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Net-zooplankton abundance and biomass from Annaba Bay (SW Mediterranean Sea) under estuarine influences

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Abstract

Zooplankton samples were collected in Annaba Bay (Algeria) from January 2009-March 2011 at three coastal sites differently affected by estuarine plumes and external currents. Aim of this survey was to analyze zooplankton composition, abundance and biomass and compare the results with previous studies to reveal possible populations and environmental changes. The mean zooplankton abundance varied between 1,200-6,000 ind. m^{-3} and biomass 6.70-25.70 mg DW m^{-3}, according to the site. Copepods constituted the main fraction of zooplankton community, and *Oithona similis* and *Paracalanus indicus* successively dominated during autumn-winter and spring-summer. The dinoflagellate *Noctiluca scintillans* was one of the major zooplankton components, and developed high numbers during February-April, becoming common in neritic and coastal regions. The singularity of the zooplankton from Annaba Bay is the prevalence of *P. indicus* throughout the entire bay and the decrease in *Acartia (Acartiura) discaudata* and *Acartia (Acartiura) clausi* (with respect to previous years), possibly replaced by *A. negligens*. Additionally, *Oithona nana* abundance markedly decreased with the large development of *O. similis*. Annaba Bay also differs from other similar Mediterranean coastal areas by the large development of *Centropages ponticus* populations during the warm period. Among the identified copepod species, the alien species *Pseudodiaptomus australiensis* and *P. arabicus* are reported for the first time in the Mediterranean Sea. The occurrence of copepodid V stages of *P. australiensis* suggests that this species survives and reproduces in Annaba Bay, but so far without developing an abundant population.

Keywords: Zooplankton, copepods, biomass, alien species, coastal waters, estuaries, Annaba Bay, SW Mediterranean Sea.

Introduction

Coastal marine areas are of important ecological, economic and social interest and are very sensitive to anthropogenic activities (Newton *et al*., 2012; Levin *et al*., 2015). Fluctuations of rivers and sewage discharge into coastal zone induce high temporal and spatial variability of environmental factors and food conditions (Macias *et al*., 2014), which controls the metabolism, feeding behavior and production of the planktonic populations (Gaudy *et al*., 2003). Studies on the dynamic of Mediterranean zooplankton are sparse or lacking (Berline *et al.,* 2012*;* Fernández de Puelles *et al*., 2003), and still far from being understood (Siokou-Frangou *et al*., 2010), and basic exploratory research is still needed. Concerning the zooplankton biomass, only few reviews were performed in the western and the eastern basins, and comparisons remain uneasy because of the lack of standardized sampling methods and data treatment (Siokou-Frangou, *et al*., 2010). Moreover, most investigations were carried out in various areas with specific objectives and various strategies, types of nets and mesh sizes, and different sampling depths.

Since the pioneering works of Rose (1925) and Bernard (1955), which were limited to the zooplankton from Algiers, very few studies have been performed in Algerian coastal waters, and very little is known regarding the zooplankton community (Khélifi-Touhami *et al*., 2007). More recently, Riandey *et al*. (2005) studied the impact of hydrodynamic features on the zooplankton dynamics in the Algerian Basin, while Hafferssas & Seridji (2010) explored the copepod communities of the Algerian basin. Although there have been several studies on the phytoplankton, physical and chemical characteristics of Annaba Bay (Ounissi & Frehi, 1999; Frehi *et al*., 2007; Ounissi *et al*., 2014), there have only been two studies of the surface zooplankton from this area by Ounissi *et al*. (1998) and Khélifi-Touhami *et al*. (2007), who examined the copepod structure of Annaba Bay and the adjacent Tunisian coast. The study of Ounissi *et al*. (1998) describes the surface zooplankton of the inner bay and provides the first zooplankton data concerning the eastern Algerian coasts. There are, however, no data on the annual distribution of zooplankton abundance, biomass, diversity and species composition. Among the published studies, there are differences in the sampling equipment, time of collection, and sampling depth of zooplankton

abundance and biomass, which makes any comparison difficult.

Annaba Bay is a singular coastal area (southwestern Mediterranean Sea) that receives large diffusive inputs from the Seybouse and Mafragh estuaries (Ounissi *et al*., 2014) and has also been subjected to severe pollution problems (Ounissi & Frehi, 1999; Ounissi *et al*., 2008) induced by direct domestic and industrial wastes. The estuaries' plumes are relatively limited to only several kilometers, but under the flooding period, the dilution zone due to their freshwater input can reach the entrance of the bay in the north western part, as reported by Ounissi *et al*. (1998). From the marine side, the entrance of Annaba Bay is submitted to the Modified Atlantic Water (MAW) intrusion, which may renew and disseminate the estuarine and land inputs (Ounissi & Frehi, 1999).

The objectives of the present study are (i) to analyze the zooplankton composition and abundance of Annaba Bay, under estuarine influences and (ii) to compare our findings with previous studies on the zooplankton structure of the bay that were conducted 20 and 10 years ago in order to reveal possible populations and environmental change. This study provide for the first time both complete annual cycle of zooplankton in the northeastern Algerian coasts and information about the zooplankton biomass. In addition, this study may facilitate the comparison between different Mediterranean coastal areas, as the zooplankton was sampled by WP2 net (200 µm mesh size) and its biomass was expressed in dry weight, following the methods mostly used for marine zooplankton studies (Harris *et al.,* 2000).

Materials and Methods

Site description

In the South-western Mediterranean Sea, Annaba Bay is characterized by the presence of two important estuaries with an enlarged catchment that covers approximately 10,000 km² (Fig. 1). The Mafragh estuary' waters act as fertilizer (Ounissi *et al*., 2014), in contrast to the Seybouse inputs, which cause severe pollution problems (Ounissi & Frehi, 1999; Frehi *et al*., 2007) in the southwest area of the bay (Fig. 1). The particularity of the bay is also expressed by the direct domestic and industrial wastes, which deliver together into the bay more than 1.2 million m^3 of wastewater/day, strongly charged with phosphate and ammonium (Frehi *et al*., 2007; Ounissi *et al*., 2014). From the marine side, external waters penetrate the bay and move eastward as a branch of the Modified Atlantic Water (MAW), with average velocity of 20-35 cm s^{-1} for surface waters (Ounissi & Frehi, 1999). In the inner part of the bay, the residual current moves southward and allows some water renewal throughout the year. These contrasting continental and marine influences may allow the existence of various biological contingencies and ecological affinities.

Sampling was conducted at three sites (B1, B2, and B3) that are differently submitted to the estuarine plumes and the MAW influences (Fig. 1). Site B1 located in the eastern sector (innermost bay: 10 m depth) is influenced by the Seybouse estuary plume. Site B2 is located in western sector (inner bay: 20 m depth) but it is submitted to the Mafragh estuary plume. Site B3 (50 m depth) located in the central bay is under the influence of the MAW (Fig. 1).

Hydrological data and plankton collection

Zooplankton samples were collected from the near bottom to the surface using a standard WP2 net (mesh size 200 µm). A total of 72 net-zooplankton samples were collected monthly from January 2009 to March 2011 at the three marine sites. Due to bad weather in the Annaba Bay, we were unable to collect three samples: September 2009 and March and December 2010. The net was rinsed gently, the samples were transferred into

