

Relationships between the Hydrodynamics and Changes in Copepod Structure on the Algerian Coast

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Aziz Hafferssas and Rabia Seridji (2010) Relationships between the hydrodynamics and changes in copepod structure on the Algerian coast. *Zoological Studies* 49(3): 353-366. We investigated the role of the Algerian Current on the structure of the copepod community during June 1990 that covered an area between 1°E and 5°E. In this area, 2 oligotrophic systems of different origins (one related to the Atlantic flow, and the other related to typical Mediterranean waters) and a frontal system were identified. Environmental differences among the 3 zones were related to changes in sea surface salinity, density, and phytoplankton biomass (chlorophyll (Chl)-a concentrations). Three main copepod assemblages were revealed to be distributed along well-defined environmental gradients characterized by the distribution of physical variables and Chl-a. The 1st group was located in the frontal zone where the highest Chl-a concentration was observed at the subsurface (> 1.5 mg/m³). This assemblage showed an important increase of herbivorous species (*Paracalanus parvus*, *Clausocalanus arcuicornis*, *C. furcatus*, *Mesocalanus tenuicornis*, and *Eucalanus elongatus*) which were numerically 4 times more abundant (> 90%) than in modified Atlantic water (MAW) and offshore surface Mediterranean water (SMW) systems (< 30% and 35%, respectively). The 2nd group occupied the inshore MAW system, and was characterized by a typical neritic fauna (*Acartia clausi*, *Euterpina acutifrons*, *Oithona nana*, and *Temora stylifera*). The 3rd group was composed of several species (*Scolecithricella dentata*, *S. vittata*, *Oncaea media*, *Oncaea* sp., *Microsetella rosea*, *Oithona helgolandica*, *Corycaeus ovalis*, *C. brehmi*, *Corycaeus* sp., *Spinocalanus longicornis*, *Scolecithrix danae*, and *Clausocalanus* spp.) and was related to the largest region among the sampled stations. In the deeper layer (200-500 m), 3 groups of copepods showing different distribution patterns were identified using a principal components analysis. No significant relationship between the pattern of each group and the measured environmental variables was identified in this study. However the small number of studies of copepods in this area makes our contribution useful for further global biogeographical studies in the western Mediterranean Sea. <http://zoolstud.sinica.edu.tw/Journals/49.3/353.pdf>

Key words: Algerian coast, Hydrography, Copepods, Zooplankton biomass, Environmental factors.

Marine ecosystem functioning is strongly dependant on the zooplankton community structure and succession (Dur et al. 2007, Lee et al. 2009). The close relationship between the distribution of zooplankton communities and environmental factors was documented in various Mediterranean ecosystems: the Balearic Sea (Fernández de Puelles and Molinero 2008, Fernández de Puelles 2009), Ligurian Sea (Boucher et al. 1987, Sournia et al. 1990, Pinca and Dallot 1995, Licandro and

Icardi 2009), Alboran Sea (Gaudy et al. 2003), and Aegean Sea (Isari et al. 2006). The pelagic ecosystems in the southern Mediterranean, i.e., the Algerian coast, however have rarely been investigated, although the spatial distribution of zooplankton populations and its relation to hydrographic patterns are fundamental for understanding the dynamics of pelagic ecosystems (Hwang and Wong 2005, Riandey et al. 2005, Dur et al. 2007, Yebra et al. 2009). In contrast,

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this type of investigation is more common in the Atlantic Ocean (Clark et al. 2001, Piontkovski et al. 2003) and the Northwest Pacific Ocean (Lan et al. 2008, Lee et al. 2009).

The circulation of water masses along the Algerian coast is characterized by intense mesoscale dynamics (Ruiz et al. 2002, Salas et al. 2002, Millot and Taupier-Letage 2005, García-Olivares et al. 2007, d'Ovidio et al. 2009). The Atlantic inflow determines a sharp boundary in terms of both physical and biological properties (COF 1991). Across the current, large horizontal gradients exist in salinity as well as in the biomass and species composition of phytoplankton and zooplankton communities (Beker 1991, Raimbault et al. 1993, Seridji and Hafferssas 2000). The offshore band of the Atlantic Current is known to be a region of high biological productivity, that originates from the mixing of inshore modified Atlantic water (MAW) and offshore surface Mediterranean water (SMW); it is surrounded by areas of low productivity (Raimbault et al. 1993, Seridji and Hafferssas 2000, Morán et al. 2001). The phytoplankton, chlorophyll (Chl) concentration, and species abundance along the offshore band of the Atlantic Current are strongly linked to interactions between Atlantic and Mediterranean waters (Raimbault et al. 1993). In the frontal system, high concentrations of nutrients and Chl ($> 1.5 \text{ mg/m}^3$) in the photic zone at 55-65 m in depth are related to high zooplankton biomass levels ($> 50 \text{ mg/m}^3$) and abundances ($> 800 \text{ mg/m}^3$) measured at 20 and 60 m of depth during the Elisa (Morán et al. 2001) and Mediproduct VI cruises (Hafferssas 2004). In summer 1997, zooplankton abundance was higher during daylight in the cyclonic eddy than in the anticyclonic eddy (Riandey et al. 2005). This distribution pattern was related to higher Chl concentrations observed in the cyclonic eddy, where the integrated Chl concentration over the upper 200 m was around 110 mg/m^2 (Taupier-Letage et al. 2003) and *Paracalanus/Clausocalanus* populations dominated (23%) the copepod community.

A study by Hafferssas (2004) described the distribution of zooplankton biomass and abundances in detail. The taxonomic composition of the copepod populations and their biodiversity in terms of species richness, evenness, and the Shannon diversity index in relation to hydrographical areas were also investigated by Seridji and Hafferssas (2000). The high value of the zooplankton standing stock (52.56 mg/m^3) in the upper water column, particularly in the frontal

system, was attributed to an increase in the biomass of the smallest size fraction (100-300 μm) (49.01 mg/m^3). In a deeper layer (200-500 m), mean values ranged from 1.28 (MAW system) to 1.59 mg/m^3 (frontal system). In this layer, the smallest organisms (100-300 μm) made up 50%-70% of the total biomass.

The aim of this study was to assess the influences of hydrological and hydrodynamic conditions on copepod populations in epipelagic and mesopelagic areas as a consequence of Atlantic inflow into Algerian waters. The spatial variability in biotic and abiotic descriptors was investigated in order to detect the main copepod assemblages and identify the environmental factors related to such associations.

