ICES Journal of Marine Science, 61: 654–666 (2004)
doi:10.1016/j.icesjms.2004.03.031

Hydrographical characteristics and zooplankton distribution in the Mallorca channel (Western Mediterranean): spring 2001

M. Luz Fernández de Puelles, Joaquín Valencia, Javier Jansá, and Ana Morillas

Fernández de Puelles, M. L., Valencia, J., Jansá, J., and Morillas, A. Hydrographical characteristics and zooplankton distribution in the Mallorca channel (Western Mediterranean): spring 2001. – ICES Journal of Marine Science, 61: 654–666.

The distribution of zooplankton in the upper 100 m of the Mallorca channel (Balearic Sea) was investigated during the spring of 2001 and related to the main hydrographic parameters. Synoptic satellite images were examined and 29 stations were sampled by means of oblique hauls. The sea surface temperature, salinity, and chlorophyll *a* in the channel show the existence of a hydrological front related to the composition of phyto- and zooplankton. The main zooplankton groups revealed a horizontal distribution pattern related to the hydrographic features of the area. The highest zooplankton abundance, mainly due to copepods (78% of the total zooplankton), was found where the coolest and more saline waters were observed, i.e. in the northern part of the channel. The lowest abundance, mainly represented by siphonophores, chaetognaths, and doliolids, was in the south in the warmer and less saline waters, indicating the input of Atlantic waters into the channel. The spatial distribution of the main species and zooplankton groups was also examined in relation to the frontal system, suggesting their function as biological indicators of the upper water hydrography in the Balearic Sea (Western Mediterranean).

Keywords: copepods, frontal system, Mallorca channel, spatial distribution, zooplankton.

M. L. Fernández de Puelles, Joaquín Valencia, Javier Jansá, and Ana Morillas: Spanish Institute of Oceanography, Baleares Center, PO Box 291, ES-07080 Palma de Mallorca, Spain. Correspondence to M. L. Fernández de Puelles: tel: +34 971 401561; fax: +34 971 404945; e-mail: mluz.fernandez@ba.ieo.es.

Introduction

The Balearic Sea is a hydrographic transition area into the Western Mediterranean (WM) that separates two sub-basins with different waters masses: the Algerian sub-basin towards the south and the North WM sub-basin. In the latter, processes such as the deep water formation in the Gulf of Lions (Estrada *et al.*, 1985), permanent frontal systems (Estrada and Salat, 1989), or river run-off (Estrada, 1996) contribute to increasing primary production in relation to other mediterranean areas. The Balearic Islands form a geographical border between these two sub-basins, whose coasts are influenced by both sub-basin waters (García Lafuente *et al.*, 1994; López-Jurado *et al.*, 1995; Pinot *et al.*, 2002), depending on the season and the mesoscale processes in adjacent areas. The main feature of the surface circulation over the Balearic Sea is the northward movement of Modified Atlantic Waters (MAW) from the Algerian Basin and the southward movement of Resident Mediterranean Waters (RMW) transported by the Northern Current (NC) that forms fronts between the MAW and RMW (López-Jurado *et al.*, 1996). The channels between the islands are areas through which the different water masses all flow and are therefore very interesting places for hydrography and plankton studies. The Mallorca channel seems to be the main route of southern waters in their northward spread (Pinot *et al.*, 2002). Our hypothesis was that the hydrography in the channel could be well matched with the zooplankton assemblages, and therefore the latter could be used as biological indicator of the water masses.

Physical–biological coupling has been well studied in many areas of the WM (Pinot *et al.*, 1995; Champalbert, 1996; Fernández de Puelles, 1996; Zagami *et al.*, 1996; Jansá *et al.*, 1998), where the importance of zooplankton as a biological indicator is stressed. However, in the Balearic channels or in oligotrophic areas of the WM, the relations between a frontal system and the zooplankton community have been documented inadequately.

The highest zooplankton abundance in neritic waters of the Balearic Sea has been found in spring (Fernández de

Puelles *et al.*, 1997, 2003a), but not always related to phytoplankton blooms (Estrada *et al.*, 1985). Since the Mediterranean is generally considered oligotrophic (Cruzado, 1985; Hopkins, 1985), some pronounced hydrographic structures could contribute to increases in productivity (Estrada, 1996). In fact, persistent frontal structures have been related to high productivity in the WM (Rodríguez *et al.*, 1982; Sabatés *et al.*, 1989; Seguin *et al.*, 1993; Thibault *et al.*, 1994). Similar structures in the Balearic Sea could explain the higher zooplankton abundance during spring.

The main objective of this study was to describe the mesoscale spatial distribution of the zooplankton in relation to the hydrographical structure of the Mallorca channel during spring 2001 and its relationship to the main physical features of the water column investigated.

Materials and methods

During 8–14 May 2001, the RV "Odón de Buén" conducted a survey of 29 stations in surface waters (0–100 m depth) in the Mallorca channel (Balearic Sea, WM), covering an area of 60×50 miles (75–900 m bottom depth; Figure 1). Five stations were located at 75 m bottom depth, five at 100 m, four on the shelf, and the rest off the insular shelf. The five transects studied were separated by 5 nm.

Vertical profiles of temperature and salinity were obtained with a CTD SBE-25. Phytoplankton and chlorophyll samples were collected with Niskin bottles at depths of 0, 25, 50, 75, and 100 m (or shallower in the neritic stations). Zooplankton were sampled by means of oblique hauls with a bongo plankton net (20-cm mouth width and

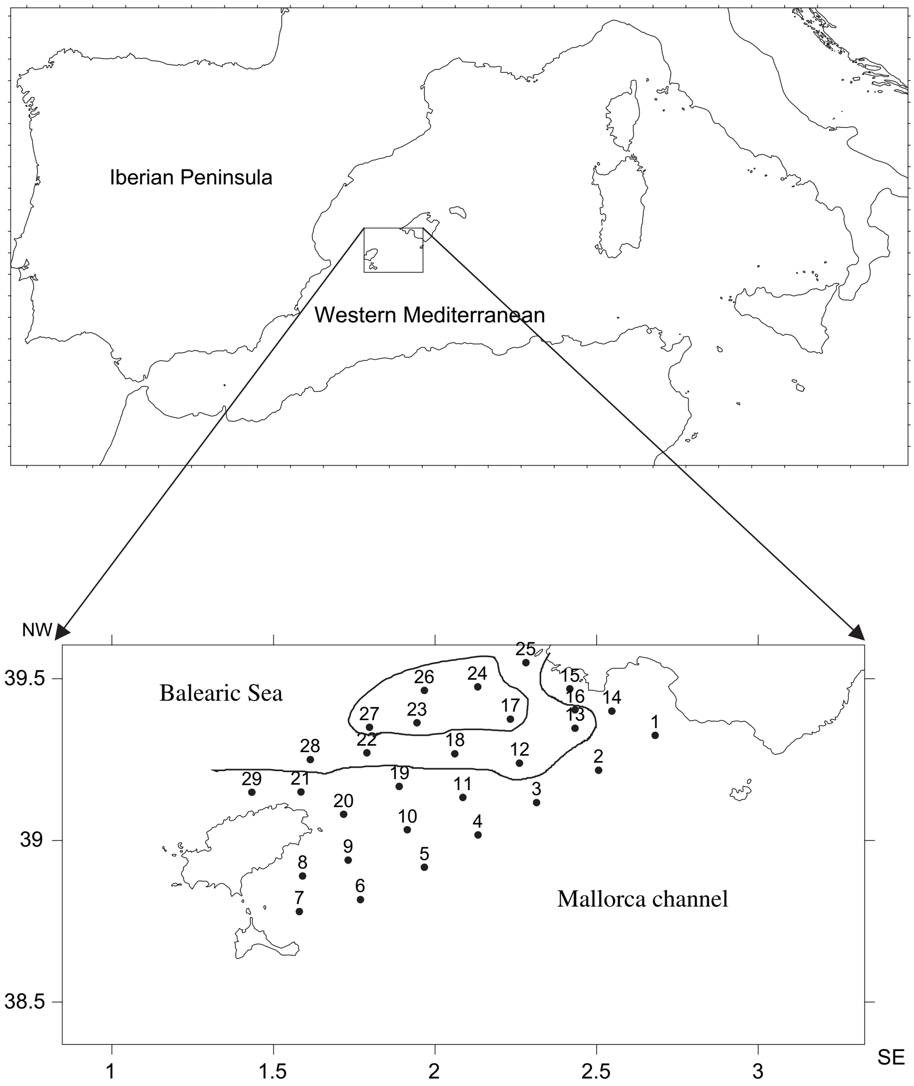

Figure 1. Location of the sampling stations in the Mallorca channel.

