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Amphipods from tidal channels of the Gulf of Gabès (central Mediterranean Sea)

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Abstract

The spatial and temporal species richness, abundance and assemblage structure of amphipods from four tidal channel of the Gulf of Gabès were studied at 26 stations and during four seasons from March 2016 to January 2017. This led to the identification of 4,378 individuals, 45 species and 21 families. The four mostly diversified families are the Ampeliscidae (6 species), the Caprellidae (5) and the Aoridae and Maeridae (4 species both), while three families account for ~ 75% of the individuals: Aoridae (45.5%), Corophiidae (20.5%) and Dexaminidae (7.2%). The species richness and abundance are higher in winter than at other seasons. The fauna is dominated by a small number of species characteristic of areas with detritus accumulation and seagrass meadows, including *Microdeutopus anomalus*, *Monocorophium acherusicum*, *Dexamine spinosa*, *Microdeutopus gryllotalpa*, *Cymadusa filosa* and *Elasmopus rapax*, which are commonly recorded in lagoons and coastal shallow waters of the Mediterranean Sea. The amphipod structure is linked to the location of tidal channels in the Gulf of Gabès. Abundances are low in the Kerkennah channel compared with other channels, especially the Maltine channel with high winter accumulation of organic matter. There are also low abundances in high-energy hydrodynamic zones with gravel sediment; conversely, the presence of macrophytes, mainly in the seagrass meadows, increases amphipod diversity. As a result of this study, five new species can be added to the inventory of the Tunisian marine amphipod fauna, including a non-native species for the Mediterranean Sea, *Paracaprella pusilla*.

Keywords: Tunisian waters; Amphipod assemblages; spatio-temporal variations; new records; *Paracaprella pusilla*.

Introduction

Amphipods are among the most diversified and abundant groups in coastal soft-bottom communities (Guerra-García *et al.*, 2014). Moreover, some species can form dense populations with more than 10,000 individuals per square metre and have an important role in the functioning of benthic habitats. They can act as engineer species by building tubes, as in the case of the family Ampeliscidae, and provide crucial food resources for demersal fish (Sanders, 1956; Bell & Harmelin-Vivien, 1983; Dauvin, 1988; Caine, 1989, 1991; Highsmith & Coyle, 1992; Zakhama-Sraieb, 2011; Rigolet *et al.*, 2014a, b). Therefore, amphipods play a fundamental role in the trophic food web, and studies of this group remain important in coastal marine ecosystems (Guerra-García *et al.*, 2014; Rigolet *et al.*, 2014a, b).

For the Mediterranean Sea, amphipod studies extend back over many decades and numerous species have been described from Mediterranean material (see Ruffo,

1982, 1989, 1993, 1998 and references therein for literature covering the end of the 20th century). Moreover, the publication of the fauna of the Amphipoda of the Mediterranean in four volumes (Ruffo, 1982, 1989, 1993, 1998) offered an exceptional opportunity to increase the knowledge of the amphipod inventory at national and regional level, as in the Adriatic and Aegean seas, as well as for the whole Mediterranean Sea. Along these lines, several recent studies have been published on the inventory and populations of amphipods in Tunisian waters (Zakhama-Sraieb *et al.*, 2006a, b, 2008, 2009, 2010, 2011, 2017; Mosbahi *et al.*, 2015a, b; Zakhama-Sraieb & Charfi-Cheikhrouha, 2011). As of April 2017, a total of 138 amphipod species have been recorded for Tunisian waters (Zakhama-Sraieb *et al.*, 2017).

Some local studies on *Posidonia oceanica* (Zakhama-Sraieb *et al.*, 2006a, b, 2010), as well as in environments such as the Bizerte lagoon (Zaabar *et al.*, 2015), also highlight the importance of amphipods in shallow-water ecosystems.

The subtidal macrobenthos of the tidal channels of the Gulf of Gabès has not been explored yet (Ben Mustapha *et al.*, 1999). This ecosystem, which is visible only at low tide, is unique because it represents a high-energy environment, extremely sensitive to climate change. These conditions promote the circulation of seawater, sediments, organic matter, nutrients and pollutants between terrestrial and coastal marine environments (Bali & Gueddari, 2011).