MATERIALS AND METHODS

The Mediproduct VI cruise was carried out in June 1990, included 19 transects, and covered the area encompassed by $1^\circ\text{-}5^\circ\text{E}$ and $36.06^\circ\text{-}39.10^\circ\text{N}$. Zooplankton sampling was performed during the day time. Physical and chemical measurements were also made at 17 stations (Fig. 1, Table 1). At each station, vertical profiles of temperature, salinity, and Chl-a were obtained using a SEABIRD rosette sampler (Sea-Bird Electronics Inc., Washington, USA), equipped with a fluorometer (COF 1991). Water samples were taken at 10 m intervals from the surface to the bottom (500 m). Zooplankton sampled using a WP2 closing net (200 μm mesh size and 57 cm in mouth diameter) with vertical hauls from 500 to 200 m in depth and from 200 m to the surface. The collected samples were preserved in 10% formalin neutralized with borate. The procedure of sub-sampling, species identification, and counting were similar to those described in Seridji and Hafferssas (2000). Only copepod adults were enumerated in each sample.

Nine variables were used to describe the environmental conditions at each station; sea surface temperature (SST), surface salinity (SS) and Chl-a (SChl-a), temperatures values in and below the thermocline (TC), the mean temperature from the depth range of 200-500 m (T), salinity values in and below the halocline (SC), the mean salinity from a depth range of 200-500 m (S), the integrated Chl concentrations in the top 100 m of the water column (IChl-a), and the Chl-a maximum value at the subsurface (DCM). Zooplankton quantitative descriptors used were the total zooplankton biomass (BT), smallest size fraction

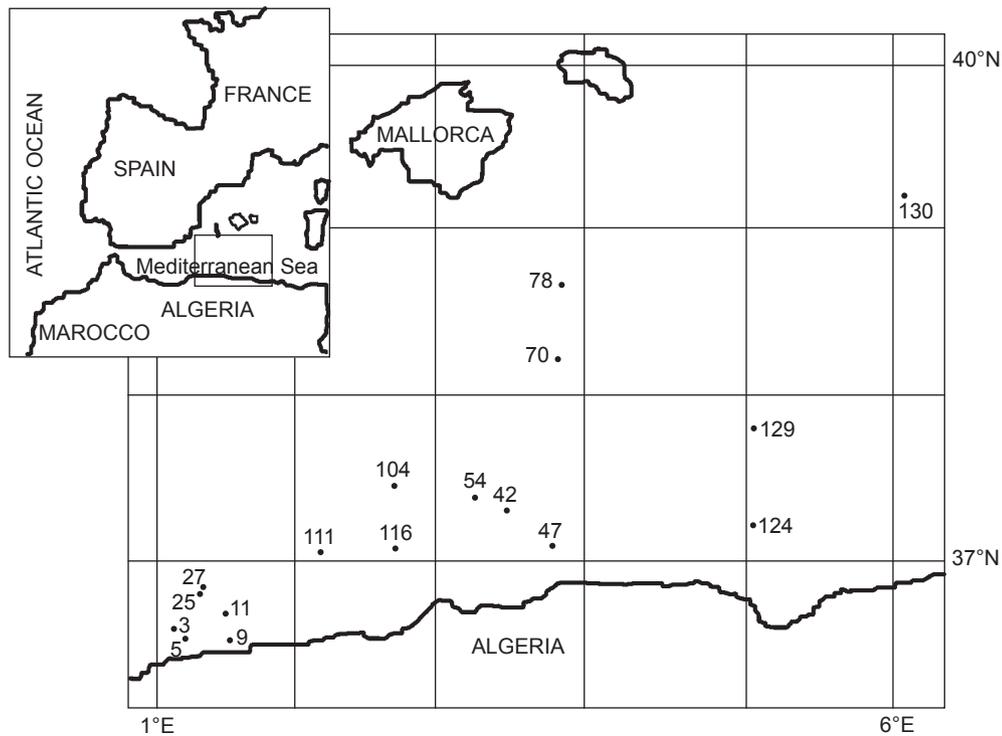


Fig. 1. Geographic positions of stations during the Mediproduct VI cruise.

Table 1. Characteristics of stations sampled during the Mediproduct VI cruise

System type		MAW						
Station	3	5	9	47	124			
Longitude (°E)	1°10'	1°10'	1°21.5'	3°30'	5°00'			
Latitude (°N)	36°46'	36°36'	36°36'	37°05'	37°10'			
Date	9 June	9 June	9 June	16 June	29 June			
Temperature (°C)	21.45	21.66	20.26	19.92	23.52			
Surface salinity	36.82	36.55	36.6	36.63	36.78			
DCM (mg/m ³)	0.34	1.30	0.61	0.61	0.99			
System type		Front						
Station	11	25	27	42	54	104	111	116
Longitude (°E)	1°23'	1°09'	1°10'	3°18'	3°09'	2°30'	2°20'	2°27'
Latitude (°N)	36°46'	36°54'	36°54'	37°20'	37°25'	37°20'	37°09'	37°12'
Date	10 June	12 June	13 June	15 June	17 June	26 June	27 June	28 June
Temperature (°C)	21.32	21.45	21.03	20.60	21.18	22.42	22.73	22.62
Surface salinity	36.56	36.7	36.78	36.59	36.61	36.82	36.72	36.73
DCM (mg/m ³)	1.73	8.20	13.03	4.40	5.79	7.30	5.25	-
System type		SMW						
Station	70	78	129	130				
Longitude (°E)	3°49'	3°47'	5°00'	6°10'				
Latitude (°N)	38°23'	38°28'	37°45'	39°10'				
Date	22 June	23 June	29 June	30 June				
Temperature (°C)	22.37	24.13	21.45	21.66				
Surface salinity	36.95	-	36.82	36.55				
DCM (mg/m ³)	0.27	0.30	0.34	0.39				

MAW, modified Atlantic water; SMW, surface Mediterranean water; DCM, deep chlorophyll a maximum.

(SSF), intermediate size fraction (ISF), and largest size fraction (LSF).

A cluster analysis with normalized Euclidean distances was used to measure levels of similarity of the salinity and Chl-a concentrations among the sampling stations, and Ward's method was used to illustrate the relations of these stations in a dendrogram (Legendre and Legendre 1998). All steps of this method were computed using Statistica 6 software (StatSoft, France).

Multivariate analyses were carried out to objectively identify spatial changes in the structure of the zooplankton community (composition, abundance, and biomass) and determine the relative contributions of various environmental variables to the variability of the zooplankton structure in the study area. The software SYSTAT® for Macintosh (Systat Software, Inc, Chicago, USA) was used for statistical treatments. In all cases, data were log-transformed [$\log_{10}(x+1)$] to avoid strong influences of the most abundant copepods and to meet the assumptions of the parametric multivariate analysis (Frontier and Pichod Viale 1991). In order to quantify relationships between the principle components, and environmental and biomass variables, a Bravais-Pearson coefficient correlation was performed. Further mathematical details of the technique and treatments are given in Ibanez (1973).