100-μm and 250-μm mesh) from 100 m to the surface or from 75 m to surface at the neritic stations. Plankton hauls were performed during day time (from 09:00 to 05:00) at a hauling speed of 20 m min^{-1} and a vessel speed of 2 knots.

A General Oceanic model 2030 flowmeter was fitted to each net in order to measure the volume of water filtered. Immediately after collection, the zooplankton samples were split into two subsamples for biomass and for taxonomic composition analysis with a Folsom Plankton splitter. The samples used for taxonomic analysis were preserved with 4% formaldehyde buffered with borax. Two aliquots from the samples for zooplankton taxonomic analysis were analysed until at least 400 individuals were counted, using the same methodology as previous studies in the area (Fernández de Puelles *et al.*, 1997). Abundance data were transformed to number of individuals m^{-3} and biomass into mg of dry wt m^{-3}. The abundance of the smallest meso-zooplankton (copepod nauplii and copepodites) was calculated from the 100-μm mesh sample.

Chlorophyll *a* concentrations were determined using the fluorimetric technique (Holm-Hansen *et al.*, 1966) after filtration of 1500 ml of seawater on Whatman GF/C Filters. Chlorophyll *a* was extracted with 90% acetone, and measured using a Perkin–Elmer 204 spectrofluorometer (Anon., 1966). Phytoplankton samples were preserved with 4% neutralized formaldehyde and analysed using an inverted microscope following Utermöhl's method (Sournia, 1978).

To group the stations according to the composition in the main zooplankton species and in relation to the location of the frontal system, cluster analyses were carried out using the Bray–Curtis similarity index derived from environmental (temperature–salinity and chlorophyll *a*, after square root transformation) and zooplankton abundance ($\ln(x + 1)$) data. These analyses were performed using the PRIMER programme (Plymouth Marine Laboratory, UK).

Results and discussion

Environmental factors

Physical properties

Sea surface temperature was obtained from satellite images collected during the beginning of the survey (Figure 2). Temperature was higher in the northernmost areas of the channel (22.4 °C compared to 18 °C in southern areas; see

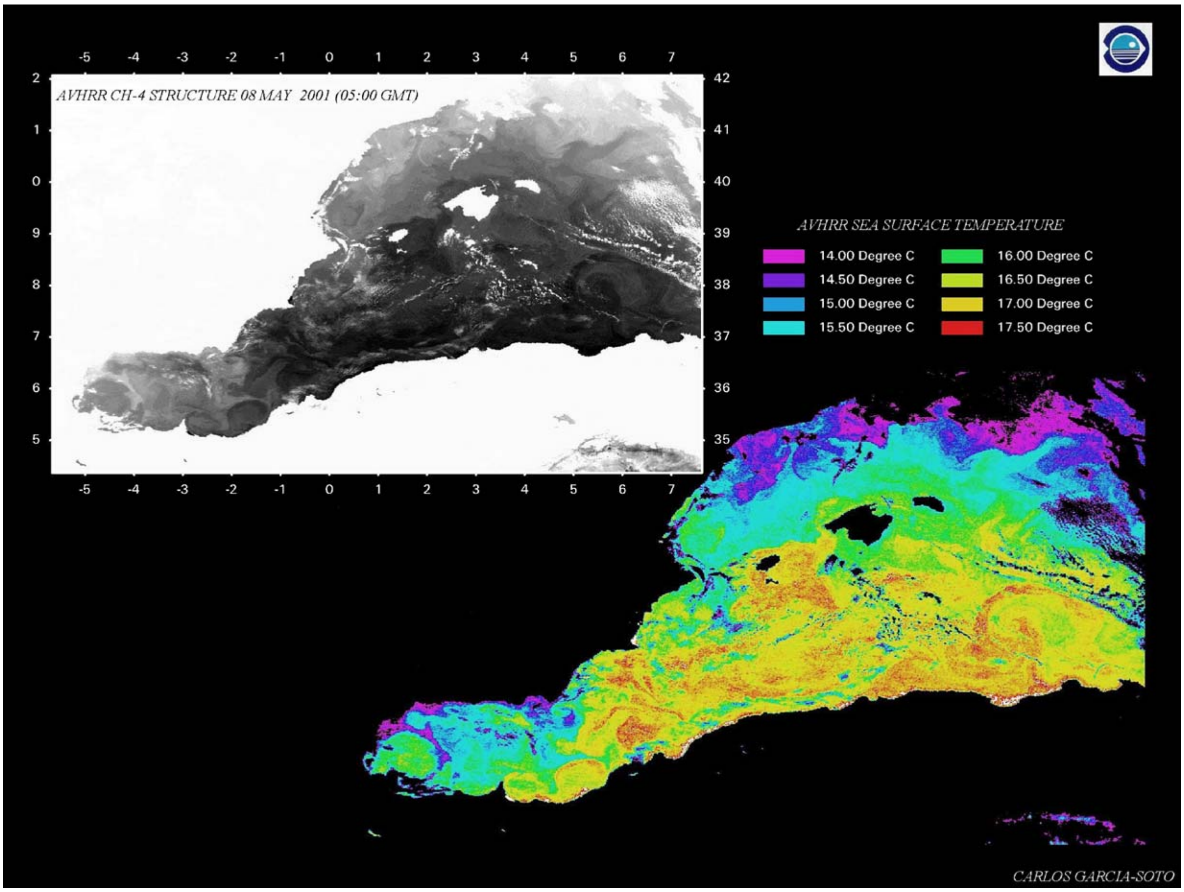

Figure 2. Satellite image of the Western Mediterranean Sea at the beginning of the survey (8 May 2001).

Figure 3a). At 100 m, the ranges varied from 13.0 to 13.9 °C in a N–S direction. Salinity was lower in the southern (37 psu) than in the northern (38 psu) channel (Figure 3b). A frontal system was observed in the central part of the area with a NW–SE orientation, separating the two different water masses: the cool (13.0 °C) and saline (> 38 psu) waters driven by the NC and the warmer (> 15 °C) and less saline (< 37.5 psu) MAW located in the south (López-Jurado *et al.*, 1995). According to these authors, it is difficult to identify a clear water-mass type in the surface waters of the Balearic Sea. However, in the neighbouring Ibiza channel, cold and saline waters (around 13.0 °C and > 38 psu) indicate northern waters, and warmer and less saline (T > 15 °C and S > 37 psu) conditions suggest that recent Atlantic waters have flowed through. Hydrological surveys carried out in the Mallorca channel during the cold spring of 1996 detected northern waters (Pinot *et al.*, 2002), but during the warmer spring of

