the Mediterranean. However, the most abundant copepods such as *Clausocalanus* and *Oithona* showed a widespread distribution in the Mediterranean, which may indicate a tolerant character within different hydrographic conditions (Gaudy, 1985) and their ability to adapt to fluctuating environments (Mazzocchi and Ribera d'Alcala, 1995).

If we compare the copepod community numbers of our study with other Mediterranean areas, they were lower than those observed in the Tyrrhenian Sea (Mazzocchi et al., 1997) or in the frontal areas of the WM, such as the Alborán Sea (Rodríguez, 1983; Seguin et al., 1993; Seridji & Hafferssas, 2000), the Catalan Sea (Sabatés et al., 1989; Calbet et al., 2001) and the Ligurian Sea (Champalbert, 1996; Licandro & Ibanez, 2000). However, the abundance found in the present study was slightly higher than waters of the Eastern Mediterranean (Siokou-Frangou, 1996; Christou, 1998).

As was previously noted, the Balearic channels appear as a boundary area in the WM (Pinot et al., 1995; Pinot & Jansá, 2001), and consequently, this may affect the dynamics of the pelagic ecosystem (Fernandez de Puelles et al., 2003b). Accordingly, during cold springs, the water mass exchange is very intense in the Mallorca channel and clear segregations appear in the species of copepods (Fernández de Puelles et al., 2004b). During the whole year of 1996, and particularly during winter and spring of 1997, the highest salinity records indicated the influence of northern waters and a higher number of copepods. On the other hand, in 1998, a lower copepod numbers were found with high influence of waters from the south of the Mediterranean. It is worth noting that the higher values of salinity registered during late 1996 and 1997 coincided with a strong negative phase of the NAO, which increases westerlies and brings moist air to the Mediterranean region (Hurrel, 1995; Trigo et al., 2000). A very high abundance of copepods was observed during these years in a coastal area of the Mallorca Island in relation to hydrography and climatic anomalies (Fernández de Puelles et al., 2004a). In contrast, low salinity was associated with mild winter atmospheric conditions (1995 and 1998), while high salinity with more severe winters (1994 and 1996). This suggests that cold stormy weather in the WM favours the southward spread of northern waters, while milder winter conditions may favour the northward spread of recent Atlantic waters (Pinot et al., 2002). The study area is characterized by low concentrations of nutrients (Jansá et al., 1998), copepod abundance and overall a low productivity (Fernández de Puelles et al., 2003b). However, it is also characterized by a high diversity of copepods (Vives, 1978; Fernández de Puelles et al., 2003a) that likely results are due to the boundary position of the Balearic zone in which the complex hydrology gathers a variety of species characteristic of different water masses. During our study, copepods mainly showed a seasonal variability, with the maximum in the first months of the year when the waters are well mixed and the minimum during the stratified and warmer season densities were similar to those recorded in other oligotrophic areas of the Mediterranean Sea (Siokou-Frangou, 1996; Christou, 1998). The high variability in the observed copepod community structure points out the complexity of this community in the Balearic area. That of course, can be linked to the copepod species timing in relation to their preference of the water masses they inhabit, as it was reported in other boundary areas of the Mediterranean Sea (Boucher et al., 1987; Thibault et al., 1994; Zagami et al., 1996; Gowen et al., 1998; Seridji & Hafferssas, 2000).

The opposite relationship between zooplankton and temperature highlights the importance of a longer duration in the stratification of the water column by limiting the input of nutrients to surface waters and the limitation of phytoplankton and zooplankton growth; a similar phenomena has been reported in waters of the Bay of Biscay during 90s (Valdés & Morales, 1998). Far from being simple, temperature is not the only trigger of biological responses; other variables should be taken into account (hydrography, food, species competition, predators…). In the early 1990s, the increase in the abundance of copepods in the Aegean Sea (Eastern Mediterranean) was related to an increase in salinity due to the intrusion of more saline open waters in the Saronikos Gulf (Christou, 1998). Similar results were reported in the northern WM, where the salinity was the most important variable in relation to the higher abundance of *Clausocalanus* spp. (Kowemberg & Razouls, 1990).

The increase in water temperature observed during our study was mainly related to the particularly mild winters recorded from 1994 to 1998, which may reduce cooling due to local mixing, thus favouring the penetration of warm AW into the Mallorca channel (Pinot et al., 2002; Fernández de Puelles et al., 2004a). With regard to hydrography, persistent eddies lying to the south of the Baleares islands have been found particularly during the period of AW input (Pinot et al., 2002). These mesoscale structures are characterized by high stratification and poor nutrient conditions in contrast with waters from the north. This suggests that southern waters are areas with limited primary and secondary production that strongly influence the structure of the copepod community (Fernández de Puelles et al., 2004b). In addition, recent investigations have shown a strong effect of the North Atlantic climate on zooplankton populations in the WM (Molinero et al., 2005a, b, 2008; Fernandez de Puelles & Molinero, 2007). This allows us to indicate that temperature and salinity changes can be linked to large-scale process, occurring at a basin scale, which in turn are indicative of the mesoscale hydrographic features to the North Atlantic atmospheric forcing.

However, further investigations on longer data sets are necessary to validate this hypothesis. Our results show a rapid response of copepods to hydrographic variability ultimately driven by meso and large-scale processes linking the North Atlantic atmospheric forcing with the WM. Such biological changes are likely to have important implications on the productivity and the functioning of the pelagic ecosystem of the WM. Future works should be focussed on identifying indicator species of other zooplankton groups at different time-scales. This will help to assess the ecological mechanisms through which planktonic functional groups respond to hydrographic regimes driven by climate.

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