RESULTS

Variations in the vertical structure along the Algerian coast

The spatial salinity distribution presented a clear south-to-north increasing trend; coastal and offshore stations were respectively associated with low and high values (Fig. 2). In addition, these 2 regions were linked to low Chl-a concentrations (Fig. 3). Consequently, from the cluster analysis, 3 regions with different levels of surface salinity and Chl-a concentration were recognized (Fig. 4): (i) the frontal area (S of 36.6-36.8 and depth-integrated Chl-a values up to 60 mg/m², cluster A) (ii); inshore MAW stations (S < 36.6 and depth-integrated Chl-a concentrations of < 25 mg/m², cluster B₁); and (iii) offshore SMW stations (S > 36.9 and Chl-a 11-50 mg/m², cluster B₂).

The subsurface signature of the Atlantic water during this period was confirmed by a deepening of the 37- and 38 isohalines in the north as well as from west to east (Fig. 5).

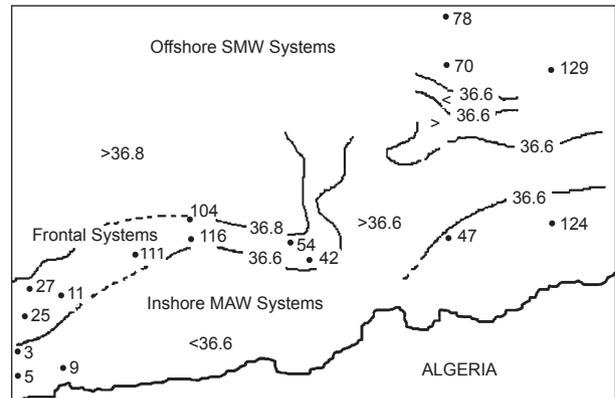


Fig. 2. Spatial distribution of sea surface salinity values.

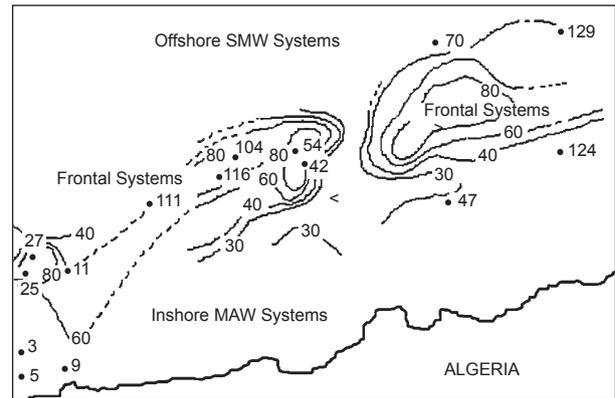


Fig. 3. Spatial distribution of integrated chlorophyll a concentrations.

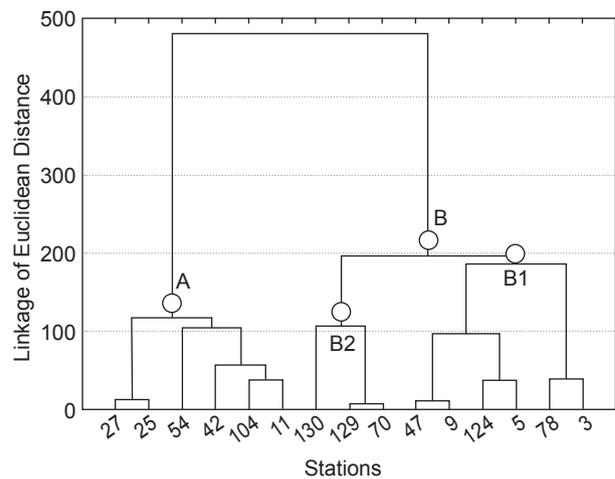


Fig. 4. Dendrogram resulting from the cluster analysis based on temperatures, salinities, and chlorophyll a concentrations of the 17 sampling stations on the Algerian coast during the Medipro VI cruise.

Figures 6, 7, and 8 respectively illustrate variations in the vertical structure of temperature, salinity, and Chl-a along the sampling transects. The upper 150 m was characterized by the lowest salinities (36.5-37.5). At 20-80 m in depth, a strong thermocline and halocline were recorded. Surface Chl-a concentrations varied between 0.10 and 0.63 mg/m³. The deep Chl-a maxima were very low in inshore MAW and offshore SMW areas (0.27-1.30 mg/m³) and high in frontal systems (1.73-13.03 mg/m³) (Fig. 8, Table 1).

Copepod abundances and species assemblages

Table 2 shows statistics for the 23 most abundant species in the upper 200 m that accounted for more than 95% of the total mesozooplankton abundance. The highest abundances were associated with the frontal zone (stations 11, 25, 27, 42, 54, 104, 111, and 116), and the lowest abundances were found in southern stations near the coast and offshore stations in oligotrophic waters (stations 3, 5, 9, 124, 70, 78, 129, and 130) (Fig. 9). Ordination of the 1st 2 principal components obtained by the PCA on log-transformed zooplankton abundances revealed 3 copepod assemblages in Algerian coastal waters (Fig. 10A). The 1st group (group 1) included 5 species with maximum abundances in the frontal region. Copepods in this group, i.e., *Paracalanus parvus*, *Clausocalanus furcatus*, *C. arcuicornis*, *Mesocalanus tenuicornis*, and *Eucalanus elongatus*, are mainly herbivores. The 2nd group (group 2), included species which were more abundant at inshore stations in the MAW. Copepods in this group are neritic species such

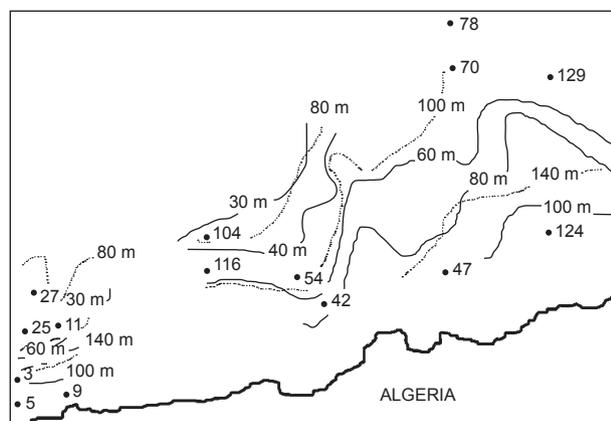


Fig. 5. Depths of the 37 (solid line) and 38 (dotted line) isohalines.