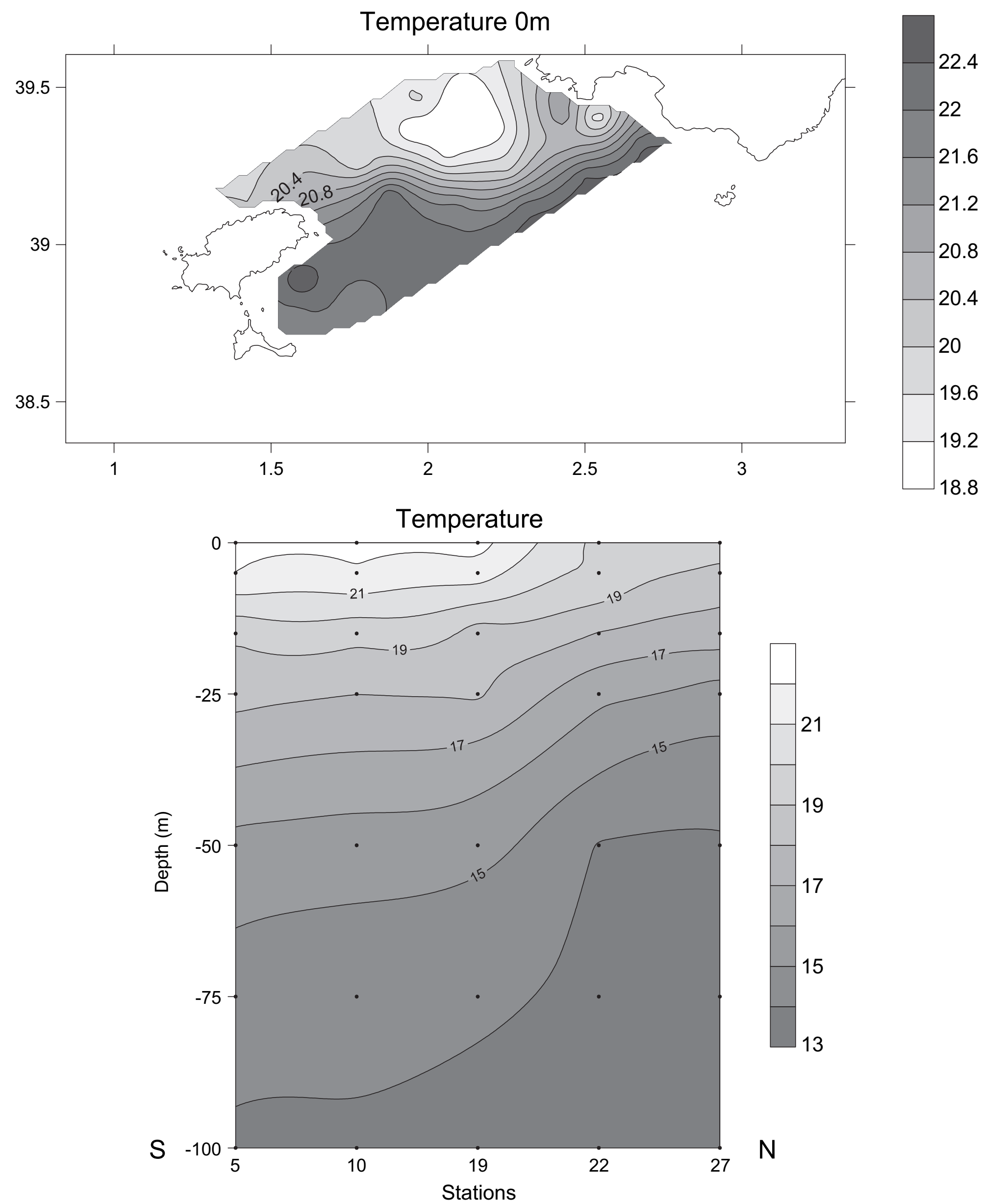

Figure 3. (a) Seawater temperature (°C) at surface and 100-m depth. (b) Salinity (psu) at surface and 100-m depth. (c) Chlorophyll *a* concentrations at the 50–60-m layer and at 75-m depth (μg l^{-1}).

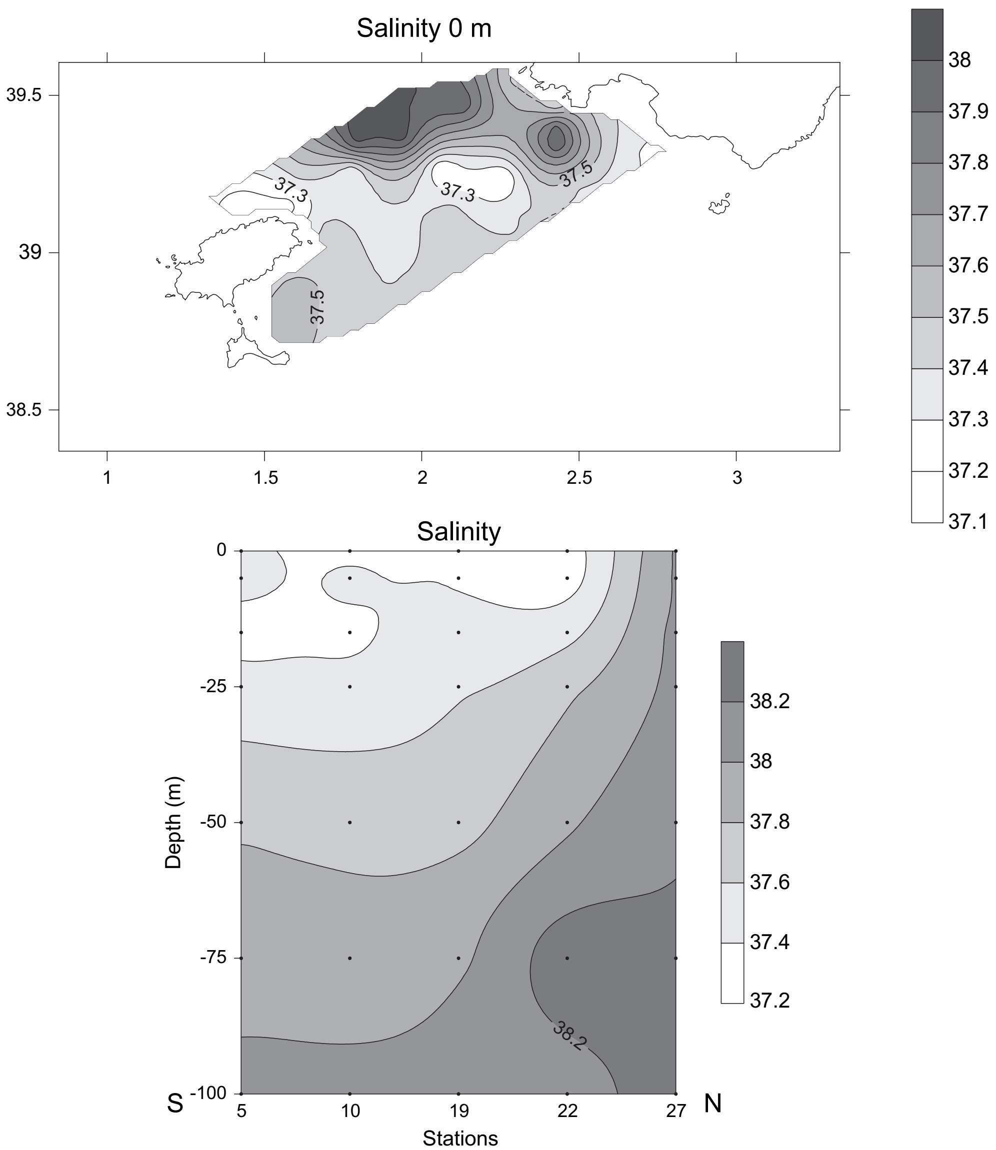

Figure 3 (*continued*)

1998 these authors only observed southern Atlantic waters in the channel. Although interannual variability exists, the Mallorca channel appears to be one of the main routes for the northward expansion of warm southern waters into the Balearic Sea.