The first objective of this paper is to define the spatio-temporal patterns of the amphipod populations in four tidal channels in the Gulf of Gabès submitted to various anthropogenic pressures at four sampling dates from spring 2016 to winter 2017. The second objective is to assess the main environmental factors responsible of the structuring. Moreover, this study provides comments on five species recorded for the first time for Tunisian waters.

Materials and Methods

Study area

The Gulf of Gabès is located on the southern shore of the central Mediterranean Sea, covering an area of ~36,000 km². It is a very shallow embayment characterized by unique geomorphological, climatic and oceanographic conditions (Hattab *et al.*, 2013). The studies of Hattour *et al.* (2010) on the general circulation in this area have shown the existence of a large Mediterranean gyre, which penetrates from the North into the Gulf of Gabès. The annual water temperature cycle exhibits a wide range (from 13°C in winter to 29°C in summer) (Hattab *et al.*, 2013). The tidal amplitude is also unusual, with tides reaching 2.3 m, the highest range observed in the Mediterranean Sea (Sammari *et al.*, 2006). Favourable geomorphological and climatic conditions support one of the most productive ecosystems in the Mediterranean (Hattab *et al.*, 2013; Halouani *et al.*, 2016a, b).

The western part of the Gulf of Gabès is characterized by the presence of the Kneiss Islands, and its extensive intertidal zone (220 km²) is mainly occupied by *Zostera noltei* beds (68 km²) (Mosbahi *et al.*, 2015a, 2016). Due to their marine biodiversity, the Kneiss Islands have been designated as a 'Specially Protected Area of Mediterranean Importance' (SPAMI) in 2001, an 'Important Bird Area' (IBA) in 2003 and as a 'RAMSAR site' in 2007. Nevertheless, intensive human activities occur in these protected areas (Mosbahi, 2016). The subtidal areas are occupied mainly by *Posidonia oceanica* meadows (Blanpied *et al.*, 1979; Zakhama-Sraieb, 2011; Zakhama-Sraieb *et al.*, 2011). In the north of the Gulf of Gabès, the Kerkennah Islands form an important zone for artisanal fisheries (Mosbahi, 2016).

In the present study, four tidal channels have been chosen as representative of distinct human activities in the northwestern part of the Gulf of Gabès. (1) The Maltine channel, which is exposed to organic pollution because of the presence of aquaculture farms. (2) The tidal channels of the Kneiss Islands, which suffer from the effects of

destructive fishing methods, especially trawling. (3) The Ben Khlaf channel, which is exposed to chemical industrial pollution due to the presence of phosphogypsum waste heaps in this area; and (4) the Minoun channel, where fishers use traditional and non-destructive fishing gear (Fig. 1).

Tidal currents have created shallow channels in the Gulf of Gabès, which are developed extensively around the Kneiss and Kerkennah islands where sediments are mainly composed of sand and coarse sand. For the Kneiss islands, Bali & Gueddari (2011) have established that the sedimentary filling of the tidal channels shows decreasing grain size from downstream to upstream, indicating that the action of tidal currents is stronger during the flood tide than during the ebb tide. Mud (< 63 µm) and fine sand (125-250 µm) cover the upstream parts of these channels, with medium sand in the middle parts and coarse sand occurring farther downstream (Bali & Gueddari, 2011).

Sampling and laboratory procedures

Sampling stations were chosen along transects from the shallow upstream to the deeper downstream parts of four tidal channels with sediment grain size varying from fine to coarse. Seven stations from 3 to 15 m water depth were sampled in the Mimoun Channel (CM) in the north-eastern sector of the Kerkennah Islands, six stations from 2 to 8 m depth in the Kneiss Channel (CK), six stations from 1 to 4 m depth in the Maltine Channel (CML) and six stations from 3 to 12 m in the Ben Khlaf Channel (CP), except in September 2016 and January 2017 when seven stations were sampled (Fig. 1; Table 1). All the stations were sampled during flood tide or at high tide. Each channel was sampled during the four seasons: March 2016 for spring, July 2016 for summer, September 2016 for autumn and January 2017 for winter. At each station and each season, macrofauna samples were collected with a 0.1-m² Van Veen grab; four replicates were collected, giving a total sampling area of 0.4 m². In addition, temperature, salinity and pH were measured *in situ* and close to the seabed, using a thermometer (WTW LF 196), a salinometer (WTW LF 196) and a pH meter (WTW 3110). The sediment was sieved on a 1-mm mesh; after sorting, the amphipods were identified under a binocular microscope. For each station and sampling date, an additional replicate was collected for analysis of the sediment and organic matter content. The species richness and abundances are expressed for a sampling area of 0.4 m².