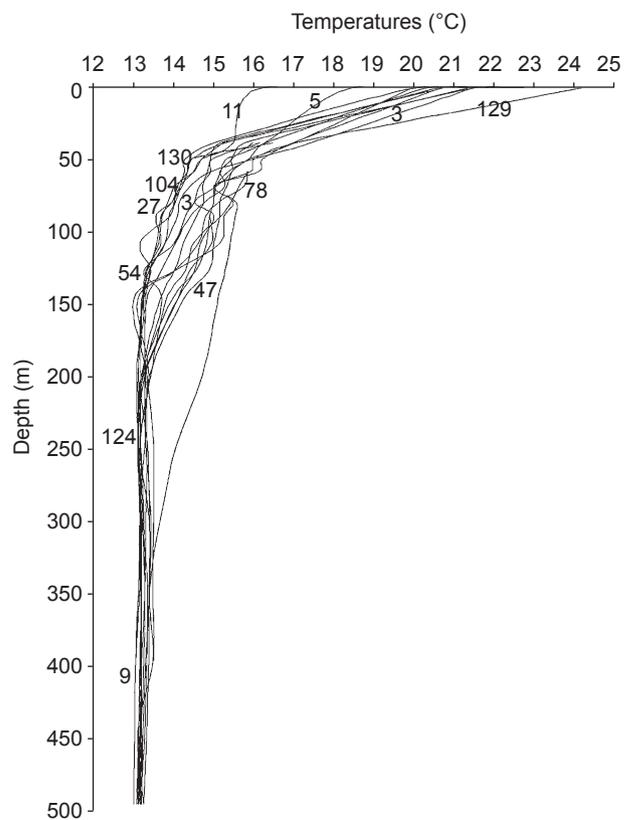


Fig. 6. Vertical profile distribution of temperature along the Algerian coast.

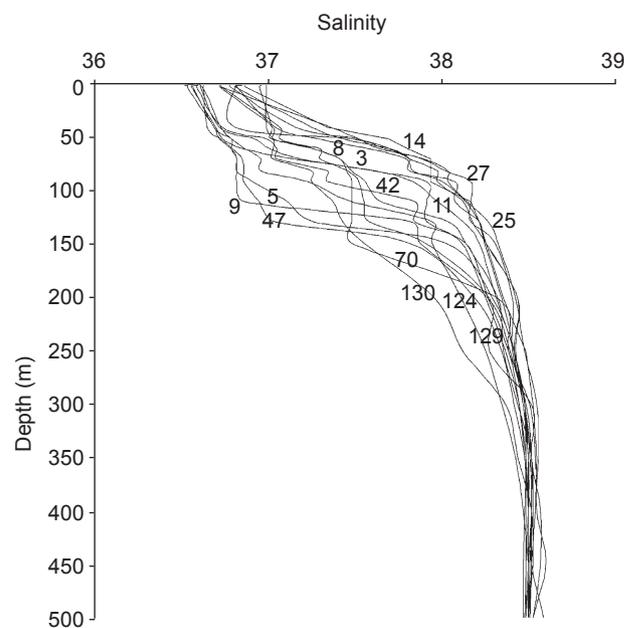


Fig. 7. Vertical profile distribution of salinity along the Algerian coast.

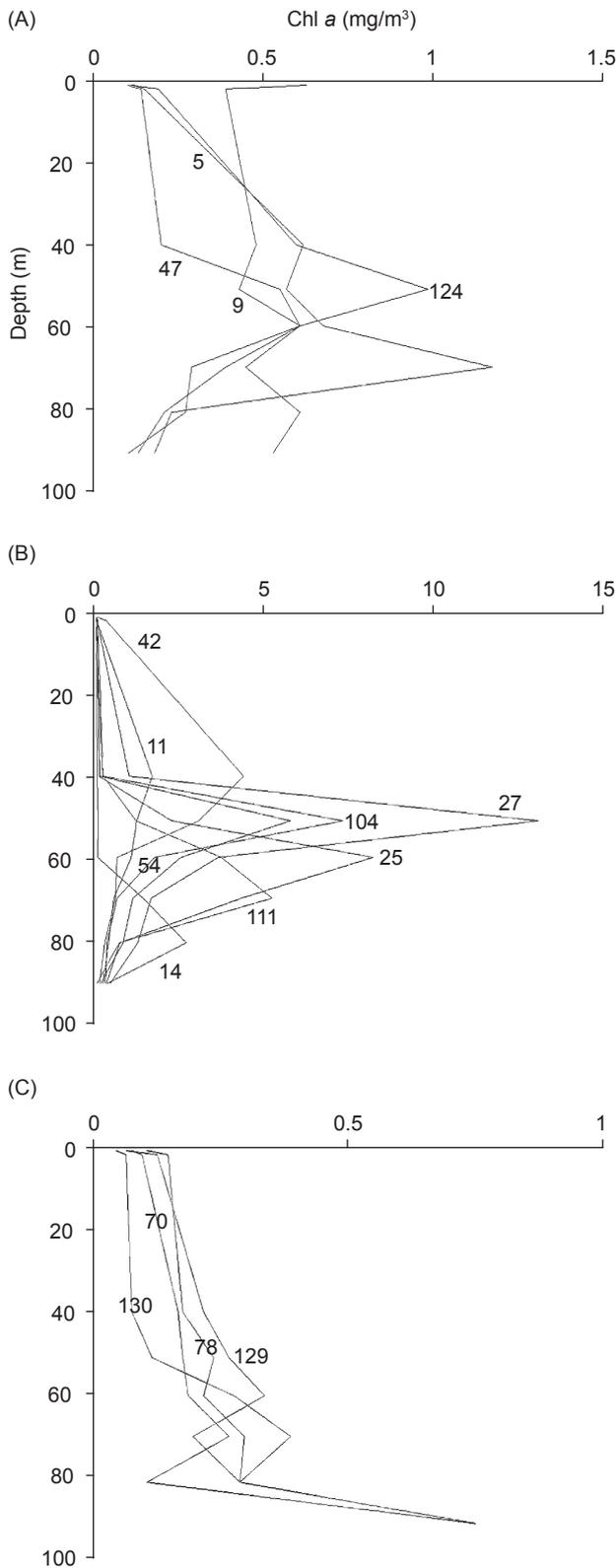


Fig. 8. Vertical profile distribution of chlorophyll a concentrations along the Algerian coast. (A) Coastal modified Atlantic water (MAW) system; (B) frontal system; (C) offshore surface Mediterranean Water (SMW) system.

as *Acartia clausi*, *Euterpina acutifrons*, *Oithona nana*, and *Temora stylifera*. The 3rd group (group 3) included 13 species with broad distributions. These species, i.e., *Scolecithricella dentata*, *S. vittata*, *Oncaea venusta*, *O. media*, *Oncaea* spp., *Microsetella rosea*, *Oithona helgolandica*, *Corycaeus ovalis*, *C. brehmi*, *Corycaeus* spp., *Spinocalanus longicornis*, *Scolecithrix danae*, and *Clausocalanus* spp. were recorded in relatively low numbers in the upper 200 m in frontal, coastal, and offshore waters. The deep water column (200-500 m depth layer) was characterized by low copepod abundances (00.60-04.17 individuals (ind.)/m³) (Table 3). The copepod community observed in deep waters of the frontal zone greatly differed from that observed in epipelagic waters (Fig. 9). The main copepod species identified by the PCA are shown in table 3 and figure 10B. The 1st group (group 1), with neritic and mesopelagic species found mainly near the front, was composed of *P. parvus*, *C. furcatus*, *C. arcuicornis*, *Clausocalanus* spp., *S. dentata*, *S. longicornis*, *Spinocalanus* spp., and *Oithona* spp. The 2nd group (group 2) included weakly migrant species, i.e., *Haloptilus longicornis* and *Lucicutia clausi*, and showed maximum abundances in coastal waters. The 3rd group (group 3) contained meso-batypelagic species. Some of them, i.e., *Paraeuchaeta acuta*, *Euchirella messinensis*, and *Euchaeta marina*, were distributed in inshore MAW as well as in offshore SMW; *Eucalanus monachus* reached maximum abundances at coastal and frontal stations, and *Candacia bipinnata* was more