Phytoplankton

Very low chlorophyll concentrations were found in surface waters of the area studied, while a deep chlorophyll maximum (DCM) reaching almost 3 μg l^{-1} was observed at 50−60 m, showing the usual spring condition in the Mediterranean Sea (Estrada, 1996). The highest concentrations of chlorophyll *a* were encountered in waters proceeding from the North, probably due to the higher primary production of the North-WM (Flos, 1985). The highest chlorophyll concentrations were found in the southwest region when considering the 75 m isolines, while the DCM in the northern area was located at 50−60 m (Figure 3c). This pattern might be due to the MAW flowing into the southern area. Accordingly, the highest phytoplankton densities (> 100 cells ml^{-1}) were encountered in coastal regions and in the frontal area (Stn 12 and 23; data not shown). Dinoflagellates (52%), coccolithophorids (17%), and diatoms (13%) were the most abundant phytoplankton groups. Nanoplankton (mainly dinoflagellates) were dominant, as has previously been found in other studies carried out in the WM during May (Estrada and Margalef,

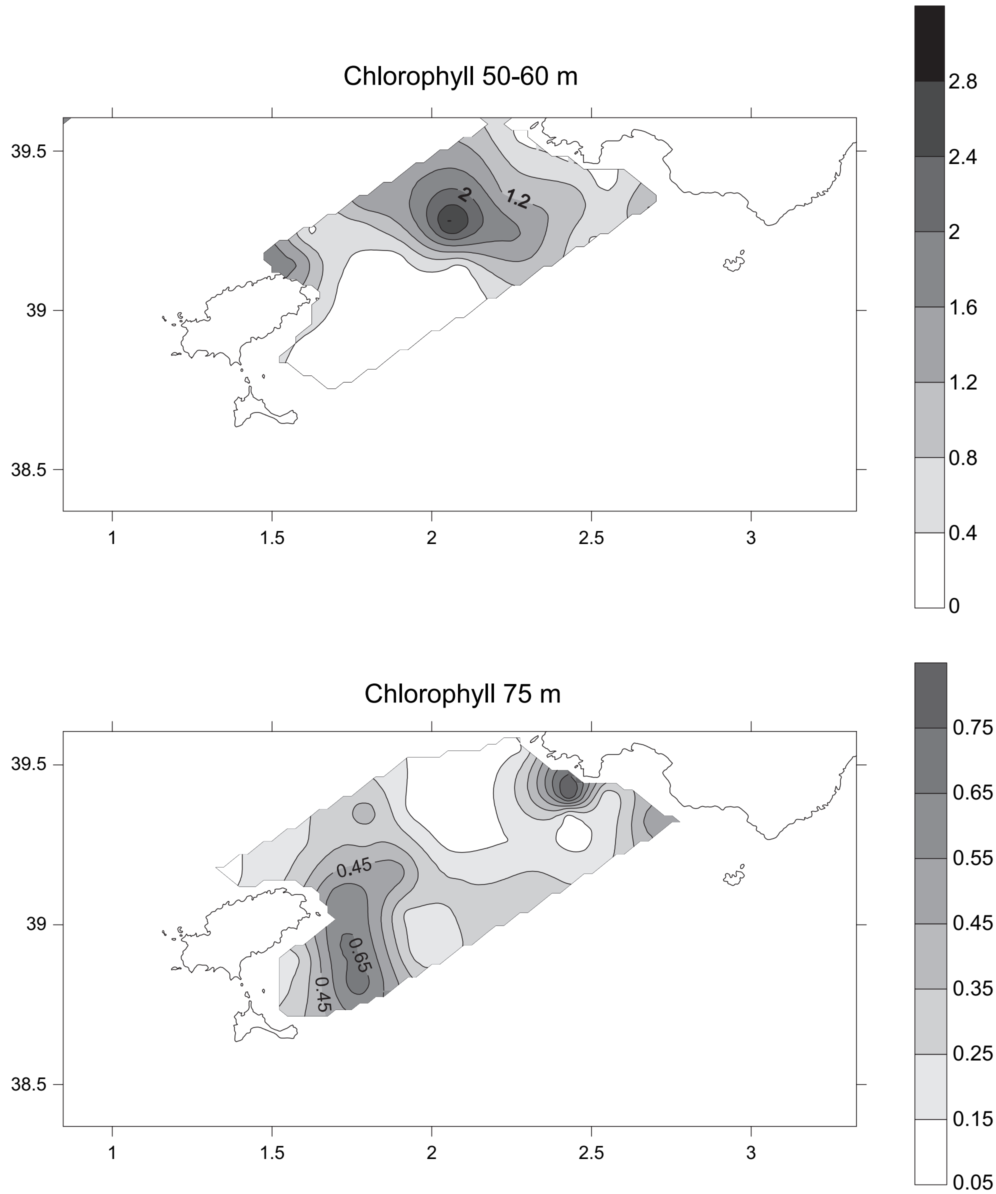

Figure 3 (*continued*)

1988; Jansá *et al.*, 1998). The diatom maxima were located in the northern area of the channel, in the frontal area (Stn 12) and close to the Bay of Palma (Stn 14), with *Pseudonitzschia* spp., *Chaetoceros* spp., and *Guinardia striata* being the predominant species.

A cluster analysis of the main environmental variables (temperature, salinity, and chlorophyll *a* data) from the upper layers (0−100 m; n = 24 and 0−75 m; n = 5) showed three main groups of stations: the neritic group (1, 21, 29, 14, and 15), the stations influenced by the northern water (northwest stations n = 12) and those locations affected by the Atlantic water coming from the south into the channel (n = 12) (Figure 4; see lines in pull-out in Figure 1 together with isolines in figures showing the temperature and salinity distributions).

Zooplankton distribution

The abundance of zooplankton in the upper layer (0−100 m) of the channel showed a horizontal distribution related to the hydrographical conditions mentioned above (Figure 5). The highest zooplankton abundance was found in the northern part of the channel (>1200 ind. m^{-3}), where the water was cooler and more saline, and where the

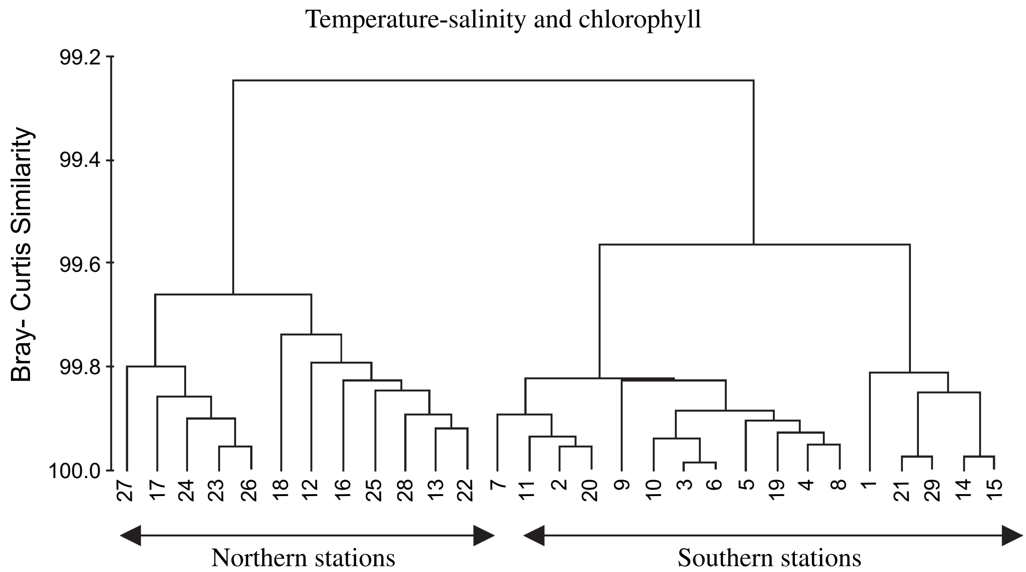

Figure 4. Dendrogram for hierarchical clustering of temperature, salinity, and chlorophyll data during the survey based on the Bray−Curtis similarity index and transformed squared root data of the station sampled.

concentration of phytoplankton was much higher (DCM; see Figure 3c). These higher zooplankton densities have been observed previously in the area surrounding Mallorca, particularly during cold winters (Fernández de Puelles *et al.*, 2003b). On the contrary, the lowest zooplankton abundance was observed in the southern area (400−800 ind. m^{-3}).