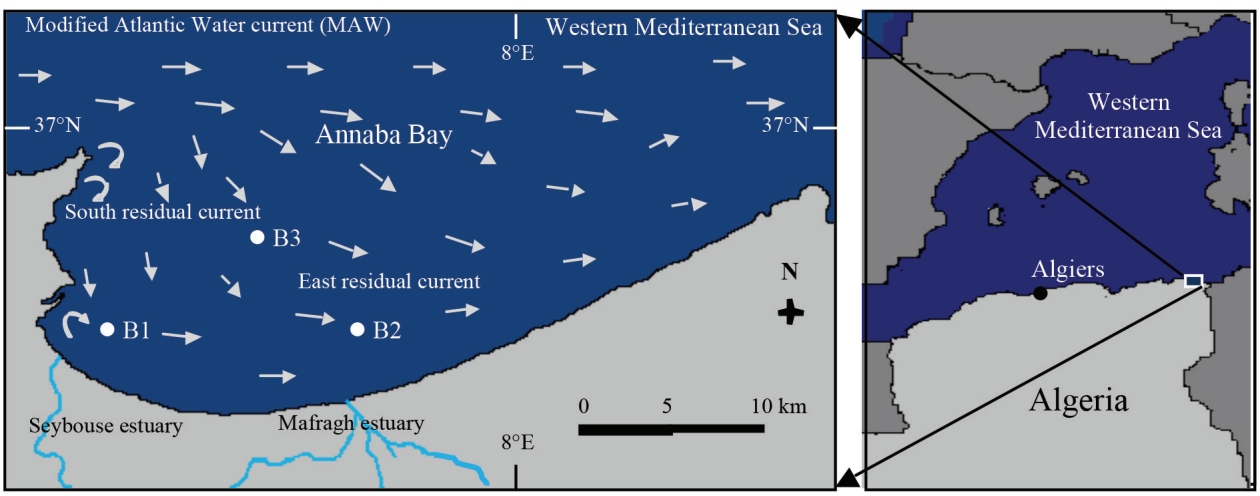

Fig. 1: Map of Annaba Bay showing the sampling stations (B1, B2 and B3) and the general circulation affecting the area.

plastic bottles, and two subsamples of 30 ml (6 to 15% of the total sample volume) were immediately filtered on pre-combusted (500°C for 2 h) and pre-weighed Whatman GF/C glass filters for zooplankton dry weight measurements. These filters were dried at 60°C for 48 h and then weighed. For each filter, the zooplankton dry weight was obtained by subtracting the final filter weight (filter + zooplankton sample) from the initial weight of the filter, and the results were expressed as dry weight (mg DW m^{-3}) according to the sample volume (200-500 ml) and the volume of seawater that was filtered through the WP2 net (3-12 m^3 depending on the station). The remaining sample was fixed by the addition of borax-buffered formaldehyde to a final concentration of 4%. The samples for taxonomic composition were sub-sampled (1/4-1/2 of the entire sample) depending on the density of individuals in the total sample, and three sub-samples were examined. Copepods and cladocerans were identified to the species level. All of the other taxa were identified to the lowest possible level. Rare species were identified from the entire sample. The abundances were expressed as the number of individuals per cubic meter (ind. m^{-3}), and the Shannon index of diversity (Shannon & Weaver, 1949) was used to estimate the copepod community diversity. The number of copepod species (richness) of each sample was also counted.

Prior to each WP2 vertical haul, surface water samples from marine sites for nutrients and chlorophyll *a* analyses were collected in 1.5-liter polyethylene bottles and processed within two days of collection. In addition to surface water sampling, bottom waters were sampled using a Niskin bottle. In the laboratory, after the filtration of the sample through Whatman GF/C glass filters (0.45 µm porosity), the concentrations of nutrients nitrite (NO_2), nitrate (NO_3), ammonium (NH_4), phosphate (PO_4), silicate (SiO_4) and of chlorophyll *a* (Chl *a*) were analyzed following the methods described by Parsons *et al*. (1989). Because of the large influence of the estuarine plumes on the adjacent coastal zone, the same nutrients were also analyzed from samples that were taken at the two estuaries' outlets. Chlorophyll *a* was determined following Lorenzen's method (Lorenzen, 1967) after filtering 1.5 liters of the sample through 0.45-µm membrane filters (Whatman GF/C). Water salinity and temperature measurements were taken with the multiparameter probe Cond WTW 197i at the marine sites and estuaries' outlet sites. The precipitation data come from Annaba meteorological station for Seybouse basin and from El-kala meteorological station for Mafragh basin.

Statistical analysis

A correspondence analysis (CA) multivariate technique was used to determine any possible co-variation between the total zooplankton abundance and biomass; the total copepods abundance, diversity and richness; 10 main copepod taxa abundance; and the environmental framework (temperature, salinity and Chlorophyll *a*) at the marine sites during 2009 and 2010. The contingency table that was analyzed with CA is a matrix of the annual averages of the above mentioned zooplankton and copepods data and their main environmental variables observed in 6 spatiotemporal situations (objects) representing the three coastal sites over two years of survey (2009 and 2010). The CA has several advantages compared to other multivariate techniques: (1) it compares rows or columns using the Chi-square distance, which offers a superior method of weighting the individual data; (2) it presents the variables and objects together in a biplot graphic, which facilitates the interpretation of the cloud points and their associations; and (3) the data do not need to be normalized, a procedure that can distort reality (Dervin, 1988). The statistical software Statistica 2008 was used to perform the CA.

Results

Environmental variables

Table 1 provides the estuary freshwater and nutrient discharges into Annaba Bay. Together, the estuaries discharged annually into the bay 1,545-2,270 million m^3 of freshwater. Although the Seybouse freshwater inputs represented 31-44% of the total delivery from the estuaries, they were heavily loaded with ammonium (NH_4) and phosphate (PO_4), in contrast to the Mafragh inputs, which reflect near-pristine water. During the rainy year of 2009 (Table 1), all of the nutrient levels increased, particularly silicates (SiO_4) and NH_4 of Seybouse waters.

As shown in Table 2, the average surface temperature in the bay varied from 19°C in the outer coastal station to 21.4 °C in the Seybouse plume, and the bottom layer had an average temperature of 18.2-19.7°C. The surface salinity average values ranged between 31.8 at station B1 during 2009 and36.6 at station B3 during 2010. In the bottom layer, the salinity values reached a minimum of 35.4 during 2009 and a maximum of 36.8 at station B3 in 2010. Because of the large estuarine freshwater inputs during 2009 (Table 2), the estuaries' plumes were spatially extended in the bay in winter and spring. The nutrient levels were always higher in the estuarine plumes, particularly the Seybouse plume, in which levels were 2-fold higher than those of the outer station B3. Paradoxically, the levels of dissolved organic nitrogen (DON) and nitrate (NO_3) were low in the wet year of 2009 compared to the values of the dry year 2010 (Table 2). Annaba Bay showed high levels of Chlorophyll *a*, ranging from 0.8 to 3 µg L^{-1} in the bottom layer and 0.93 to 2.75 µg L^{-1} in surface waters. These phytoplankton biomasses have the same distribution of inorganic dissolved nutrients, with maximum values in the estuarine plumes' stations during the wet year of 2009.

Table 1. Precipitation over the Seybouse and Mafragh basins and average (± standard error) hydrological data at the Seybouse and Mafragh estuaries' mouths that fed Annaba Bay, January 2009-March 2011.

	Seybouse estuary's outlet			Mafragh estuary's outlet		
	2009	**2010**	**2011***	**2009**	**2010**	**2011***
Precipitation (mm) over the basin	870	518	248	700	575	261
Discharge (10^6 m^3 yr^{-1})	1170	630	381	1103	915	832
NH_4 (µmol l^{-1})	179.4	68.0	39.2	10.6	6.7	6.6
	(± 20.7)	(± 10.4)	(± 6.02)	(± 1.8)	(± 1.7)	(± 4.05)
NO_3 (µmol l^{-1})	33.9	31.4	41.6	17.9	16.3	6.7
	(± 3.7)	(± 5.5)	(± 9.01)	(± 5.5)	(± 2.8)	(± 1.0)
DIN (µmol l^{-1})	224	109.2	85.0	33.6	26.3	17
	(± 20)	(± 10.5)	(± 15)	(± 6.5)	(± 2.8)	(± 3.93)
DON (µmol l^{-1})	ND	18.0	9.9	ND	19.2	12.9
		(± 7.2)	(± 1.07)		(± 6.0)	(± 1.26)
PO_4 (µmol l^{-1})	5.0	5.1	5.6	2.5	1.7	4.2
	(± 0.7)	(± 0.6)	(± 2.0)	(± 0.6)	(± 0.2)	(± 1.22)
SiO_4 (µmol l^{-1})	104	66.1	54.6	55.5	50.6	46.8
	(± 12)	(± 4.4)	(± 4.9)	(± 9)	(± 8.2)	(± 7.01)

*: average of January, February and March.
ND: not determined.