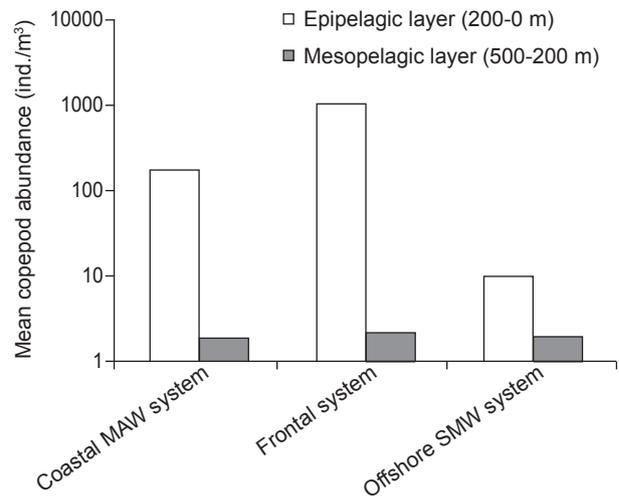


Fig. 9. Copepod abundance distribution in the 0-200 and 200-500 m depth ranges.

abundant in subsurface waters near the coast and in the frontal and offshore SMW systems.

Relationships between parameters

Linkages between environmental factors and zooplankton PC1 and PC2 in the 0-200 m layer are shown in figure 10A. The 1st component, which explained 25.39% of the total variance, was significantly correlated to surface temperature ($r = 0.65$), surface salinity ($r = 0.69$), the halocline, and the integrated Chl-*a* concentrations ($r = 0.55$), Chl-*a* concentrations in the upper 100 m ($r = -0.90$), and the subsurface Chl-*a* maximum ($r = -0.89$) (Fig. 10A). The total zooplankton biomass and the biomass of small zooplankton, mainly herbivores, were inversely correlated to PC1 ($r = -0.90$ and -0.93 , respectively). The 2nd component, which explained 19.16% of the total variance, was significantly correlated to surface Chl-*a* concentrations ($r = -0.48$) and to the biomass of the 300-500 μm zooplankton size fraction ($r = -0.60$). The projections of all variables in a

bidimensional plane defined by the 1st 2 components (Fig. 10A) mirrored the link between the species of the 1st group (the majority of which were predominately herbivorous species), Chl-*a* maximum values in the subsurface (DCM), the total zooplankton biomass, and the standing stocks of the smallest size fraction (100-300 μm). In terms of a given relationship, a trophic association was revealed between the herbivorous population, such as *P. parvus*, *C. furcatus*, *C. arcuicornis*, and *M. tenuicornis*, and the increase in phytoplanktonic biomass available in the frontal area. The peaks of standing stocks recorded within the 100-300 μm size fraction were related to the peak abundances of herbivorous species.

The 2nd group of species (predominantly coastal copepods) was essentially linked to Chl-*a* concentrations in the 0-10 m layer and was associated with the 300-500 μm zooplankton biomass size fraction, suggesting that the coastal species *T. stylifera*, *E. acutifrons*, *A. clausi*, and *O. nana* were actively consuming the phytoplankton standing stock.

Table 2. The most important copepod species in determining the grouping obtained in the principal component analysis (in the depth range of 0-200 m). Abbreviations of variables used in the analysis are given in parentheses

Species	Occurrence (%)	Abundance (individuals/m ³)			
		Range		Mean \pm SD	
<i>Oncaea media</i> (Onm)	41	0.28	-	0.82	0.51 \pm 0.09
<i>Scolecithricella dentate</i> (Scd)	41	0.20	-	0.98	0.53 \pm 0.13
<i>Oithona nana</i> (Oin)	59	0.02	-	1.00	0.38 \pm 0.13
<i>Clausocalanus arcuicornis</i> (Cla)	82	0.36	-	30.04	9.67 \pm 3.02
<i>Acartia clause</i> (Acc)	41	0.10	-	10.00	2.71 \pm 1.56
<i>Oncaea</i> sp. (Onsp)	35	0.12	-	1.10	0.68 \pm 0.18
<i>Oncaea venusta</i> (Onv)	41	0.32	-	2.00	1.01 \pm 0.21
<i>Eucalanus elongates</i> (Eue)	47	0.50	-	4.20	1.68 \pm 0.49
<i>Paracalanus parvus</i> (Pap)	82	0.32	-	1284.90	608.26 \pm 155.09
<i>Clausocalanus furcatus</i> (Clf)	76	0.34	-	13.00	3.60 \pm 1.08
<i>Mesocalanus tenuicornis</i> (Met)	35	1.00	-	7.00	3.87 \pm 0.96
<i>Corycaeus brehmi</i> (Crb)	35	0.34	-	1.02	0.77 \pm 0.13
<i>Corycaeus ovalis</i> (Cro)	41	0.20	-	1.06	0.67 \pm 0.18
<i>Oithona heigolandica</i> (Oih)	53	0.02	-	0.46	0.16 \pm 0.05
<i>Temora stylifera</i> (Tes)	24	0.20	-	815.00	205.38 \pm 45.28
<i>Spinocalanus longicornis</i> (Spl)	18	0.90	-	1.18	1.03 \pm 0.10
<i>Pontella mediterranea</i> (Pom)	29	0.04	-	2.00	0.79 \pm 0.41
<i>Clausocalanus</i> spp. (Clsp)	29	0.06	-	1.02	0.52 \pm 0.24
<i>Microsetella rosea</i> (Mir)	24	0.02	-	1.08	0.62 \pm 0.30
<i>Euterpina acutifrons</i> (Eua)	18	0.92	-	5.00	3.64 \pm 1.67
<i>Scolecithricella vitata</i> (Scv)	29	0.20	-	0.82	0.46 \pm 0.16
<i>Scolecithrix danae</i> (Sxd)	18	0.40	-	0.96	0.59 \pm 0.23
<i>Corycaeus</i> sp. (Crsp)	47	0.22	-	1.02	0.75 \pm 0.11