The copepods were the dominant group (78% of the total zooplankton), being more abundant in the northern area (Figure 5). They closely mirrored the distribution of the total zooplankton. Appendicularians were the second most abundant group (10%), particularly on both neritic sides of the channel. This distribution pattern could be due to their high sensitivity to water temperature (Acuña and Anadón, 1992). Siphonophores (3%), doliolids (2%), and chaetognaths (1%) were less abundant and appeared to be associated with warmer and less saline waters coming from the south (Figure 6) (Furnestin, 1968).

Sixty zooplankton species were identified in the Mallorca channel during the survey, the 25 most abundant species constituted 78% of the total (Figure 7). *Clausocalanus furcatus*, *C. pergens*, and *Centropages typicus* were the most abundant copepods (33%), followed by *C. arcuicornis*, *Oithona plumifera*, *Paracalanus parvus*, *Ctenocalanus vanus*, *Mecynocera clausi*, and *Oncaea mediterranea* (16%). *Oikopleura* spp. were the most abundant appendicularian (6%), followed by *Fritillaria* spp. Three main species of cladocerans were also important in the area during this month (*Evadne spinfera*, *E. nordmanni*, and *Podon intermedius*) as is usual at these latitudes due to seasonal fluctuations in temperature (Fernández de Puelles *et al.*, 1997). *Evadne spinifera* was the predominant species amongst them (4%) with highest abundance in both coastal areas of the channel.

Copepod nauplii were most abundant in the cooler and more saline northern area. A similar distribution was found for the copepodites and some other copepod species, such as *C. furcatus*, *C. typicus*, *O. plumifera*, *P. parvus*, and *Calanus helgolandicus* (Figure 8). The limit in their distribution seems to correspond to the hydrographic front in the line NW−SE of the channel (stations 28, 22, 19, 12, and 13). On the other hand, copepods such as *C. pergens*, *M. clausi*, *Nannocalanus minor*, *Farranula rostrata*, and *Ischnocalanus tenuis* were more abundant in the south of the channel (Figure 9).

The cluster analysis of the most abundant groups and species found in the channel indicated two groups (Figure 10). The doliolids, chaetognaths, appendicularians, meroplankton larvae and some copepods such as *M. clausi*, *O. mediterranea*, *I. tenuis*, *F. rostrata*, and *N. minor* comprise a zooplankton group that appeared in the southern area and could be related to the warm Atlantic waters. The other group, represented by copepodites, copepod nauplii, *C. furcatus*, *C. typicus*, *P. parvus*, and *C. helgolandicus* was more numerous in the northeastern area, where cooler and more saline waters were observed.

According to these data, the above zooplankton species could be good indicators of the hydrological regime in the waters of the Balearic Sea. They exhibit a higher abundance in relation to their physical and ecological preference depending on the water masses they inhabit. During spring 2001, a NW−SE hydrological front was observed in the Mallorca channel, where the northeastern area exhibited a higher phytoplankton and zooplankton abundance, particularly due to the main group of copepods. The greatest abundance found almost every year during spring on the Mallorcan Shelf (Fernández de Puelles *et al.*,

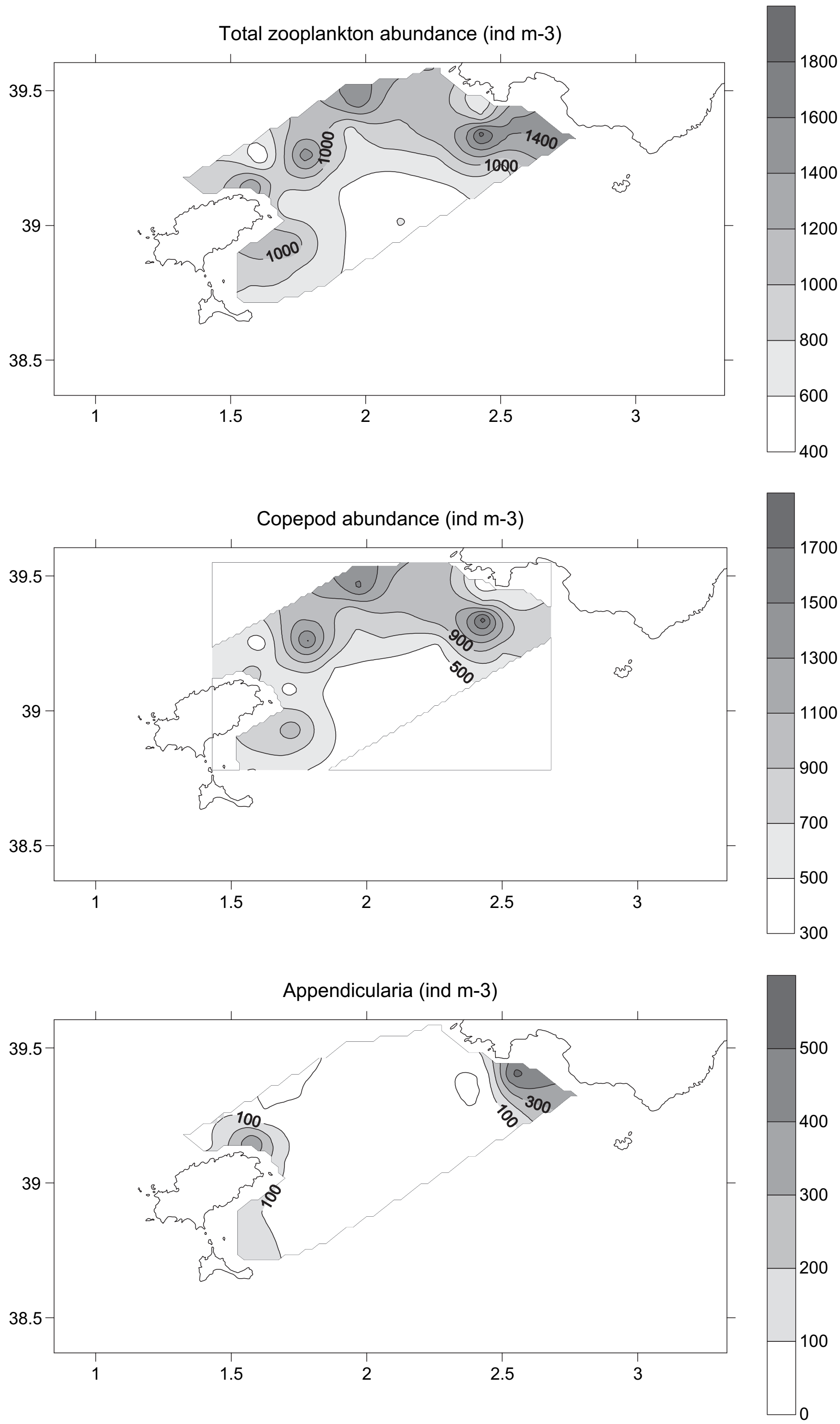

Figure 5. Horizontal distribution of total zooplankton, copepods, and appendicularian abundance in the upper waters (0−100 m) of the Mallorca channel (ind. m^{-3}) during the sampling period.