Zooplankton abundance and biomass

The list of identified taxa from Annaba Bay is given in Table 3. The total zooplankton abundance, without the dinoflagellate *Noctiluca scintillans* (hereafter referred to as TZ-N), fluctuated largely between seasons, years and sites, as shown in figure 2. The annual average densities varied from 700-1,000 ind. m^{-3} at the outer site and 1,900-2,000 ind. m^{-3} at the inner sites under the influence of estuaries' plumes. At the outer site, opened to external water intrusion, the maximum abundance was encountered during May-August 2009, due mainly to increased copepods and cladocerans. TZ-N was abundant throughout the year in the inner bay sector (Fig. 2), peaking in the warm season (July-September). The cladocerans and copepods were the most abundant components during this warm and dry period. However, exceptionally low densities (100-300 ind. m^{-3}) were recorded at the estuaries' plumes (Fig. 2) due to the riverine floods, which may bring the whole water layer (and its plankton) up to the outer waters during November 2010 and February 2009.

N. scintillans followed regular seasonal cycle, with the highest values in spring (Fig. 2), but was almost absent in samples during summer and autumn. *N. scintillans* was a major component in the Seybouse estuary's plume, forming 61 to 78% of the total zooplankton, and peaked in April (17,980 ind. m^{-3} in 2009 and 42,170 ind. m^{-3} in 2010). At the Mafragh plume, its fraction was less important: 16% in 2009, 41% in 2010 and 68% in early 2011. The species was not rare in the outer site but represents on average 20 to 30% of the total zooplankton.

Excluding *N. scintillans*, copepods and cladocerans were the most abundant groups in both 2009 and 2010, representing 82 to 90% of the total zooplankton, and showed clear seasonality. Copepods were the most abundant group, representing 54-76% of the total abundance, and their contribution to TZ-N increased during winter and spring (60-92%), when cladocerans and other group abundances decrease. The copepod abundances increased in estuaries' plumes (1,100-1,560 ind. m^{-3}) and were two- or three-fold higher than in the outer waters at site B3 (Fig. 2). However, during early 2011, copepod populations were abundant in all samples, reaching exceptionally high densities at the site B3. Their maximum abundance was encountered in July-August 2009 and September 2010 (Fig. 2).

In Annaba Bay, the seven known marine Mediterranean cladocerans species (Table 3) were registered in the samples, but *Podon leuckartii*, *Podon intermedius* and *Evadne nordmanni* were rare and appeared sporadically in late winter and spring. *Pleopis polyphemoides*, *Pseudevadne tergestina*, *Evadne spinifera* and *Penilia avirostris* were the most abundant species particularly during the warm period (May-October). Cladocerans were the second most abundant group within TZ-N (8-30%), and reached high densities in the warm season (Fig. 2). Due to the blooming of the parthenogenetic females of *P. tergestina* and, to a lesser degree *P. avirostris*, very elevated densities of cladocerans occurred in July 2009 at site B2 (3,820 ind. m^{-3}). The bloom of September 2010 spreading in all stations, however, was related to *P. avirostris*.

The meroplankton amounted to less than 5%, with fish eggs continuously sampled from April to October. The cnidarian group was always recorded at the outer site but with very low densities (5-25 ind. m^{-3}). This group was mainly composed of siphonophores and the cosmopolitan hydromedusa *Aglaura hemistoma* which was in particular was linked to the Seybouse estuary plume

Table 2. Average values (± standard error) of the hydrological data at the studied stations of Annaba Bay, January 2009-March 2011.

		Station B1			Station B2			Station B3		
		2009	2010	2011*	2009	2010	2011*	2009	2010	2011*
Temperature (°C)	Surface	20.0 (± 1.5)	21.4 (± 1.4)	17.1 (± 0.7)	19.4 (± 1.5)	20.2 (±1.4)	16.7 (± 1.0)	19.0 (±1.4)	20.4 (±1.5)	17.3 (±0.9)
	Bottom	19.7 (±1.4)	19.7 (±1.4)	16.4 (±1.0)	19.0 (±1.3)	19.8 (± 1.5)	16.9 (± 0.7)	18.2 (±1.1)	18.7 (±1.5)	16.1 (±1.2)
Salinity (pss)	Surface	31.8 (± 1.8)	35.1 (± 0.6)	34.8 (± 0.6)	34.1 (± 1.1)	36.4 (± 0.2)	34.6 (± 0.5)	36.5 (± 0.2)	36.6 (± 0.2)	34.6 (± 1.2)
	Bottom	35.4 (± 1.0)	36.4 (± 0.2)	35.1 (± 0.5)	36.2 (± 0.3)	36.7 (± 0.2)	34.7 (± 1.3)	36.6 (± 0.2)	36.8 (± 0.2)	35.9 (± 0.5)
PO_4 (µmol l^{-1})	Surface	4.40 (± 1.5)	1.29 (± 0.2)	0.7 (± 0.1)	2.6 (± 0.8)	0.95 (± 0.2)	0.20 (± 0.1)	2.52 (± 0.6)	0.44 (± 0.1)	0.27 (± 0.1)
	Bottom	3.88 (± 1.4)	1.38 (± 0.3)	0.7 (± 0.3)	2.7 (± 0.9)	1.26 (± 0.2)	0.27 (± 0.1)	1.73 (± 0.5)	0.39 (± 0.1)	0.25 (± 0.1)
NH_4 (µmol l^{-1})	Surface	6.00 (± 0.9)	1.10 (± 0.5)	16.7 (± 6.7)	3.6 (± 0.7)	0.3 (± 0.2)	22.7 (± 16)	2.7 (± 0.5)	0.0 (± 0.0)	3.9 (± 1.4)
	Bottom	5.50 (± 1.3)	0.60 (± 0.6)	27.3 (± 17)	6.0 (± 1.6)	0.3 (± 0.3)	26.7 (± 22.5)	2.9 (± 0.6)	0.1 (± 0.1)	3.8 (± 2.2)
NO_3 (µmol l^{-1})	Surface	3.01 (± 1.4)	5.35 (± 0.8)	12.5 (± 7.1)	1.1 (± 0.4)	3.17 (± 1.2)	7.49 (± 4.2)	1.3 (± 0.3)	2.70 (± 1.5)	5.91 (± 3.5)
	Bottom	2.54 (± 1.5)	3.74 (± 0.6)	7.1 (± 2.4)	1.47 (± 0.6)	2.84 (± 0.9)	6.30 (± 3.3)	1.9 (± 0.8)	2.54 (± 1.3)	5.07 (± 2.4)
DIN (µmol l^{-1})	Surface	10.6 (± 2.9)	6.57 (± 1.0)	29.3 (± 11)	5.55 (± 1.0)	3.50 (± 1.2)	30.2 (± 13)	4.47 (± 0.8)	2.73 (± 1.5)	9.80 (± 2.1)
	Bottom	8.92 (± 2.0)	4.41 (± 0.7)	34.4 (± 15)	8.29 (± 1.9)	3.18 (± 0.9)	33.1 (± 20)	5.25 (± 1.1)	2.63 (± 1.4)	8.90 (± 1.4)
DON (µmol l^{-1})	Surface	5.13 (± 1.0)	7.39 (± 1.3)	4.72 (± 2.1)	4.14 (± 0.9)	7.34 (± 0.9)	4.66 (± 1.4)	4.16 (± 0.9)	4.09 (± 0.6)	3.73 (± 0.9)
	Bottom	5.24 (± 1.1)	8.11 (± 1.9)	6.52 (± 1.1)	3.22 (± 0.7)	6.07 (± 0.8)	3.95 (± 1.8)	3.97 (± 0.9)	4.29 (± 0.8)	4.27 (± 1.0)
$Si(OH)_4$ (µmol l^{-1})	Surface	6.02 (± 1.1)	5.96 (± 1.2)	12.6 (± 5.3)	3.85 (± 0.9)	4.37 (± 0.5)	2.23 (± 0.9)	2.87 (± 0.6)	3.68 (± 0.5)	3.40 (± 0.7)
	Bottom	5.63 (± 0.8)	5.28 (± 1.0)	5.00 (± 0.9)	3.21 (± 0.9)	3.79 (± 0.5)	2.90 (± 0.6)	4.70 (± 0.8)	4.04 (± 0.7)	3.86 (± 0.3)
Chl *a* (µg l^{-1})	Surface	4.2 (± 0.8)	2.75 (± 0.7)	0.93 (± 0.5)	2.5 (± 0.5)	1.51 (± 0.6)	1.91 (±0.4)	1.8 (± 0.2)	1.65 (± 0.4)	2.00 (± 0.6)
	Bottom	4.5 (± 0.9)	3.00 (± 0.9)	1.16 (± 0.2)	2.8 (± 0.3)	1.35 (± 0.3)	1.60 (± 0.5)	1.9 (± 0.5)	1.73 (± 0.2)	0.80 (± 0.4)

*: average of January, February and March.