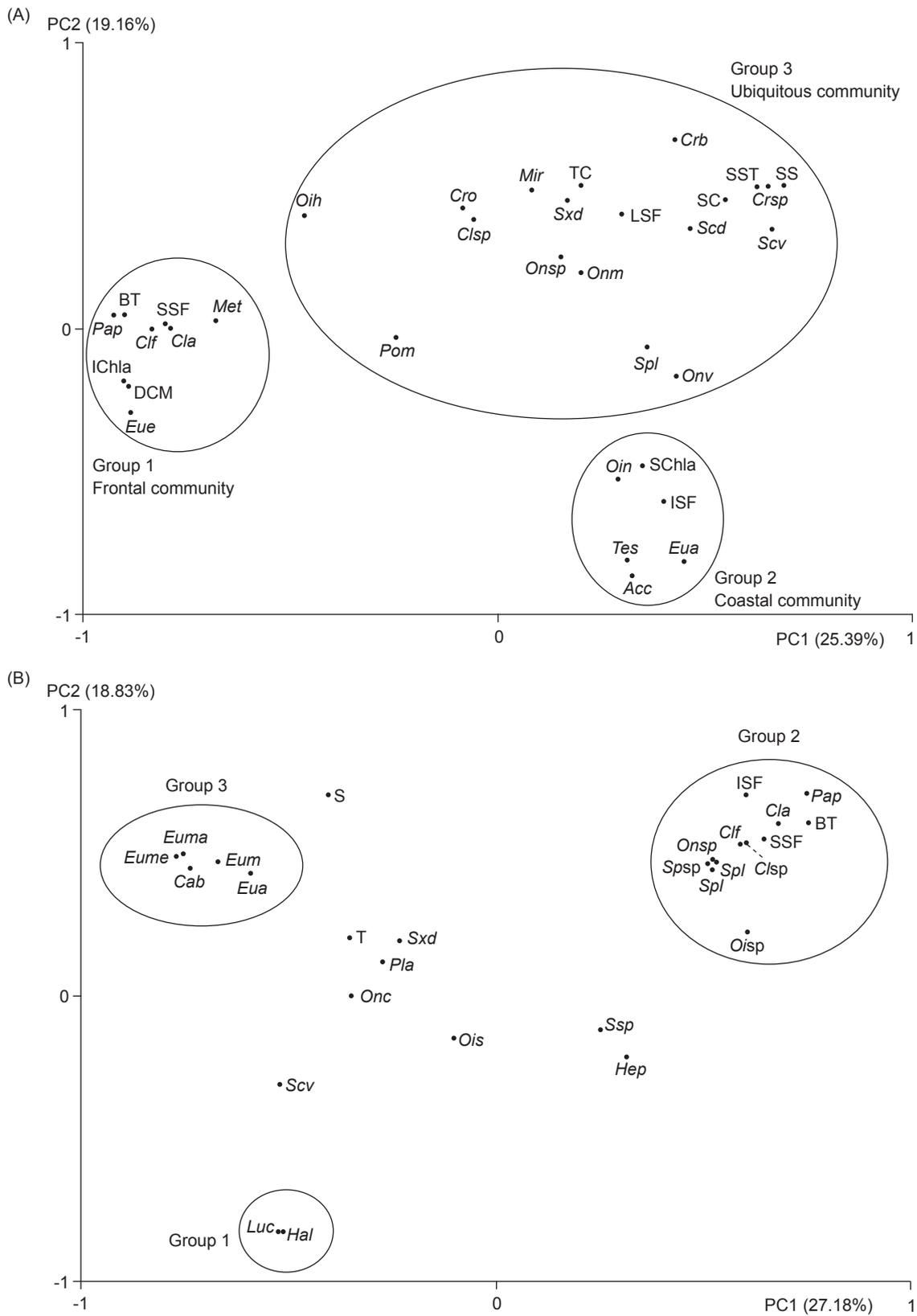


Fig. 10. Ordination of selected species in the space configured by the 1st and 2nd axes of the principal component analysis. (A) 0-200 m depth range; (B) 200-500 m depth range. The amount of variance explained by each axis is given in parentheses. Analysis (see tables 2 and 3).

The 3rd group of species was associated with surface temperature, the thermocline, surface salinity, and the halocline. The species in this association were significantly correlated to the biomass of the largest zooplankton (> 500 μm). They were linked to less-saline surface water (< 37) and cooler temperatures ($\leq 14.25^\circ\text{C}$), but they were also found at various depths characterized by a wide range of temperatures and salinities.

The results of the PCA on data in the mesopelagic layer (200-500 m in depth) (Fig. 10B) showed no significant correlation between the assemblages of species and the measured environmental variables. Groups 1 and 3 were correlated with the zooplankton biomass. Species of the 1st group (*P. parvus*, *C. furcatus*, *C. arcuicornis*, *C. spp.*, *S. dentata*, *S. longicornis*, *Spinocalanus sp.*, and *O. spp.*) were related to zooplankton biomass of both the 100-300 and 300-500 μm size fractions. Group 3, comprising 5 species (*P. acuta*, *E. messinensis*, *E. marina*, *E. monachus*, and *C. bipinnata*) were related to the

biomass of the largest zooplankton.

DISCUSSION

We investigated spatial patterns of the pelagic copepod community and possible roles of the main hydrographic features on the spatial structure of copepods in Algerian waters.

Hydrography

All findings of this paper are based on the analysis of a single dataset collected in June 1990. The situation described was only representative of that month of that particular year, and we do not claim that it represents the mean or summer situation of this region. The inflow of MAW into the survey area is driven by the Algerian Current (La Violette 1986, Johnson et al. 1989, Fuda et al. 2000, Onken and Sellschopp 2001, D'Ovidio et al. 2009). During the period investigated, the path of the Algerian Current was in a uniform band

Table 3. The most important copepod species in determining the groups obtained by the principal component analysis (in the depth range of 200-500 m). Abbreviations of variables used in the analysis are given in parentheses