Species names were checked using the World Register of Marine Species list (<http://www.marinespecies.org>) on 15 October 2017.

A trophic guild analysis was performed attributing the identified species to five trophic categories, according to recent literature (Guerra-García *et al.*, 2014; Zaabar *et al.*, 2015) as follows: S, Suspension feeders; DS, Deposit-Suspension feeders; He, Herbivores; De, Deposit feeders; and O, Omnivores (Table 2).

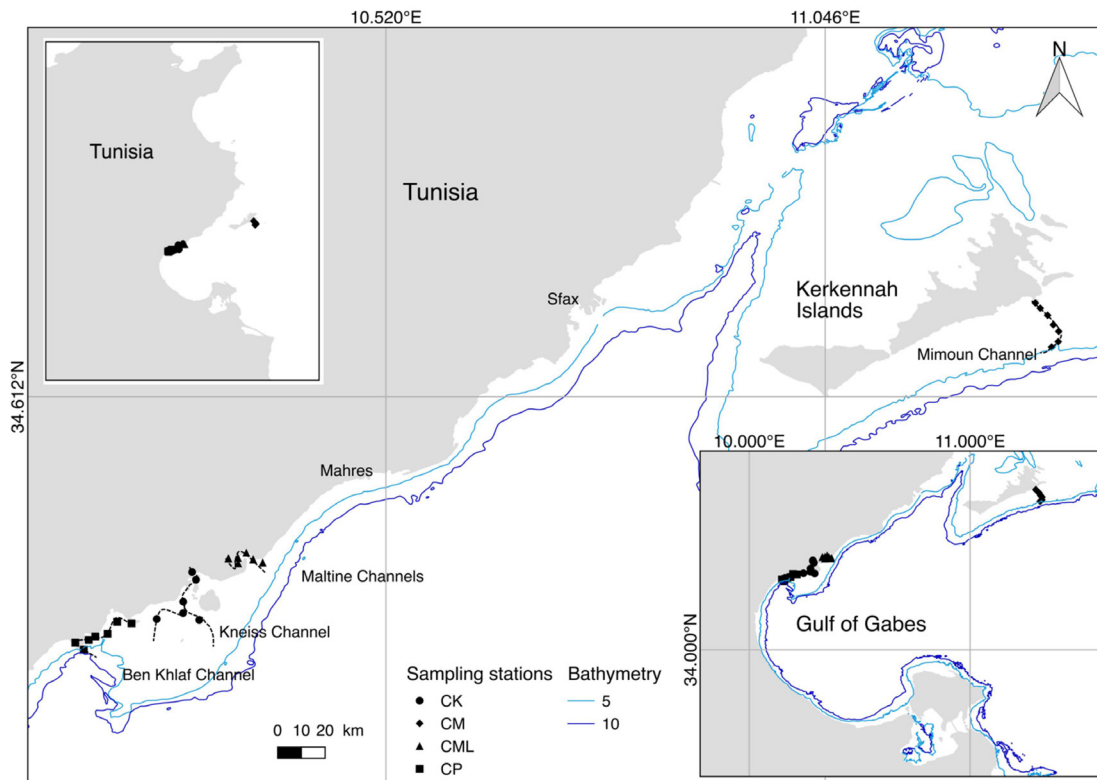


Fig. 1: Map of the study area showing the location of stations in the four channels sampled in the Gulf of Gabès.