(Fig. 2). The appendicularians were collected throughout the year and represented 2-5% of TZ-N abundance, but was rather more abundant at site B1, particularly in winter and spring (Fig. 2). The chaetognaths that were collected in all samples were more abundant in autumn and winter, especially at the outer site B3, which constituted 2.2% of the TZ-N abundance (Fig. 2). Doliolids and salps (*Doliolum nationalis, Dolioletta gegenbauri,* and *Thalia democratica*) were rare and appeared sporadically at the estuaries' plumes but were more present at the outer site (1.5%) from winter to summer. Other taxonomic groups (amphipods, radiolarians, euphausiids, foraminifera, and mysids) collectively represented less than 3% of the TZ-N and generally showed very low numbers (30-60 ind. m^{-3} on average).

In Annaba Bay, the zooplankton biomass (Fig. 2) varied between medium values (6.7-8.3 mg DW m^{-3}) at the outer site to high values in the estuaries' plumes (12-25.40 mg DW m^{-3}). The seasonal variation of total zooplankton abundances was different from the general pattern of the biomasses (Fig. 2), which peaked in spring 2009 and September 2010. There is however a significant correlation between the total zooplankton abundance and biomasses: 0.68; 0.62 and 0.61, respectively, at stations B1, B2 and B3 ($n = 24$; $p<0.05$). The zooplankton biomass, on the other hand, was the highest at site B1 during April 2009 and 2010 and during March 2011 due to the blooming of *N. scintillans* and to possible contamination with detritus re-suspension and phytoplankton, which increases habitually in this period of the year (Fig. 2). The shallow water layer in this area may allow detritus and phytoplankton re-suspension, in particular the colonial diatoms such as *Chaetoceros* species.

The copepod community

The mean copepod abundances (excluding copepodids) ranged from 368 to 670 ind. m^{-3} with elevated values at inner sites, as shown in Figure 3. Seventy-three

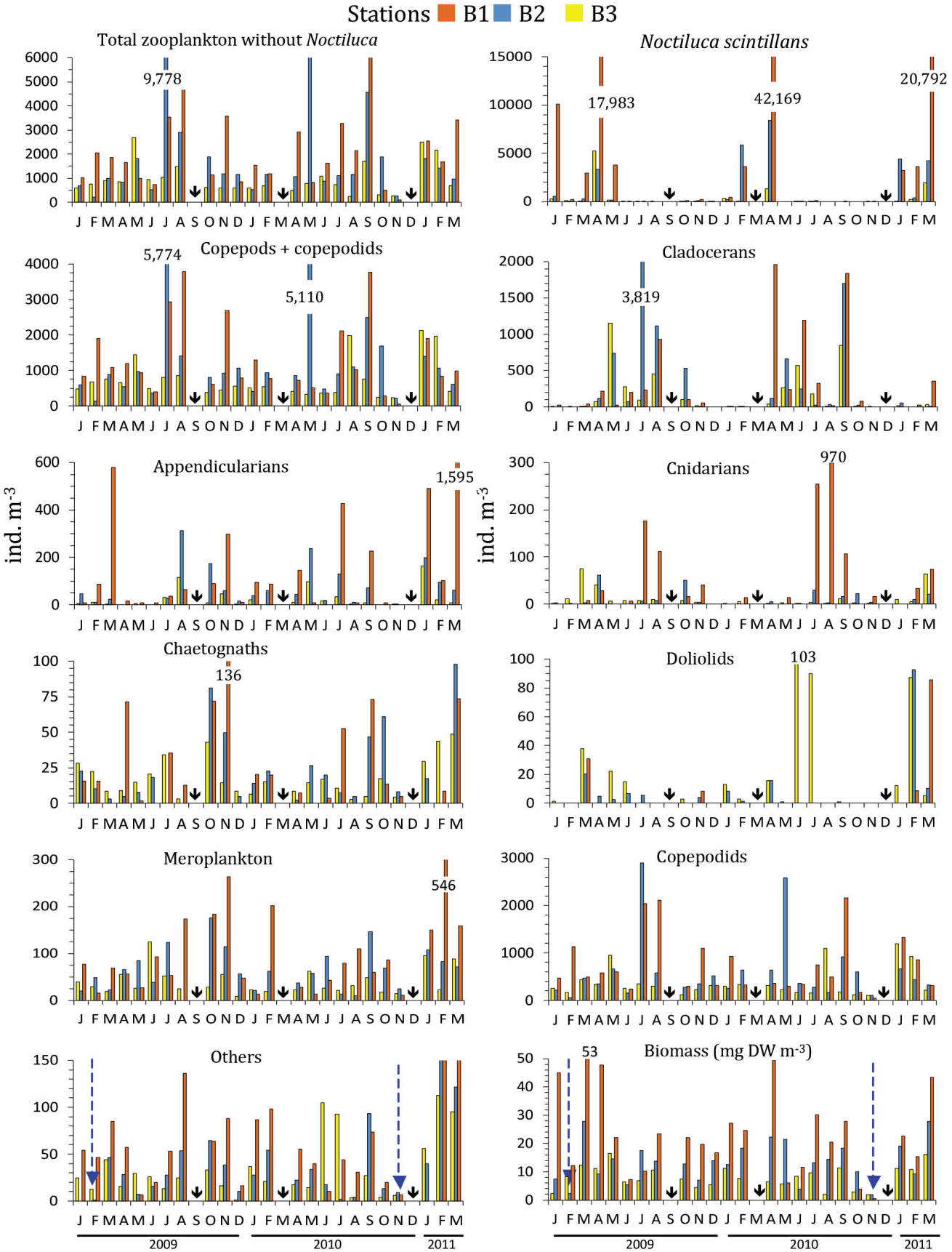

Fig. 2: Variation in the zooplankton and its main component abundances (ind. m^3) and biomass collected from the three stations (B1, B2 and B3) of Annaba Bay from January 2009-March 2011. ⇓: not sampled. Vertical dashed arrows designated the river' flood periods.

copepod species were identified, but only 10 species accounted for 80-90% of the total copepod abundance. *Paracalanus indicus* (20.5-35.4%), *Oithona similis* (10-19.6%), *Euterpina acutifrons* (4.9-22.6%), *Centropages ponticus* (6.6-18.5%), *Oncaea venusta* (3-12.5%), *Oithona plumifera* (3.8-7.9%), *Clausocalanus furcatus* (1-7.6%), *Oithona nana* (2.7-5.8%), *Temora stylifera* (1.8-2.7%) and *Acartia (Acartia) negligens* (0.6-1.5%) were the most common species throughout the year. *P. indicus* and *O. similis* as the most abundant species (27.4 and 14.5%, respectively), dominated the copepod community successively in winter-spring and summer-autumn and were especially abundant in the inner bay sector, which is directly submitted to estuarine water exchange. In contrast to *O. similis, P. indicus* displayed winter minima and late summer-autumn maxima, reaching 1,360 ind. m^{-3} and 1,293 ind. m^{-3} in July 2009 and May 2010 at site B2, respectively (Fig. 3). *O. similis*, *O. plumifera* and *O. nana* made up 40-70% of the copepod community abundance during winter and spring 2009 (Fig. 3). *O. nana* occurred in the plankton throughout the year with maximum in spring-summer, and had the highest densities at the inner site B1, in contrast to *O. plumifera* which was more abundant during autumn-winter.