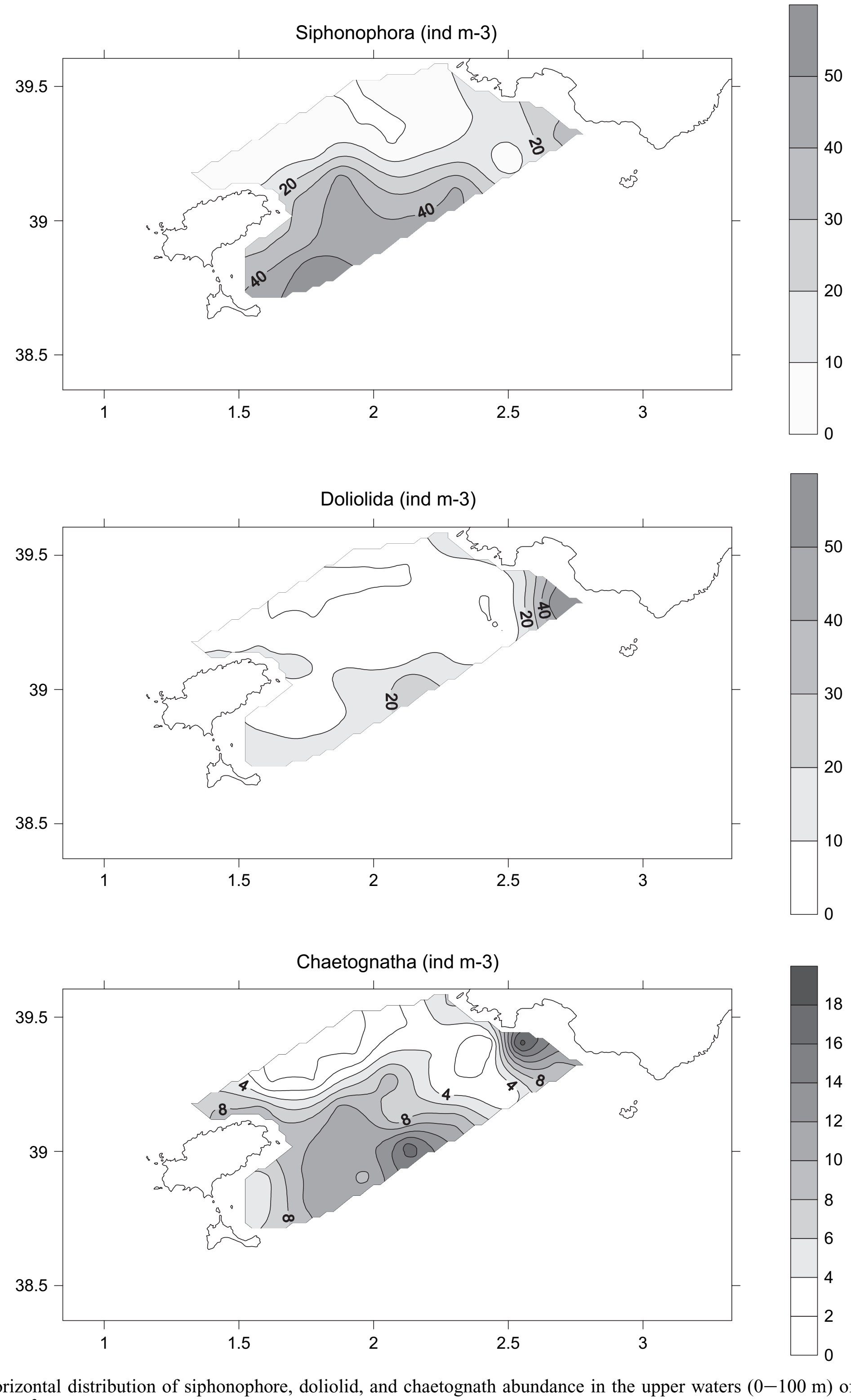

Figure 6. Horizontal distribution of siphonophore, doliolid, and chaetognath abundance in the upper waters (0–100 m) of the Mallorca channel (ind. m^{-3}).

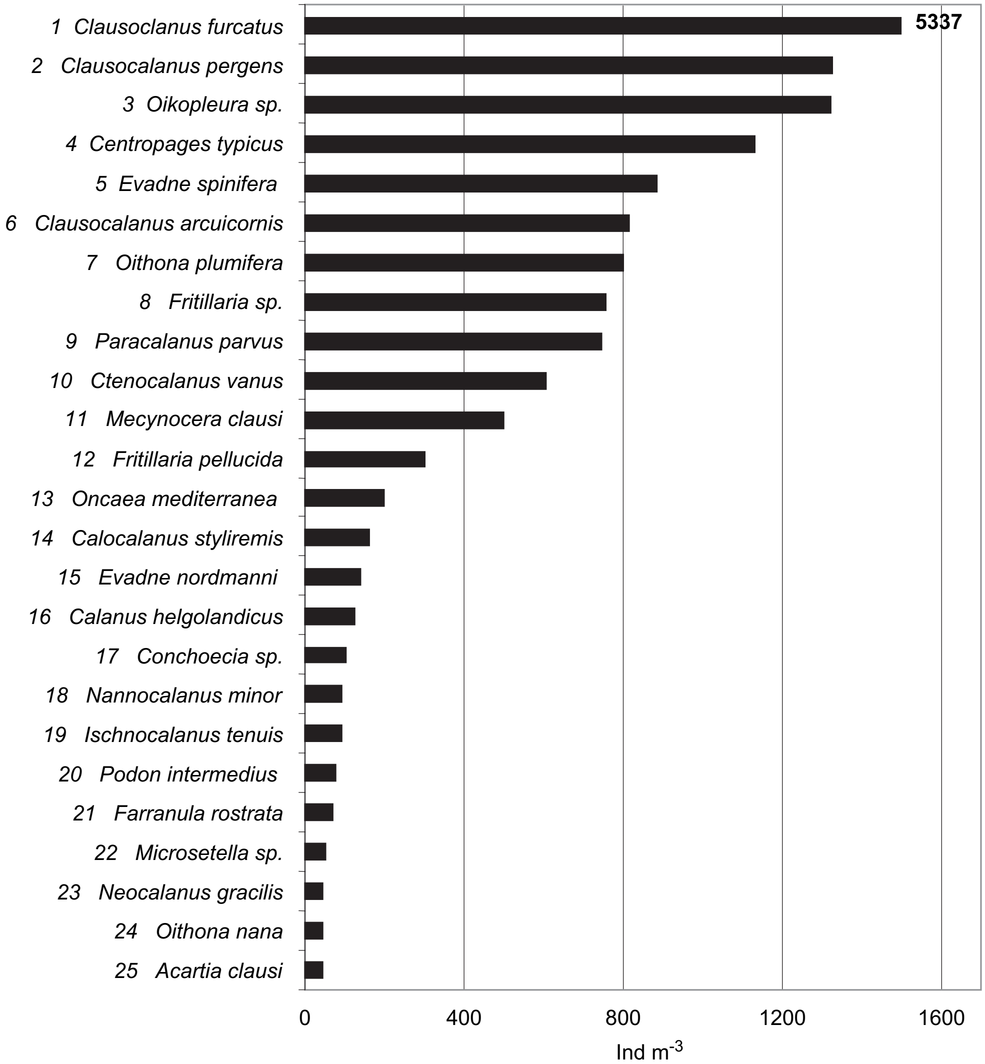

Figure 7. The 25 most abundant zooplankton species collected during the survey (ind. m^{-3}). Data are based on mean accumulated values at all stations.

2003b) could be related to the cold northern water input into the channel. The importance of external inputs as fertilization mechanisms has been reported in oligotrophic waters of the WM Sea (Estrada *et al.*, 1985; Gaudy, 1985). Furthermore, the high densities of zooplankton close to the hydrographic front confirm the tendency of zooplankton to concentrate along these structures and the enrichment in the northern part of the Mallorca channel. This phenomenon is consistent with other frontal systems studied in different areas of the WM Sea, such as in the Alborán Sea (Rodríguez *et al.*, 1982), Almería–Orán front (Thibault *et al.*, 1994), Catalán front (Sabatés *et al.*, 1989), and the Ligure-Provenzal front (Boucher *et al.*, 1987).