Species	Occurrence (%)	Abundance (individuals/m ³)	
		Range	Mean \pm SD
<i>Paracalanus parvus</i> (<i>Pap</i>)	41	0.16 - 0.51	0.35 \pm 0.07
<i>Pareuchaeta acuta</i> (<i>Pac</i>)	67	0.03 - 0.49	0.21 \pm 0.06
<i>Spinocalanus longicornis</i> (<i>Spl</i>)	80	0.13 - 0.49	0.28 \pm 0.04
<i>Eucalanus monachus</i> (<i>Eum</i>)	47	0.07 - 0.24	0.15 \pm 0.03
<i>Pleuromamma abdominalis</i> (<i>Pla</i>)	53	0.01 - 0.23	0.16 \pm 0.03
<i>Oncaea conifera</i> (<i>Onc</i>)	41	0.01 - 0.14	0.10 \pm 0.02
<i>Euchirella messinensis</i> (<i>Eume</i>)	47	0.01 - 0.27	0.13 \pm 0.04
<i>Euchaeta marina</i> (<i>Euma</i>)	87	0.03 - 0.36	0.19 \pm 0.03
<i>Candacia bipinnata</i> (<i>Cab</i>)	53	0.09 - 0.27	0.19 \pm 0.02
<i>Haloptilus longicornis</i> (<i>Hal</i>)	73	0.01 - 0.27	0.09 \pm 0.03
<i>Heterorhabdus pappiliger</i> (<i>Hep</i>)	33	0.01 - 0.07	0.06 \pm 0.01
<i>Sapphirina sp.</i> (<i>Ssp</i>)	33	0.01 - 0.11	0.04 \pm 0.02
<i>Oithona sp.</i> (<i>Oisp</i>)	20	0.01 - 0.14	0.06 \pm 0.05
<i>Lucicutia clausi</i> (<i>Luc</i>)	41	0.01 - 0.20	0.10 \pm 0.03
<i>Scolecithricella dentata</i> (<i>Scd</i>)	27	0.26 - 0.39	0.35 \pm 0.03
<i>Clausocalanus arcuicornis</i> (<i>Cla</i>)	27	0.01 - 0.50	0.34 \pm 0.13
<i>Scolecithricella vittata</i> (<i>Scv</i>)	27	0.21 - 0.34	0.26 \pm 0.03
<i>Oncaea sp.</i> (<i>Onsp</i>)	27	0.07 - 0.26	0.17 \pm 0.05
<i>Clausocalanus furcatus</i> (<i>Clf</i>)	27	0.01 - 0.43	0.19 \pm 0.12
<i>Oithona setigera</i> (<i>Ois</i>)	33	0.11 - 0.36	0.20 \pm 0.07
<i>Scolecithrix danae</i> (<i>Sxd</i>)	20	0.01 - 0.24	0.15 \pm 0.09
<i>Clausocalanus spp.</i> (<i>Clsp</i>)	20	0.23 - 0.27	0.30 \pm 0.05
<i>Spinocalanus sp.</i> (<i>Spsp</i>)	27	0.11 - 0.44	0.29 \pm 0.06

along the Algerian coast (COF 1991, Raimbault et al. 1993, Seridji and Hafferssas 2000). The MAW can be traced by a subsurface salinity minimum (37-38) (Raimbault et al. 1993). As an example, in the coastal area from the western to eastern stations (stations 3, 5, 9, 47, and 124) by comparing the pattern of the position of the surface salinity (around 36.6) and the depth pattern of the 37 isohaline, the boundary of the current can be approximately located along the position where this isohaline reached 100 m. This suggested a strong influence of the Atlantic current and its further eastward extension (Raimbault et al. 1993, Millot and Taupier-Letage 2005).

The vertical water temperature and salinity profiles revealed thermo- and haloclines at 20-80 m in depth.

Relationships between biological and environmental factors

The PCA allowed us to identify the front and its associated high copepod abundances ($> 800 \text{ ind./m}^3$) and zooplankton biomass levels ($> 20 \text{ mg/m}^3$); zooplankton populations were mainly composed of small (100-300 μm) herbivorous copepods (group 1, Fig. 6a) such as *P. parvus*, *C. arcuicornis*, *C. furcatus*, and *M. tenuicornis* that are efficient grazers (Vidal and Smith 1986, Thibault et al. 1994, Pesant et al. 1998, Mariano et al. 2001, Gaudy et al. 2003). These copepods were located in the productive zone between the MAW and SMW where the salinity gradient was between 36.6 and 36.8 (Seridji and Hafferssas 2000). No relationship was found for the distribution of zooplankton in this zone with salinity or temperature. However this zooplankton assemblage was correlated with the Chl-a concentrations in the upper 100 m and the deep Chl maximum, recorded at 40-99 m in depth. This layer was associated with high diatom abundances (COF 1991). In the Almeria-Oran frontal system, the DCM reached up 2 mg/m^3 and extended over a 50 m thickness. As pointed out by Ashjian et al. (2001), the distribution of taxa observed in the frontal area resulted either from advection of plankton into the front in particular water masses (e.g., the Algerian Current and MAW) or, more likely, from establishment of populations in specific regions.

The coastal community (*A. clausi*, *E. acutifrons*, *O. nana*, and *T. stylifera*; group 2) was linked to the MAW system. This area was strongly

influenced by the Atlantic flow where the salinity surface was < 36.6 (COF 1991). The assemblage showed (i) a significant relationship with Chl-a concentrations available at the surface and (ii) a significant correlation with the biomass collected within the intermediate size fraction (300-500 μm).

According to many authors (Raimbault et al. 1993, Fuda et al. 2000, Seridji and Hafferssas 2000, Morán et al. 2001, Millot and Tapier Letage 2005), hydrodynamic processes, such as the cyclonic and anticyclonic eddies which produce small upwellings, enhance the concentration of Chl in the inshore MAW zone. Consequently, nutrient enrichment has significant effects on coastal communities (Riandey et al. 2005). Species can graze heavily on diatoms and organic particles (Razouls et al. 1998, Gaudy and Youssara 2003), and were in a period of active reproduction (Thibault et al. 1994) and development (Kiorboe and Sabatini 1995).

No correlations between the copepod community in this group and hydrographic characteristics were observed. These species were probably influenced by other non-quantified factors, such as small-scale turbulence (Millot et al. 1997, Salas 2003) that seems to have an effect on the distribution of coastal species such as *Acartia* and *Oithona* (Maar et al. 2002). On the other hand, near the Spanish coast, *T. stylifera* showed a positive relationship with temperature (Villate et al. 1997), with the peak of its population coinciding with the warmest temperatures. In the continental shelf waters of the Northwest Pacific Ocean, temperature is an important factor regulating the geographical distribution and seasonal occurrence of copepod species (Hwang et al. 2005, Liao et al. 2006).

Multivariate analysis identified a ubiquitous community (group 3) composed of individuals of *S. dentata*, *S. vittata*, *O. media*, *Oncaea* sp., *M. rosea*, *O. helgolandica*, *C. ovalis*, *C. brehmi*, *C. sp.*, *S. longicornis*, *S. danae*, and *Clausocalanus* spp. These species were recorded in low abundances in both oligotrophic waters (e.g., the inshore MAW and offshore SMW) and the frontal area, indicating they were able to cross the horizontal haline gradient located from the inshore MAW to the offshore SMW systems (Raimbault et al. 1993). Recent studies on the Algerian coast (Riandey et al. 2005) described some populations of *Oithona*, *Spinocalanus*, and *Oncaea* genera in both inshore and offshore zones. The thermocline showed no relationship with the distribution of the zooplankton community in group 3. Factors other than

temperature probably play a role in determining the depths at which these animals concentrate (Sameoto 1986). In the Mediterranean Sea, all of these species have broad distributions ranging from the surface to 2500 m (Scotto di Carlo et al. 1991).