The small harpacticoid *E. acutifrons* appeared in relatively high abundance during the warm period, especially at the inner site B1, where it constituted on average 22% of the total copepod abundances. Other dominant species in the outer site included the cyclopoid *O. venusta* (12.5%) and the calanoid *C. furcatus* (7.6%), which occurred throughout the year but with no clear seasonal pattern. *Centropages ponticus* was the most abundant copepod during the warm season. The Calocalanidae, which comprised 6 species (Table 3), appeared sporadically during autumn and early winter (Fig. 3), constituting 3-4% of the total copepod abundances. *Calocalanus pavo* was the most abundant among the calocalanid species, reaching 103-112 ind. m^{-3} at the inner sites during November 2009. *T. stylifera* was collected in all seasons but with very low densities, particularly during winter-spring. Species of the Acartiidae family attained low abundances, and paradoxically, *Acartia (Acartiura) clausi* was rare during the study period. *A. negligens* was present in almost all of the samples with low frequencies and *A. danae* occurred in late autumn-winter at the outer site. The family Corycaeidae contributed with 9 species (Table 3) that occurred sporadically at very low abundances. However, *Onchocorycaeus ovalis*, *Farranula curta* and *F. rostrata* were present in most of the samples with no seasonal pattern.

During late autumn and winter, coinciding with the mixing period, the external input from open sea waters brought several mesopelagic/bathypelagic and oceanic species, such as *Calanus helgolandicus*, *Nannocalanus minor*, *Spinocalanus magnus, Scolecithrix danae, Diaixis hibernica, Sapphirina opalina, Pleuromamma abdominalis, P. borealis, P. xiphias, P. piseki, P. gracilis, Centropages violaceus, C. chierchiae, Lucicutia flavicornis, Cymbasoma longispinosum, Ctenocalanus vanus, Acartia danae, Candacia varicans, Agetus typicus , Urocorycaeus lautus , Onchocorycaeus latus* and *Clausocalanus pergens.* These immigrants and rare species (< 1%, named DIV or diverse species) did not spread in the whole bay but were mainly limited to the outer station influenced by the open sea.

The species *Pseudodiaptomus arabicus* and *P. australiensis* were encountered during the year 2010 for the first time in Annaba Bay and are unknown in the Mediterranean Sea. *P. australiensis* females were observed (1-3 individuals) during May and June (station B1) and July and August (station B3) and as female copepodids during September. For *P. arabicus* 4 females were encountered in September at the inner stations B1 and B2.

The Shannon-Wiener diversity index (H') varied largely throughout the year, with high values during autumn and winter. Exceptionally, during late winter-spring 2009, the diversity index decreased to its lowest values because of the high density of *O. similis*, which dominated the copepod community at 65-84% in February, 61-69% in March and 32-61% in April. Due to the numerical abundance of *P. indicus*, the copepod community was also unstructured during July-August 2010, and the diversity decreased to 0.8-1.9 at the inner sites (Fig. 3). The copepod community was well structured from October 2009 to February 2010, where the diversity index and the number of species peaked. In addition, the outer site, which is well exposed to external neritic and oceanic species intrusion, had high diversity values for both 2009 and 2010 (Fig. 3). During the mixing period in November 2009, more than 20 species co-occurred (with moderate densities), which led to exceptionally high diversity values. The principal components of the community were *Paracalanus nanus, P. indicus*, *T. stylifera*, *Calocalanus pavo*, *C. styliremis, C. plumatus, Clausocalanus furcatus, Oithona plumifera, O. similis, A. clausi, A. negligens, O. venusta, Corycaeus typicus, C. ovalis, Farranula curta,* and *Nannocalanus minor*. As shown in Figure 3, site B3 was 2-fold richer in species than was station B2 and approximately 3-fold richer than station B1.

Statistical analysis

Data analysis with a correspondence analysis (CA) provides the co-variation between the spatiotemporal distribution of the zooplankton abundances and biomasses and the copepod species in relation to their major environmental parameters (Fig. 4). According to the factorial plan (F1 × F2), which brings 72.7% of the total inertia, the zooplankton and its main component copepod taxa are segregated into three major groups. The axis F1 segregates the summer coastal group mainly composed of *Paracalanus indicus* (Pin) and *Centropages ponticus*

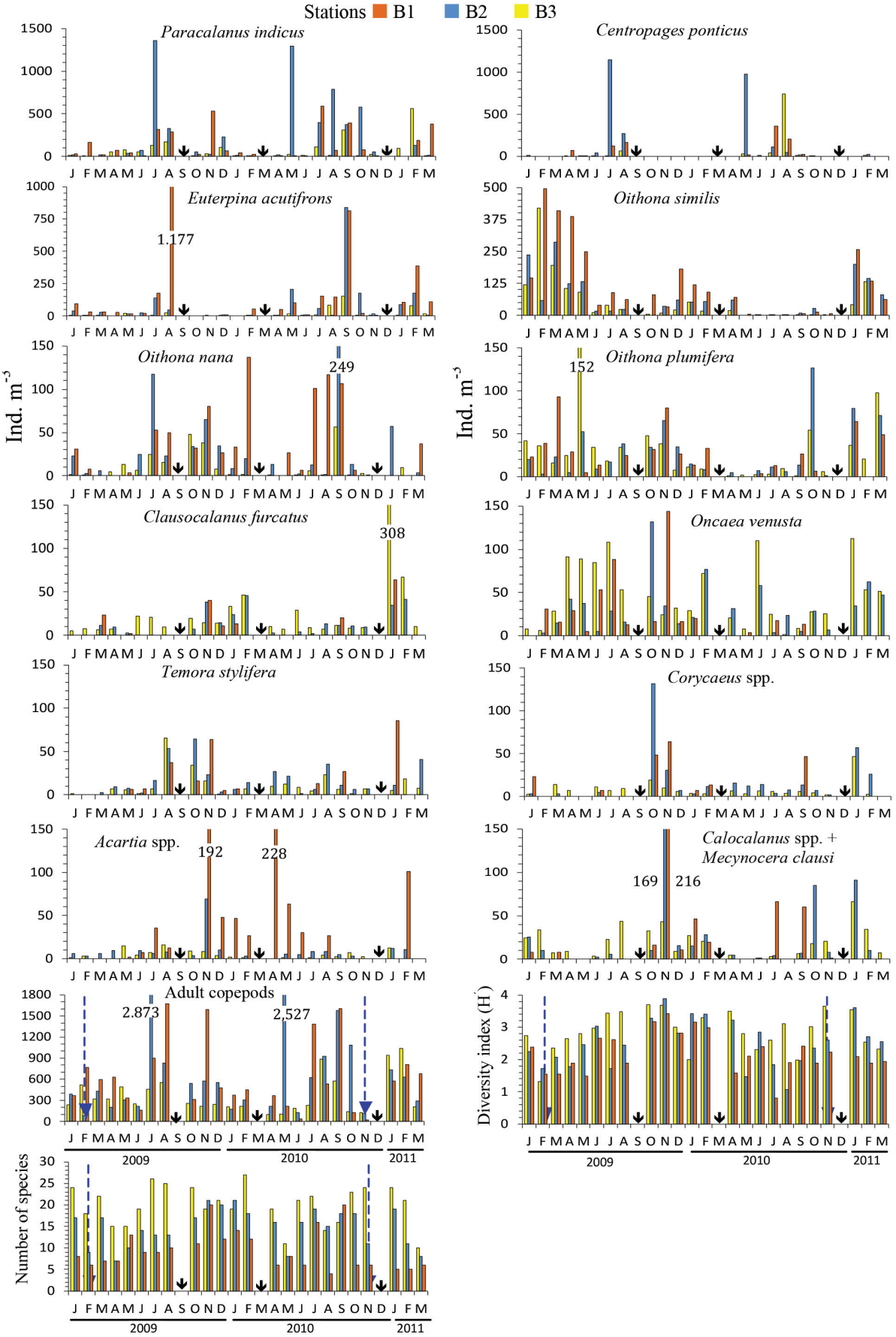

Fig. 3: Variation in the adult copepods and main species' abundances (ind. m³) and the copepod diversity index (H') and richness at the three stations (B1, B2 and B3) of Annaba Bay from January 2009-March 2011. ⇓: not sampled. Vertical dashed arrows designated the river' flood periods.

Table 3. List of the identified zooplankton taxa that were collected from Annaba Bay, January 2009-March 2011.