Concerning the copepod species composition, little difference was seen between sites into the Almería–Orán front, since due to their tolerance they can be found over a wide range (Seguin *et al.*, 1993). In the northern Mediterranean, the Ligure-Provenzal front, closer observations were found but different species were also observed. In this case the authors considered as principal factors not only the temperature but also the salinity gradient (Boucher *et al.*, 1987). Since high complexity appears in the frontal regions, the species distributions observed are related to the alternative advection/convection transport. However, for some species of copepod, their motion should also be considered, such as *C. helgolandicus* or other migratory species (ontogenetic and vertical migration). Temperature and salinity seem to be the most important factors in the spatial distribution of zooplankton. Therefore, at mesoscale the zooplankton horizontal distribution is mainly associated with complex physical structures. Since most copepods

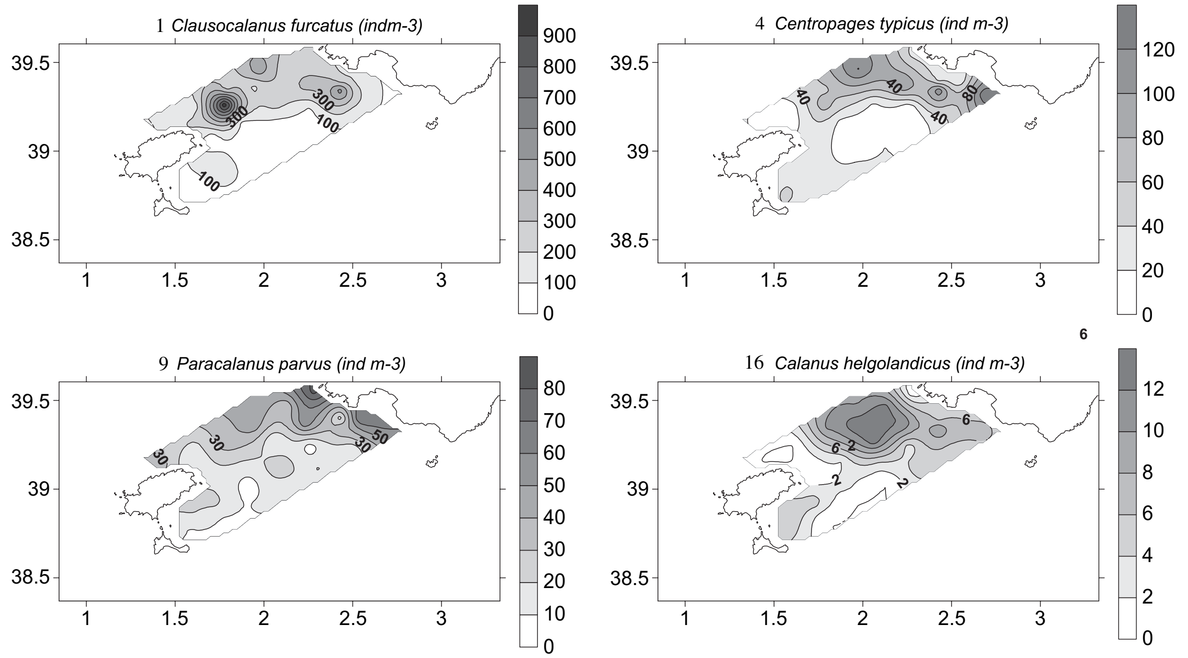

Figure 8. Horizontal distribution and abundance (ind. m^{-3}) of *Clausocalanus furcatus*, *Centropages typicus*, *Paracalanus parvus*, and *Calanus helgolandicus* in the top 100-m depth of the area surveyed.

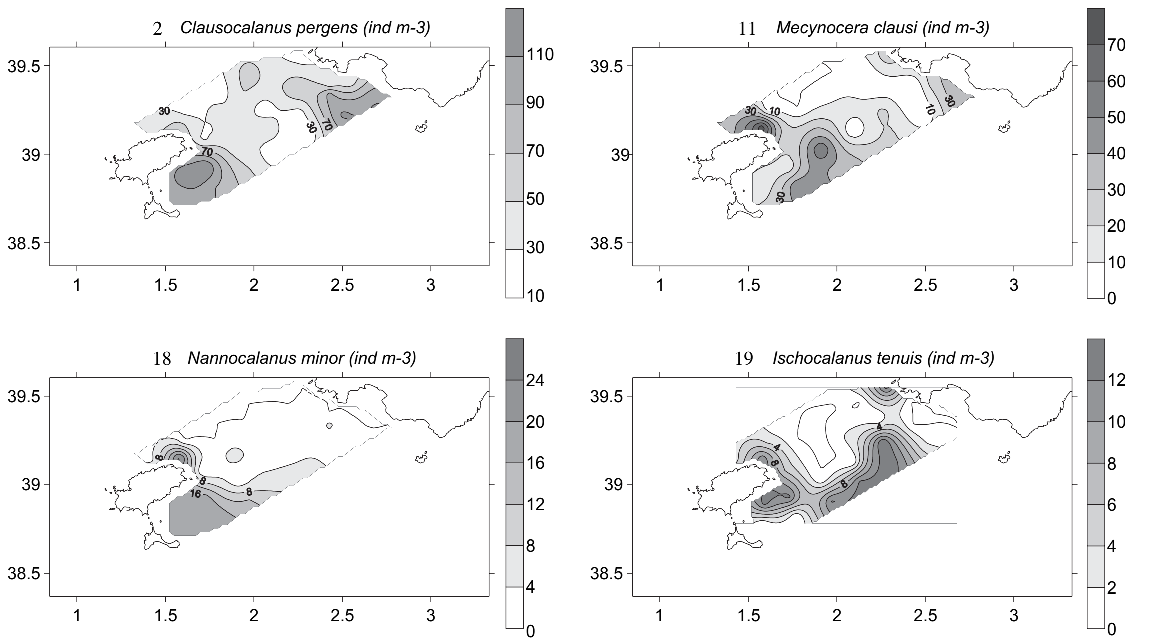

Figure 9. Horizontal distribution and abundance (ind. m^{-3}) of *Clausocalanus pergens*, *Mecynocera clausi*, *Nannocalanus minor*, and *Ischnocalanus tenuis* in the top 100-m depth of the area surveyed.

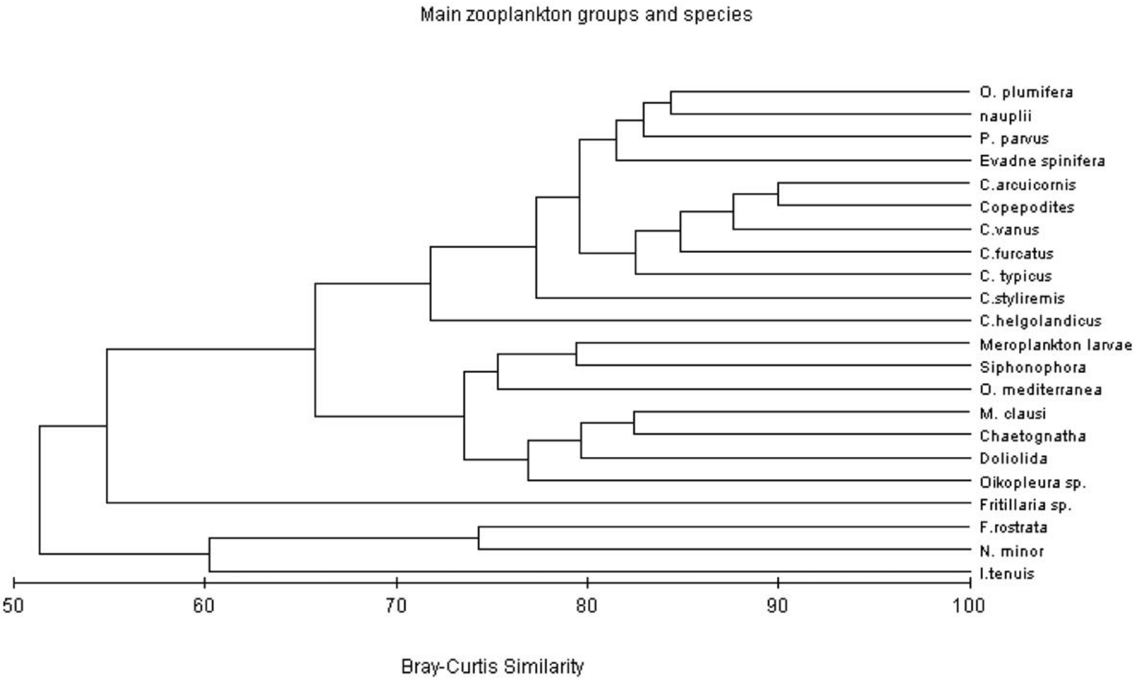

Figure 10. Cluster analysis of the main zooplankton groups and species from standardized abundance data using group average linking and the Bray–Curtis similarity index.

consist of species commonly found in the whole WM, it is difficult to find species with a very defined region distribution (Gaudy, 1985). In this regard, the transitional waters of the Balearic Sea and its hydrographic structure give us the chance to study the upper water masses and the associated zooplankton assemblages.