Sediment grain-size analysis and organic matter content

Sediment from each sample was homogenized and wet-sieved through a 63 µm mesh to separate muddy (including silt and clay), gravelly and sandy fractions (retained on the sieve). After being oven dried to constant weight at 60°C, sediment fractions were separated using a mechanical shaker (column of five sieves with mesh sizes of 1000, 500, 250, 125 and 63 µm) during 10 min. All fractions (including <63 µm) were then weighed and their percentages determined. For the organic matter content analyses, sediment samples were dried at 60°C to constant weight and ground to a fine powder. Organic matter content was determined on the powder samples by 'loss on ignition' at 450°C for 4 h.

Statistical analyses

Environmental parameters

A two-way ANOVA was used to test differences for each environmental parameter independently: temperature, salinity, pH, depth and organic matter content in sediment for channels and seasons. Prior to each ANOVA, a Shapiro-Wilk normality test and a Bartlett test for homogeneity of variances were performed to check whether the assumptions of ANOVA were met and if it was necessary to transform the data. The Tukey Honestly Significant Difference test was applied when ANOVA showed significant differences.

Biological parameters

A two-way ANOVA was used to test for spatio-temporal changes (channels and seasons factors) in species richness and total abundance of amphipods in the Gulf of Gabès. Again, prior to each ANOVA, a Shapiro-Wilk normality test and a Bartlett test for homogeneity of variances were performed. The Tukey Honestly Significant Difference test was applied when ANOVA showed significant differences.

The spatial and temporal changes considering all amphipods (abundance matrix) were analysed separately by group-average sorting classification, using a hierarchical clustering procedure (CLUSTER mode) based on the Bray-Curtis similarity index with a square-root transformation of abundances. Additionally, environmental variables that best matched the observed community changes were statistically assessed using the BIOENV algorithm of the BEST analysis routine. The significance of the correlation coefficients was determined by a random permutation test.

The CLUSTER and BEST analyses and permutation tests were carried out using the PRIMER v6 software package (Clarke & Gorley, 2006). The R software package was used to perform ANOVAs as well as the Shapiro, Bartlett and Tukey tests.

Table 1. Main characteristics of the sampling stations. CP: Ben Kelaf; CML: Maltine; CK: Kneiss and CM: Kerkennah. 2017/01: January 2017 (winter), 2016/09: September 2016 (autumn), 2016/07: July 2016 (summer), 2016/04: April 2016 (spring). MO%: percentage of organic matter content in dry sediment.