PROTOZOA
PHYTOFLAGELLATA
Dinoflagellata
Noctiluca scintillans (Macartney) Kofoid and Swezy, 1921

ZOOFLAGELLATA
Foraminifera
Globigerina bulloides d'Orbigny, 1826
Globigerina spp.
Radiolaria
Arachnosphaera myriacantha Haeckel, 1860

CNIDARIA
SIPHONOPHORA
Abylopsis eschscholtzii (Huxley, 1859)
Eudoxoides spiralis (Bigelow, 1911)
Lensia subtilis (Chun, 1886)
Muggiaea atlantica Cunningham, 1892
Muggiaea kochi (Will, 1844)
MEDUSAE
Aglaura hemistoma Péron & Lesueur, 1810
Obelia spp.
Nausithoe punctata Kölliker, 1853
Paraphyllina intermedia Maas, 1903
Pelagia noctiluca (Forsskål, 1775)
Persa incolorata McCrady, 1857
*Rhopalonema funerarium*Vanhöffen, 1902

ANNELIDA
Magelona papillicornis McIntosh, 1878
Nereis sp.
Sabellaria sp.
Polydora spp.
Nephtys sp.

MOLLUSCA
Gastropods and bivalve larvae
Pteropoda

ARTHROPODA
BRANCHIOPODA
Cladocera
Evadne nordmanni Lovén, 1836
Evadne spinifera Müller P.E., 1867
Pleopis polyphaemoides (Leuckart, 1859)
Pseudevadne tergestina (Claus, 1877)
Penilia avirostris Dana, 1849
Podon intermedius Lilljeborg, 1853
Podon leuckartii (Sars G. O., 1862)

OSTRACODA (undetermined)

COPEPODA
Calanoida
Acartia (Acartiura) clausi Giesbrecht, 1889
Acartia (Acartia) danae Giesbrecht, 1889
Acartia (Acartiura) discaudata (Giesbrecht, 1881)
Acartia (Acartia) negligens Dana, 1849
Calocalanus pavo (Dana, 1852)
Calocalanus plumatus Shmeleva, 1965*
Calocalanus plumulosus (Claus, 1863)
Calocalanus styliremis Giesbrecht, 1888
Calocalanus tenuis Farran, 1926
Candacia armata Boeck, 1872
Candacia bipinnata (Giesbrecht, 1889)
Candacia varicans (Giesbrecht, 1893)
Calanus helgolandicus (Claus, 1863)
Candacia simplex (Giesbrecht, 1889)
Centropages chierchiae Giesbrecht, 1889
Centropages kroyeri Giesbrecht, 1893
Centropages ponticus Karavaev, 1895*
Centropages typicus Krøyer, 1849
Centropages violaceus (Claus, 1863)
Clausocalanus furcatus (Brady, 1883)
Clausocalanus jobei Frost & Fleminger, 1968
Clausocalanus lividus Frost & Fleminger, 1968
Clausocalanus paululus Farran, 1926
Clausocalanus pergens Farran, 1926
Ctenocalanus vanus Giesbrecht, 1888
Diaixis hibernica (Scott A., 1896)*
Labidocera wollastoni (Lubbok, 1857)
Lucicutia flavicornis (Claus, 1863)
Mecynocera clausi Thompson I.C., 1888
Monstrilla longicornis Thompson I.C., 1890*
Nannocalanus minor (Claus, 1863)
Paracalanus indicus Wolfenden, 1905
Paracalanus nanus Sars G.O., 1925
Paracartia grani Sars G.O., 1904
Paracartia latisetosa (Krichagin, 1873)
Pleuromamma abdominalis (Lubbock, 1856)
Pleuromamma borealis Dahl F., 1893
Pleuromamma piseki Farran, 1929*
Pleuromamma xiphias (Giesbrecht,1889)
Pseudodiaptomus arabicus Walter, 1998**
Pseudodiaptomus australiensis Walter, 1987**
Scolecithrix bradyi Giesbrecht, 1888*
Scolecithrix danae (Lubbock, 1856)*
Spinocalanus magnus Wolfenden, 1904*
Temora stylifera (Dana, 1849)
Cyclopoida
Oithona linearis Giesbrecht, 1891
Oithona nana Giesbrecht, 1893
Oithona plumifera Baird, 1843
Oithona similis Claus, 1866
Poecilostomatoida
Agetus flaccus (Giesbrecht, 1891)
Agetus limbatus (Brady, 1883)
Agetus typicus Krøyer, 1849
Copilia lata Giesbrecht, 1891
Corycaeus crassiusculus Dana, 1849
Corycaeus speciosus Dana, 1849
Farranula curta (Farran, 1911)*
Farranula rostrata (Claus, 1863)
Oncaea media Giesbrecht, 1891
Oncaea mediterranea (Claus, 1863)
Oncaea venusta Philippi, 1843
Oncaea spp.
Onchocorycaeus latus (Dana, 1849)
Onchocorycaeus ovalis (Claus, 1863)
Sapphirina opalina Dana, 1849
Urocorycaeus lautus (Dana, 1849)
Harpacticoida
Distioculus minor (Scott T., 1894)
Clytemnestra scutellata Dana, 1847
Euterpina acutifrons (Dana , 1847)
Goniopsyllus rostratus Brady, 1883
Macrosetella gracilis (Dana, 1847)
Microsetella norvegica (Boeck, 1865)
Microsetella rosea (Dana, 1847)
Monstrilloida
Cymbasoma longispinosum (Bourne, 1890)*
Monstrilla sp.

CIRRIPEDIA
Undetermined larvae

PERACARIDA
Amphipoda
Undetermined

EUCARIDA
Euphausiacea
Undetermined larvae
Decapoda
Eriphia verrucosa (Forsskål, 1775)
Rathke, 1837
Palaemon elegans Rathke, 1837
Porcellana spp.
Necora puber (Linnaeus, 1767)
Processa spp.

CHAETHOGNATHA
Sagitta bipunctata Quoy & Gaimard, 1827
Sagitta enflata Grassi, 1881
Sagitta serratodentata Krohn, 1853

ECHINODERMATA
ECHINIDA
Undetermined larvae

OPHIURIDA
Undetermined larvae

TUNICATA
APPENDICULARIA
Fritillaria pellucida (Busch, 1851)

THALIACEA
Doliolida
Dolioletta gegenbauri (Uljanin, 1884)
Doliolum nationalis Borgert, 1893
Salpidae
Thalia democratica (Forsskål, 1775)

VERTEBRATA
Anchovy (*Engraulis encrasicolus* L.) eggs and clupeid eggs and larvae

**: new species for the Mediterranean Sea.
*: unknown species for Annaba Bay.

(Cep) from the neritic-oceanic/autumn-winter group, regrouping species of DIV community. *Oithona* spp. (Oit), mainly *Oithona plumifera* and *O. similis,* belong also to this group, which has some affinity to neritic water and appeared with high numbers during the cold season. The first group dominates at the area of the Mafragh estuary's plume (B2-10, B2-9 are badly projected on both axes), while the second group mainly inhabits the open site to MAW intrusion (B3-9 and B3-10). According to the second factor F2, *Clausocalanus furcatus* (Clf), *Oncaea venusta* (Onv), and *Calocalanus* spp., in addition to DIV species that rather inhabit the more saline (Sal) and cold (Tem) waters of the opened area, are separated from *Euterpina acutifrons* (Eut) *and Acartia* spp. (Aca: *A. clausi* + *A. discaudata* + *A. negligens*), which are typical of the innermost and eutrophicated sector (the Seybouse plume: B1-9 and B1-10). The G2, more diversified (C-H': copepod H' index diversity) and richer in species (NCP: number of copepod species), is associated with the outer site B3 (Fig. 4). In addition to *E. acutifrons* and *Acartia* spp., indicators of eutrophic areas, the G3 included high zooplankton (TZA) abundances and biomass (ZB), which characterizes the Seybouse plume. Overall, it appears from the CA that axis F1 may correspond to a temporal factor segregating the autumn-winter group from the summer coastal one, while the axis F2 may represent a spatial factor separating the inner coastal productive sector from the outer waters with relatively low zooplankton abundance and biomass, high diversity and richness.