Our results indicate a close link between zooplankton distribution and physical features in the area investigated. Moreover, we have defined for the first time the distribution of the main copepod species associated with a hydrographic front in the upper waters of the Mallorca channel. *Calanus furcatus*, *C. pergens*, *C. typicus*, *P. parvus*, *O. plumifera*, *C. helgolandicus*, *M. clausi*, *F. rostrata*, *I. plumulosus*, and *N. minor* could be considered key copepod species in the identification of these water masses. Therefore, many of them might be used as indicators of the hydrological regime in the WM Sea. Other seasons, hydrological structures and not only crustaceans, but also gelatinous plankton, should be taken into account in order to define the complex hydrography around the channels of the Balearic Sea.

Acknowledgements

Thanks to the crew of the RV "Odón de Buén" and to M. Serra for his help with sampling and to L. Vicente for sample counting. Thanks also to Dr Hernández-León and the two reviewers who helped us improve the manuscript. Financial support was received from the Instituto Español de Oceanografia (IEO) within the framework of the "Ecobaleares" project. The satellite image was collected by Carlos Garcia Soto from the IEO located in Santander, Spain.

References

Acuña, J. L., and Anadón, R. 1992. Appendicularian assemblages in a shelf area and their relationship with temperature. Journal Plankton Research, 14: 1233–1250.

Anon. 1966. Determination of photosynthetic pigment. *In* Monographs on Oceanographic Methodology 1, pp. 11–18. SCOR/UNESCO Working Group 17. Unesco, Paris.

Boucher, J., Ibanez, F., and Prieur, L. 1987. Daily and seasonal variations in the spatial distribution of zooplankton populations in relation to the physical structure in the Ligurian Sea Front. Journal Marine Research, 45: 133–173.

Champalbert, G. 1996. Characteristics of zooplankton standing stock and communities in the Western Mediterranean Sea: relations to hydrology. Scientia Marina, 60: 97–113.

Cruzado, A. 1985. Chemistry of Mediterranean waters. *In* Western Mediterranean, pp. 126–147. Ed. by R. Margalef. Pergamon Press, Oxford. 363 pp.

Estrada, M. 1996. Primary production in the northwestern Mediterranean. Scientia Marina, 60: 55–64.

Estrada, M., and Margalef, R. 1988. Supply of nutrients to the Mediterranean photic zone along a persistent front. Oceanologica Acta, 9: 133–142.

Estrada, M., and Salat, J. 1989. Phytoplankton assemblages of deep and surface water layers in a Mediterranean frontal zone. Scientia Marina, 53: 203–214.

Estrada, M., Vives, F., and Alcaraz, M. 1985. Life and productivity of the open sea. *In* Western Mediterranean, pp. 148–197. Ed. by R. Margalef. Pergamon Press, Oxford. 363 pp.

Fernández de Puelles, M. L. 1996. Plankton dynamics in relation to physical structures around the Ibiza channel. Bulletin de l'Institut Oceanographique, Monaco 17, CIESM Science Series, 2: 65–80.

Fernández de Puelles, M. L., Gras, D., and Hernández de Leon, S. 2003a. Annual cycle of zooplankton, biomass, abundance and species composition in the neritic area of the Balearic Sea, Western Mediterranean. PSZN Marine Ecology, 23: 1–17.

Fernández de Puelles, M. L., Jansá, J., Gomis, C., Gras, D., and Amengual, B. 1997. Variación anual de los principales parámetros oceanográficos y planctónicos en un área nerítica del Mar Balear. Boletín del Instituto Español de Oceanografía, 13: 13–33.

Fernández de Puelles, M. L., Pinot, J.-M., and Valencia, J. 2003b. Seasonal and interannual variability of zooplankton community in waters off Mallorca island (Balearic Sea, Western Mediterranean): 1994–1999. Oceanologica Acta, 26: 673–686.

Flos, J. 1985. The driving machine. *In* Western Mediterranean, pp. 60–99. Ed. by MargalefR.. Pergamon Press, Oxford. 363 pp.

Furnestin, M. L. 1968. Le zooplancton de la Mediterranée (bassin occidental). Essai de synthese. Journal du Conseil International pour l'Exploration de la Mer, 32: 25–69.

García Lafuente, J., López-Jurado, J. L., Cano, N., Vargas, M., and Aguilar, J. 1994. Surface circulation and dynamics of the Balearic Sea. Seasonal and interannual variability of the Western Mediterranean Sea. Coastal and Estuarine Studies, 46: 73–91.

Gaudy, R. 1985. Features and peculiarities of zooplankton communities from the Western Mediterranean. *In* Mediterranean Marine Ecosystem, pp. 279–301. Ed. by M. Moraitou-Apostolopoulou, and V. Kiortsis. Plenum Press, New York, USA.

Holm-Hansen, O., Lorenzen, C. J., Holmes, R. W., and Strickland, J. D. H. 1966. Fluorometric determination of chlorophyll. ICES Journal du Conseil, 30: 3–15.

Hopkins, T. S. 1985. Physics of the sea. *In* Western Mediterranean, pp. 100–125. Ed. by R. Margalef. Pergamon Press, Oxford. 363 pp.

Jansá, J., López-Jurado, J. L., Morillas, A., and Amengual, B. 1998. Seasonal and mesoscale variability of biological and chemical parameters related to the hydrodynamics of the Ibiza Channel (Western Mediterranean). Boletín del Instituto Español de Oceanografía, 14: 31–47.

López-Jurado, J. L., García Lafuente, J., and Cano, N. 1995. Hydrographic conditions of the Ibiza Channel during November 1990, March 1991 and July 1992. Oceanologica Acta, 18(2): 235–243.

López-Jurado, J. L., García Lafuente, J., Pinot, J. M., and Alvarez, A. 1996. Water exchanges in the Balearic channels. Bulletin de l'Institut océanographique, Monaco 17, CIESM Science Series, 2: 41–63.

Pinot, J. M., López-Jurado, J. L., and Riera, M. 2002. The CANALES experiment (1996–1998). Interannual, seasonal and mesoscale variability of the circulation in the Balearic Channels. Progress in Oceanography, 55: 335–370.

Pinot, J. M., Tintoré, J., López-Jurado, J. L., Fernández de Puelles, M. L., and Jansá, J. 1995. Three-dimensional circulation of a mesoscale eddy/front system and its biological implications. Oceanologica Acta, 18: 389–399.

Rodríguez, J., García, A., and Rodríguez, V. 1982. Zooplanktonic communities of the divergence zones in the northwestern Alborán Sea. Marine Ecology, 3: 133–142.

Sabatés, A., Gili, J., and Pagès, F. 1989. Relationship between zooplankton distribution, geographic characteristics and hydrographic patterns off the Catalan Coast. Marine Biology, 103: 153–159.

Seguin, G., Gaudy, R., Errhif, A., and Thibault, D. 1993. Observations sur l'abondance, la composition taxonomique et les affinités écologiques des copépodes pélagiques récoltés dans la région du front Almería–Orán. Marine Life, 3: 19–29.

Sournia, A. 1978. Phytoplankton Manual. Monographs on Oceanographic Methodology, 6. Unesco, París. 240 pp.

Thibault, D., Gaudy, R., and Le Fevre, J. 1994. Zooplankton biomass, feeding and metabolism on a geostrophic frontal area (Almería–Oránt Front, Western Mediterranean). Significance to pelagic food webs. Journal of Marine Systems, 5: 297–311.

Zagami, G., Badalamanti, F., Guglielmo, L., and Manganero, A. 1996. Short-term variations of the zooplankton community near the straits of Messina: relationships with the hydrodynamics regime. Estuarine Coastal Shelf Science, 42: 667–681.