Station	Latitude N	Longitude E	Depth in m	Sediment type	MO %				Flora presence
					2017/01	2016/09	2016/07	2016/04	
CP1	34.341015°	10.215410°	3.5	Fine sand	0.8	6.7	3.8	0.1	<i>Cymodocea nodosa</i> and <i>Zostera noltei</i>
CP2	34.342924°	10.198216°	2.8	Fine sand	1.8	0.7	0.7	0.5	<i>Cymodocea nodosa</i>
CP3	34.328536°	10.186751°	3.2	Gravelly sand	5.1	0.2	3.1	1.2	<i>Cymodocea nodosa</i>
CP4	34.321259°	10.164106°	6.1	Fine sand	1.7	0.9	0.6	1.3	-
CP5	34.317975°	10.148052°	7.6	Fine sand	0.9	3.1	2.3	1.2	-
CP6	34.309736°	10.158242°	11.9	Silty sand	5.6	8.1	7.9	7.8	-
CP7	34.325377°	10.172043°	0.9	Fine sand	4.7	0.6	1.2	1.1	-
CML1	34.418648°	10.331352°	1.0	Silty sand	9.2	11.1	8.2	8.6	<i>Zostera noltei</i> and <i>Ulva</i> spp.
CML2	34.412911°	10.343088°	2.1	Shells and gravelly sand	1.9	8.9	1.2	0.4	<i>Zostera noltei</i> , <i>Ulva</i> spp., <i>Cymodocea nodosa</i> and <i>Halophila stipulacea</i>
CML3	34.419326°	10.342777°	2.1	Shells and gravelly sand	2.2	3.1	1.5	0.2	<i>Ulva</i> spp. and <i>Cymodocea nodosa</i>
CML4	34.425158°	10.352827°	3.1	Gravelly sand	4.4	0.7	0.5	0.4	<i>Halophila stipulacea</i> and <i>Posidonia oceanica</i>
CML5	34.417411°	10.360994°	4.4	Fine sand	4.7	0.3	0.1	0.4	-
CML6	34.413740°	10.372413°	3.7	Coarse sand	4.4	0.8	0.4	0.5	<i>Halophila stipulacea</i>
CK1	34.402458°	10.287937°	2.0	Fine sand	6.8	2.7	4.9	2.3	<i>Cymodocea nodosa</i> and <i>Halophila stipulacea</i>
CK2	34.393265°	10.292605°	8.5	Medium sand	0.9	0.5	0.9	0.5	-
CK3	34.367014°	10.277292°	5.3	Fine sand	1.0	1.2	5.3	2.1	<i>Cymodocea nodosa</i> and <i>Caulerpa cylindracea</i>
CK4	34.353309°	10.277084°	7.4	Medium sand	4.0	0.9	1.1	0.5	-
CK5	34.346221°	10.245557°	5.3	Fine sand	4.4	2.2	0.1	0.1	<i>Cymodocea nodosa</i> and <i>Zostera noltei</i>
CK6	34.345107°	10.296409°	8.3	Silty sand	12.7	3.5	3.8	3.1	<i>Cymodocea nodosa</i>
CM1	34.724143°	11.297655°	3.3	Medium sand	17.3	2.1	2.8	1.2	-
CM2	34.717922°	11.303455°	3.3	Fine sand	14.6	0.1	4.6	1.5	<i>Cymodocea nodosa</i>
CM3	34.709478°	11.312304°	3.6	Medium sand	13.6	0.4	3.3	2.4	<i>Posidonia oceanica</i>
CM4	34.698124°	11.319149°	4.1	Gravelly sand	6.1	0.1	0.3	0.2	-
CM5	34.690267°	11.325533°	10.0	Gravelly sand	5.3	0.8	0.2	0.8	-
CM6	34.677917°	11.325002°	13.5	Gravelly sand	7.1	0.1	2.8	0.2	-
CM7	34.671495°	11.317064°	15.0	Fine sand	14.1	1.1	5.6	0.9	<i>Posidonia oceanica</i>

Table 2. Numbers of amphipods collected in each channel during the four seasons. 2017/01: January 2017 (winter), 2016/09: September 2016 (autumn), 2016/07: July 2016 (summer), 2016/04: April 2016 (spring). Sampling area at each season, CK and CML: 2.4 m²; CM and CP: 2.8 m² except CP 2.4 m² in spring and summer. TG: Trophic group, S: suspension feeders; DS: deposit-suspension feeders; He: herbivores; De: plants deposit feeders and O: omnivores, * New species for Tunisian waters.