Discussion

Features of zooplankton biomass and abundance

In the two last decades, changes in the coastal area of Annaba Bay were induced by various and intensive coastal development. The western sector of the bay is particularly heavily impacted by the direct input of untreated household and industrial wastes, despite the diffusive nutrient and particulate matter deliveries from the Seybouse estuary (Ounissi *et al*., 2014). In contrast, the eastern sector has the advantage of the Mafragh estuary' near-pristine water inputs (Khélifi-Touhami *et al*., 2006; Ounissi *et al*., 2014). The plumes of the estuarine flow are usually relatively limited (5-10 km), but the dilution area during flooding events can influence more distant areas, reaching the northwestern part of the bay. In one such event, Ounissi *et al*. (1998) reported that the inner sector was nearly defaunated and that the zooplankton was transported around the entrance of Annaba Bay, located 12 km from the Seybouse mouth, which is usually opened to oceanic water intrusion. During this event, 30 adult copepods m^{-3} at the estuary plume and 40,500 copepods m^{-3} at the boundary plume have been reported, with abundances never encountered before. During our research, the flooding of November 2010 due to the Seybouse freshwater discharge has led to comparable effects, where the zooplankton biomass and abundance decreased to their lowest values.

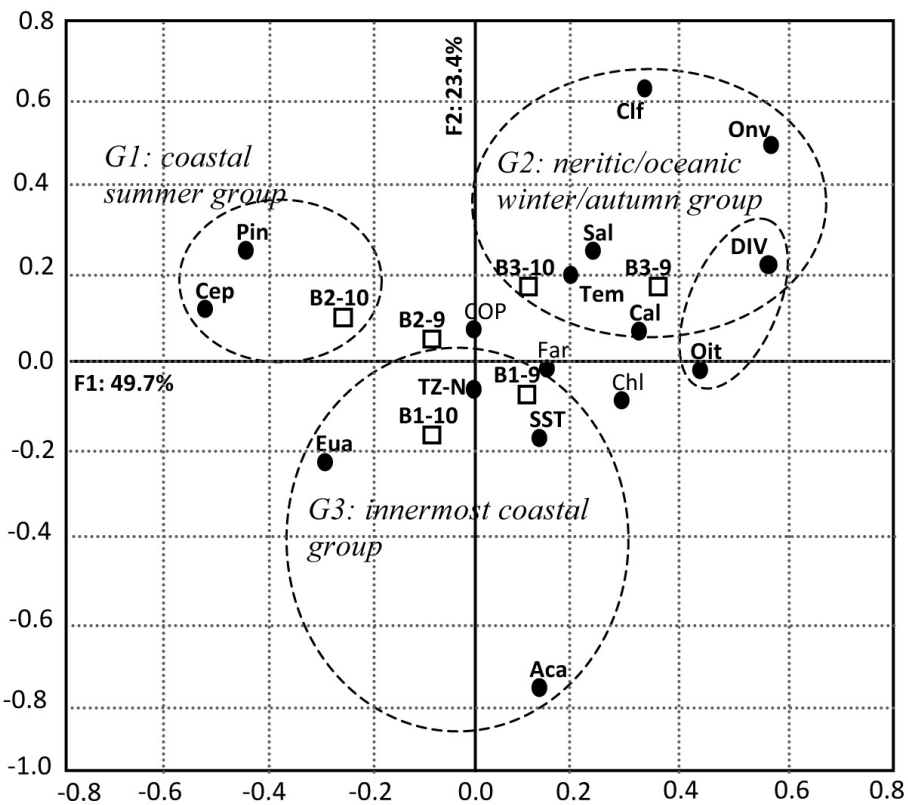

Fig. 4: Correspondence analysis (F1 x F2 factorial plane) showing the three segregated groups (G1; G2 and G3) of zooplankton data that were collected from Annaba Bay. Variable symbols are as indicated in Statistical analysis section.

The highest zooplankton abundances and biomass in the Annaba Bay were encountered in the shallow area close to the coast, particularly during the wet year of 2009, where the inputs of nutrients from Seybouse and Mafragh estuaries have sustained a high phytoplankton biomass, which supplied large nutritional base for the zooplankton. Comparable findings in some similar Mediterranean coastal waters have been reported in Tunis Bay (Daly Yahia *et al*., 2004), North Adriatic (Benović *et al*., 1984), Izmit Bay, Marmara Sea (Isinibilir *et al*., 2008) and Annaba Bay (Ounissi *et al*., 1998). Compared to the zooplankton biomass from other parts of the Mediterranean, Annaba Bay can be considered among the moderate to richest bays (6.70-25.37 mg DW m^{-3}). The review of zooplankton biomass in the W Mediterranean Sea of Champalbert (1996) reported that biomasses from the whole Mediterranean varied from 2-20 mg DW m^{-3}, and values over 20 mg DW m^{-3} are considered highly productive zones. Similar biomass values (2.1-14.4 mg DW m^{-3}, mean 7 mg DW m^{-3}) for the epipelagic zone in the open sea have been reported by Siokou-Frangou *et al*. (2010) and in the Adriatic Sea (6.6-18.5 mg DW m^{-3}: Benović *et al*., 1984). The study of zooplankton biomass from an open coastal zone of Algiers, Algeria (Riandey *et al*., 2005), was remarkably comparable (4-9.6 mg DW m^{-3}) to our findings for the outer site B3 (6.7-8.3 mg DW m^{-3}), as well as the biomasses from the neritic zone of the Balearic Sea (7.40 mg DW m^{-3}, *Fernández de* Puelles *et al*., 2003). The elevated values of zooplankton biomass might be due to the proliferation of tolerant non-selective feeding zooplankton species, such as copepods *Oithona similis* (Nishibe *et al*., 2010) and *Euterpina acutifrons* (Sautour and Castel, 1993) or the dinoflagellate *Noctiluca scintillans,* which can use even detritus as a greater or smaller fraction of their diet (Fonda Umani *et al*., 2004).

In Annaba Bay, *N. scintillans* peaked during late winter-spring, but almost disappeared in samples during summer-autumn. At the same site, Ounissi *et al*. (1998) reported a high red bloom (nearly 1 million ind. m^{-3}) in April 1992 and a smaller bloom in February 1992, but it was weakly represented at the area more influenced by external neritic water intrusion. *N. scintillans,* as a phagotrophic dinoflagellate, has a broad food spectrum, feeding on phytoplankton, detritus, protozoans, and copepod and fish eggs (Nakamura, 1998; Quevedo *et al*., 1999), which allows it to be flexible in nutrition strategy and produce mass development events, including red tides in many areas of the world ocean (Mikaelyan *et al*., 2014). Such nutritional environment spreads largely over the inner sector of Annaba Bay, which is under the strong influence of continental inputs; Ounissi *et al*. (1998) reported that the small zooplankton such as tintinnids and copepods nauplii developed high abundances throughout the year, reaching 11,000-50,000 ind. m^{-3} in February-April period, despite the high phytoplankton biomass (Chlorophyll *a*: 10.5 mg. m^{-3}).

The copepod community

Based on scarce earlier data, the copepod fauna from the Annaba region consisted of 143 species (Khélifi-Touhami *et al*., 2007), to which we have now added ten new species for the area and two new species (*Pseudiatoptomus australiensis* and *Pseudiatoptomus arabicus*) for the Mediterranean Sea. The occurrence of copepodid V stages of *P. australiensis* suggests that the species survives and reproduces in Annaba Bay but does not develop an abundant population, contrary to results reported for *Pseudodiaptomus marinus* recently introduced in the North Sea (Brylinski *et al*., 2012) and the Mediterranean Sea (Italian waters; Sabia *et al.,* 2015). Among the ten new species, *Farranula curta* was presumably previously confused with *Farranula rostrata, Centropages ponticus* was presumably confused with *Centropages kroyeri*. The discovery of several rare species (*Spinocalanus magnus, Scolecithrix bradyi, S. danae, Pleuromamma piseki, Monstrilla longicornis, Diaixis hibernica,* and *Calocalanus plumatus*), which are considered to have a more oceanic and deep water distribution (Razouls *et al*., 2005-2015) may be mainly due to the increased sampling effort, during more than two successive annual cycles. The presence of tropical and coastal demersal species, such as *P. australiensis* and *P. arabicus* (Walter, 1987; 1998), in the inner coastal waters of Annaba Bay may be caused by discharge of ballast water from international shipping. This way of transport is a spreading factor of globally invading coastal copepods (Brylinski *et al*., 2012; De Olazabal & Tirelli, 2011; Rajakaruna *et al*., 2012; Sabia *et al*., 2014).