General decreases in copepod abundance and biomass with depth were described on the Algerian coast (Hafferssas 2004). In the deeper layer (200-500 m), 3 patterns were recognized by a statistical analysis among the copepods. No relationship was identified between these trends and environmental factors. *P. parvus*, *C. furcatus*, *C. arcuicornis*, *Clausocalanus* spp., *S. dentata*, *S. longicornis*, *Spinocalanus* sp., and *Oncaea* sp. were major contributors to the zooplankton standing stock and were generally restricted to the front. The presence of *P. parvus* and *C. furcatus* at the 200-500 m depth may be related to sinking and dying individuals unable to maintain themselves in the epipelagic layer (Sameoto 1986). This type of vertical distribution is common in pelagic organisms between 10 and 100 μm in length (Rudyakov and Tseytlin 1980). Few subsurface species (*Haloptilus longicornis* and *Lucicutia clausi*) were confined to the deep layer of the coastal area. The comparison with other Mediterranean regions showed that populations of *H. longicornis* were mainly present at 620-650 m in the Ionian Sea (Scotto di Carlo et al. 1991). By contrast, *L. curta* was rare and very sporadic in the Levantine Sea (Scotto di Carlo et al. 1991), with few individuals (0.001 ind./m³) being sampled in the deep-sea zone (500-600 m). Strongly migrant copepods (*P. acuta*, *E. messinensis*, *E. marina*, *E. monachus*, and *C. bipinnata*) were not strictly associated with the depth layer of the inshore MAW system, as they were also recorded in epipelagic waters. As reported by Padmavati et al. (1998) in the Arabian Sea and Scotto di Carlo et al. (1984) in the Tyrrhenian Sea, these species reside in the surface layer during the night. In our case, these strong migrants were positively correlated with the largest fraction of the zooplankton biomass. In Algerian waters, during the summer of 1997, zooplankton vertical migrations were limited to a handful of taxa: *Pleurommama*, *Calocalanus*, ostracods, and jellyfish (Riandley et al. 2005).

Copepod assemblages and their relationships with hydrological and hydrodynamic features

First of all, copepod species recorded during the present study (Mediproduct VI cruise) were

already cited in Algerian waters by other authors (Scotto di Carlo et al. 1991, Riandey et al. 2005, Razouls et al. 2005-2008). Herein, we found species composition assemblages organized in response to the dynamic structure of the area, in which 2 oligotrophic systems of different origins and a frontal system occur.

In the frontal zone, the quantitative compositions significantly differed for the coastal MAW and offshore SMW ecosystems. Fronts have wide-ranging effects on pelagic organisms (Sournia et al. 1990). In the case of the Algerian Basin front, it works as a special ecosystem, as corroborated by its physical and biological characteristics (Seridji and Hafferssas 2000). From Legendre and Legendre's (1984) point of view, in an area of very high biological activity, the copepod community is in a stressed condition: the environment is disturbed and unstable, leading to predominance (concentrations of up to 800 ind./m³) of opportunistic populations of *P. parvus*, *C. arcuicornis*, *C. furcatus*, and *M. tenuicornis*. In the Alboran Sea, the distribution of *C. furcatus* was linked to the Almeria-Oran front where populations could find favorable feeding conditions (Youssara and Gaudy 2001). In that region, Thibault et al. (1994) and Gaudy and Youssara (2003) found higher copepod abundances of herbivores compared to the surrounding waters which displayed a more-carnivorous or -detritivorous character. In the southern East China Sea between the early and late northeasterly monsoon, the relationship between Chl-a concentrations and copepod assemblages is complex and hard to characterize in short-term research (Lan et al. 2008). Zuo et al. (2006) reported that salinities and temperatures were more important than Chl-a concentrations in characterizing copepod assemblages of the continental shelf of the Yellow Sea and East China Sea of the Northwest Pacific.

In coastal zones, hydrodynamic processes like cyclonic and anticyclonic eddies generate small upwellings which lead to high concentrations of Chl in the epipelagic layer (Millot et al. 1997). In our study, the coastal community (*A. clausi*, *E. acutifrons*, *O. nana*, and *T. stylifera*) grazed heavily on diatoms and was in a period of active reproduction (Thibault et al. 1994). The cyclonic eddy found in the inshore region of the Algerian Basin in summer 1997 was very suitable for filter-feeders (Riandey et al. 2005). Nevertheless, generally during the ELISA-1 campaign (in 1997), an impact of Algerian hydrodynamic structures on zooplankton communities was not

found. In fact, lower zooplankton abundances and biomass levels were recorded in coastal and neritic waters. The sampling period (summer) is traditionally characterized by the lowest zooplankton biomass in the inshore zone of the western Mediterranean Sea (Champalbert 1996), as well as in oceanic waters of the Gulf of Lions (Razouls and Kouwenberg 1993). Throughout wintertime, the Algerian Current showed little influence on zooplankton biomass, but there were high abundances of gelatinous organisms such as salps and doliolids. Thus, mesoscale features may have a strong impact on the Algerian Basin ecosystem, but this depends on their intrinsic dynamics, their position on the Algerian coast, and the season (Riandley et al. 2005). In the Northeast Atlantic in July 1996, variations in the zooplankton structure were coincident with changes in the physical structure (fronts or eddies or with high surface Chl concentrations (Rodriguez and Mullin 1986). In the northwestern Pacific Ocean, the biodiversity and structure of copepod communities were strongly influenced by the Kuroshio Current in waters northeast of Taiwan (Lee et al. 2009).

Mixing water and turbulence were absent from the offshore SMW zone (Raimbault et al. 1993). This zone is characterized as an oligotrophic system with low species abundances. Such a situation is similar to that encountered in the depth layer. The copepod community revealed a strong presence of carnivores and omnivores (*S. dentata*, *S. vittata*, *O. venusta*, *O. media*, *O. helgolandica*, *C. ovalis*, *C. brehmi*, and *S. danae*). Thus, the effect of predation was quite important. Copepod populations recorded in waters surrounding the Almeria-Oran front displayed more-carnivorous behavior (Thibault et al. 1994). Copepods must consume many non-phytoplankton food sources to meet their nutritional requirements (Romam and Gauzens 1997, Razouls et al. 1998, Tseng et al. 2008). Indeed, many omnivorous species select their prey on the basis of size rather than type, or change food types as individuals grow, e.g., most detritus feeders are facultative predators, most predators feed occasionally on dead organic matter, and some herbivores can use animal prey at certain times (Valiela 1995, Morgado et al. 2008).

The presence of species such as *P. parvus* and *C. furcatus* in the mesopelagic layer was likely due to exportation of a part of the secondary production from the epipelagic layer downward into the mesopelagic zone.

Similar investigations on the spatial distri-

bution of zooplankton are needed for other seasons to explain how the copepod communities are affected by biotic and abiotic changes that seasonally occur in this area. The present results can be used as a baseline for further studies on copepod ecology in the southwestern Mediterranean.

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