	TG	Kerkennah (CM)				Maltine (CML)				Kneiss (CK)				Ben Kelaf (CP)				Total			
		2016/04		2016/09		2016/07		2016/09		2016/04		2016/07		2016/09		2017/01			Total		
<i>Abludomelta gladiosa</i> (Bate, 1862)*	Ds	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	1
<i>Ampelisca brevicornis</i> (Costa, 1853)	S	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	3
<i>Ampelisca diadema</i> (Costa, 1853)	S	1	-	5	2	8	-	4	23	27	-	1	9	11	21	16	22	24	24	86	142
<i>Ampelisca rubella</i> A. Costa, 1864	S	-	-	-	2	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
<i>Ampelisca spinipes</i> Boeck, 1861	S	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1
<i>Ampelisca tenuicornis</i> Lilljeborg, 1855	S	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	-	2	-	2	3
<i>Ampelisca typica</i> (Spence Bate, 1856)	S	2	-	14	-	16	2	1	1	4	-	-	-	-	-	-	-	-	1	1	21
<i>Ampithoe riedli</i> Krapp-Schickel, 1968	He	-	1	-	-	1	-	-	3	3	-	-	1	8	9	-	-	-	1	1	14
<i>Apherusa chierighinii</i> Giordani-Soika, 1949	Ds	5	4	-	-	9	27	1	4	31	63	-	1	21	22	1	4	1	15	21	115
<i>Bathyporeia guilliamsoniana</i> (Bate, 1857)	Ds	-	-	-	-	-	-	-	-	-	-	5	-	4	9	-	-	-	-	-	9
<i>Caprella acanthifera</i> Leach, 1814	O	-	7	3	3	13	-	-	14	14	14	-	-	-	-	-	-	-	-	-	27
<i>Caprella hirsuta</i> Mayer, 1890	O	-	3	-	-	3	-	-	-	-	-	1	-	-	1	-	-	-	-	-	4
<i>Corophium orientale</i> Schellenberg, 1928	Ds	-	-	-	3	3	-	-	10	10	10	5	-	-	5	-	-	-	-	-	18
<i>Cymadusa filosa</i> Savigny, 1816	He	-	1	1	-	2	2	1	15	29	-	-	-	-	10	10	4	30	2	36	171
<i>Dexamine spinosa</i> (Montagu, 1813)	De	9	14	9	1	33	7	1	13	49	70	52	-	3	58	113	3	35	5	57	316
<i>Elasmopus rapax</i> Costa, 1853	S	-	46	-	8	54	-	2	14	17	17	-	21	1	23	-	1	-	4	5	99
<i>Erichthonis brasiliensis</i> (Dana, 1853)	Ds	-	4	-	-	4	-	7	-	29	-	-	-	-	-	-	1	-	-	1	34
<i>Gammarella fucicola</i> (Leach, 1814)	He	-	-	-	-	-	-	-	22	22	22	-	-	-	1	1	-	-	2	2	25
<i>Gammarus aequicauda</i> (Martynov, 1931)	De	-	-	-	-	-	64	-	2	68	-	-	-	-	-	-	-	-	1	1	69
<i>Leptocheirus pectinatus</i> (Norman, 1869)	Ds	14	7	2	-	23	-	-	-	-	-	-	-	1	1	1	-	-	-	1	25
<i>Leucothoe incisa</i> Robertson, 1892	O	8	-	3	1	12	3	-	1	4	64	2	1	8	64	2	3	-	9	14	94
<i>Leucothoe denticulata</i> A. Costa, 1851	O	-	3	2	6	11	1	-	1	3	5	5	-	-	5	-	2	-	-	2	23
<i>Liljeborgia dellavallei</i> Stebbing, 1906	O	-	-	-	2	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
<i>Lysianassa costae</i> (H. Milne Edwards, 1830)	O	2	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
<i>Lysianassina longicornis</i> (Lucas, 1846)	O	-	4	1	1	6	4	-	4	18	26	-	-	-	1	1	-	-	-	-	33
<i>Maera grossimana</i> (Montagu, 1808)*	Ds	2	-	-	1	3	-	-	-	-	-	-	1	-	1	5	-	-	-	5	9
<i>Maera hironidellei</i> Chevreux, 1900	Ds	-	-	1	-	1	-	-	-	-	-	-	1	-	1	2	-	-	-	2	4
<i>Megaluroptus massiliensis</i> Ledoyer, 1976	Ds	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	6
<i>Melita palmata</i> (Montagu, 1804)	Ds	1	-	-	-	1	3	23	-	38	64	-	-	-	-	-	-	-	-	-	65
<i>Metaphoxus fultoni</i> (Scott, 1890)	O	1	-	-	-	1	1	-	1	3	3	-	-	-	-	-	10	7	-	17	21
<i>Microdeutopus anomalous</i> (Rathke, 1843)	Ds	14	90	37	31	172	250	3	39	860	1152	2	3	46	111	162	40	75	32	184	1670
<i>Microdeutopus bifidus</i> Myers, 1977*	Ds	-	-	-	1	1	-	-	-	2	2	-	-	-	1	1	-	-	2	2	6

(continued)