Oithona spp. constituted 40-70% of the copepod community abundance during winter and spring 2009. *Oithona* as a eurythermal, euryhaline, omnivorous and thus is adapted to a wide range of habitats (Fransz *et al*., 1991) is probably the most abundant copepod in the world (Gallienne & Robins, 2001). Compared to its abundance in 1992 (340-1430 ind. m^{-3} in the warm period; Ounissi *et al*., 1998), *Oithona nana* has decreased and seems to be replaced by *Oithona similis,* which spreads throughout the entire bay (Table 4). In the Black Sea, the native species *O. nana* has disappeared completely since the 1970s and has been replaced by the non-indigenous *Oithona davisae*, which occupied the same niche (Gubanova *et al*., 2014). In the same context, Gubanova *et al*. (2014) reported that *Acartia margalefi* and *Paracartia latisetosa* have disappeared, and *Acartia tonsa* became established in the Black Sea during the 2000s. Comparable restructuration occurred in the Annaba Bay copepod community, where *Acartia clausi* and *Acartia discaudata* abundances have decreased sharply since 1992 (*A. discaudata* was particularly numerous during spring 1992, reaching 700 ind. m^{-3}), and the species *Acartia negligens* became more abundant (Table 4). The other change in copepod community composition is that the large dominance of

Table 4. Comparison of the main copepod species composition (relative frequency in%) from Annaba Bay of several samplings during the two last decades (1992-2011).

	1992[a]		2002[b]	2003[b]	2006[c]	2006[c]	2009[d]		2010[d]		2011[d]
	F-Mr-A	Jn-J-Au	F-Mr	Mr-A	Mr	Jn	F-Mr-A	Jn-J-Au	F-A	Jn-J-Au	F-Mr
Paracalanus indicus	1.0	0.0	2.0	9.0	16.4	46.5	3.8	33.3	4.1	37.4	20.4
Oithona similis	6.4	0.0	7.0	17.0	9.4	1.3	62.2	4.6	18.2	0.8	15.9
Oithona nana	3.5	52.1	0.0	9.0	+	0.2	1.1	4.9	3.7	1.3	0.5
Acartia clausi	5.3	0.5	0.0	0.0	0.2	2.8	1.0	1.3	0.0	0.6	0.0
Acartia discaudata	17.3	0.6	0.0	2.0	+	0.1	0.6	0.2	0.0	0.0	0.4
Acartia negligens	0.0	0.0	0.0	0.0	0.0	0.2	0.4	0.6	0.6	2.0	5.0
Euterpina acutifrons	43.7	25	3.0	3.0	0.6	0.6	1.4	4.4	1.8	5.2	11.2
Clausocalanus furcatus	1.9	0.9	12.0	3.0	45.8	13.1	2.1	2.5	12.0	5.3	4.4
Sum of the frequency (%)	79	80	24.0	43.0	72.5	64.8	72.6	51.7	40.3	52.6	58.0
Total copepods (ind. m^{-3})	448	2883	210	299	644	434	311	864	207	363	542

a: Ounissi et al. (1998); b: Khélifi-Touhami et al. (2007); c: Ounissi, unpublished data; d: present study.
+: presence; F: February, Mr: March; A: April; M: May; Jn: June; J: July; Au: August.

Paracalanus indicus during the warm period and its proportion increased in Annaba Bay (Table 4) since its first record in the area and the Mediterranean Sea (Ounissi *et al*., 1998). This coastal and neritic species has been particularly scarcely studied both in the Mediterranean Sea and worldwide, and has often been confused with congeners *Paracalanus parvus* and *Paracalanus quasimodo* (Khélifi-Touhami *et al*., 2007). More recently, genetic diversity analyses of *P. parvus* complex from all oceans were performed by Cornils & Held (2014). The authors stated that only *P. indicus* is truly widespread on an oceanic scale and revealed that *P. parvus* is restricted probably to the Northeast Atlantic. The copepod community of Annaba Bay also differs from other similar Mediterranean bays and gulfs by the presence of *Centropages ponticus*, which develop intense populations during the warm period, particularly in the inner eastern sector. In Marmara Sea, this warm water species occurred, however, throughout the year, but its abundance increased during late winter-spring (Isinibilir, 2009).

Concerning the spatiotemporal distribution of the copepod community, the correspondence analysis determined the summer coastal group (*P. indicus, C. ponticus*, *E. acutifrons*, *O. nana* and *Acartia*) and the autumn-winter group (composed mainly of carnivorous species: *Oncaea venusta*, *Farranula* spp., *Corycaeus* spp. and the omnivorous or carnivorous *O. similis* and *O. plumifera*, and *Candacia varicans*), which have different spatial preferences. The summer coastal group is more abundant and less diversified and preferably inhabits the inner coastal regions, while the autumn-winter group, with a relatively low abundance and high diversity and richness, is rather associated with the neritic waters. Copepod species of autumn-winter group have some affinity to the more saline and cold waters of this area, as previously determined by the correspondence analysis. Raybaud *et al*. (2008) revealed that the structure of the copepod community (offshore Nice, France) can change largely with a slight decrease in water salinity and found a large correlation between water salinity and the community structure. In addition, during late autumn-winter, water mixing induces important interactions between neritic, oceanic and deep plankton (Siokou-Frangou *et al*., 2010), which can change the distribution of copepod community. In such hydrodynamic conditions, several species (belonging to autumn-winter group) that are common to oceanic and deep waters (e.g., Scotto di Carlo *et al*., 1984; Raybaud *et al*., 2008) enter the bay. The copepod community richness and diversity increase to the highest values with the contribution of these immigrants.

Conclusions

- In this study, the zooplankton of Annaba Bay seems to be spatially very heterogeneous and is under three contrasting hydrological influences:

(i) The Seybouse estuary plume is highly productive and weakly diversified and allows the dominance of some opportunistic species, which tolerate the fluctuation and the weak resilience of this innermost coastal sector.

(ii) The Mafragh estuary inputs produce near-pristine waters. In addition, in contrast to the confining western sector, the Mafragh estuary adjacent coast is heavily exposed to wind stress and storm events and, to a lesser degree, external water intrusion. The zooplankton under these influences is both moderately productive and abundant but more diversified than the western sector. Thus, this area allows for the inhabitation of neritic species and opportunistic species.

(iii) The MAW residual current entering in the north central bay plays a major role in the diversity, abundance and composition of the zooplankton from this area. The zooplankton from this more stable and well-renewed area is less abundant and less productive but highly diversified. The number of copepod species of this area is three-

fold and two-fold higher than that of the areas close to the Seybouse and Mafragh estuarine effects, respectively, and in contrast, its zooplankton abundance is two-fold lower. The central bay is then mainly inhabited by the copepod neritic species *Oithona similis*, *O. plumifera*, *Oncaea venusta*, *Calocalanus* spp., and *Corycaeus* spp. In addition, during late autumn-winter, water mixing induces important interactions between neritic, oceanic and deep plankton, which can bring several species that are common to oceanic and deep waters into the bay.

- Compared to the zooplankton biomass from other parts of the Mediterranean, Annaba Bay can be considered among the moderate to the richest bays, and the biomass enhances during the wet year.
- *N. scintillans* was a major zooplankton component even at the open sector and, with its flexible nutrition strategy, can produce mass development events during February-April, being common in neritic and coastal regions.
- The particularity of the zooplankton from Annaba Bay is in the dominance of *P. indicus* throughout the entire bay and the decrease in *Acartia discaudata* and *A. clausi*, which seem to be replaced by *A. negligens*. In addition, *O. nana* abundance markedly decreased with the large development of *O. similis*.
- The presence of two new alien species (*P. australiensis* and *P. arabicus*) for the Mediterranean Sea was also determined. Moreover, the occurrence of copepodid V stages of *P. australiensis* suggests that this species survives and truly reproduces in Annaba Bay but without developing an abundant population.

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