Table 2 continued

TG	Kerkennah (CM)				Malline (CML)				Kneiss (CK)				Ben Kelaf (CP)				Total					
	2016/04	2016/07	2016/09	2017/01	Total	2016/04	2016/07	2016/09	2017/01	Total	2016/04	2016/07	2016/09	2017/01	Total	2016/04		2016/07	2016/09	2017/01	Total	
<i>Microdeutopus gryllotalpa</i> Costa, 1853	12	-	-	1	13	150	3	-	127	280	2	-	-	5	7	13	-	-	-	-	13	313
<i>Monocorophium acherusicum</i> (Costa, 1853)	-	-	-	1	1	114	2	13	292	421	102	17	2	55	176	6	35	33	181	255	853	
<i>Orchomene humilis</i> (Costa, 1853)	-	-	-	-	-	1	-	-	-	1	-	-	-	-	-	-	-	-	2	2	3	
<i>Paracaprella pusilla</i> Mayer, 1890*	-	-	-	-	-	-	-	-	-	-	-	5	-	-	5	-	-	-	3	3	8	
<i>Perioculodes longimanus</i> (Bate & Westwood, 1868)	7	-	1	1	9	-	-	-	2	2	-	-	-	3	3	-	-	1	36	37	51	
<i>Phisica marina</i> Slabber, 1769	10	7	1	-	18	-	-	-	4	4	-	-	-	-	-	26	-	-	3	29	51	
<i>Pontocrates arenarius</i> (Spence Bate, 1858)	-	-	-	-	-	-	-	-	-	-	1	-	-	4	5	-	-	-	-	-	5	
<i>Pseudoprotella phasma</i> (Montagu, 1804)	-	-	-	-	-	-	-	-	2	2	-	-	-	-	-	-	-	-	-	-	2	
<i>Quadrimaera reishi</i> (J.L. Barnard, 1979)	-	7	11	9	27	-	-	2	3	5	-	-	-	-	-	-	-	1	-	1	33	
<i>Stenothoe eduardi</i> Krapp-Schickel, 1975	-	-	-	-	-	-	-	-	1	1	-	-	-	1	1	-	-	-	5	5	7	
<i>Synchelidium maculatum</i> Stebbing, 1906*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	3	3	
<i>Tethylembos viguieri</i> (Chevreux, 1911)	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	
<i>Urothoe grimaldii</i> Chevreux, 1895	-	6	1	-	7	-	-	-	-	-	2	5	-	-	7	-	-	-	-	-	14	
TOTAL	88	204	92	75	459	629	43	109	1547	2328	229	57	160	303	749	112	157	180	393	842	4378	

Results

General characteristics of the tidal channels

The difference in Organic Matter content between winter and the other seasons is statistically significant (Table 3), but there are no significant differences among channels (Table 3). No differences are observed in sea temperature between channels at any given season, although temperatures are generally lower in winter than in autumn, summer or spring and lower in spring than in summer or autumn (Table 1). Salinity does not change as a function of seasons, but is higher at CML than at the three other sites (Table 3). The pH values were higher at CK and CML than at the two other sites, being lower in winter than in summer and spring, and lower in autumn than in summer and spring (Table 3). Depths are shallower at CML compared with CK or CM (Table 1).

A total of 15 stations out of 26 show the presence of macrophytes, mainly represented by *Cymodocea nodosa* and *Posidonia oceanica* meadows (Table 1). The shallowest stations are characterized by fine sand, while medium sand, shells and gravelly sand, as well as coarse sand or gravelly sand, were found at the intermediate-depth stations, while the deeper stations again showed fine sediment (Table 1).

General characteristics of the amphipod fauna

A total number of 4,378 individuals were collected and identified, resulting in 45 species belonging to 21 families (Table 2). The most diverse families were Ampeliscidae (6 species), Caprellidae (5 species) and Aoridae and Maeridae (4 species each). Three other families accounted for three species, while three families comprised two other species and eleven families comprised only one species each. More than 73% of the individuals were assigned to three families, i.e. Aoridae (45.5%), Corophiidae (20.5%) and Dexaminidae (7.2%); seven species represented more than 80% of the total number of individuals collected (given in brackets after each species name): *Microdeutopus anomalus* (Rathke, 1843) (1,670), *Monocorophium acherusicum* (Costa, 1851) (853), *Dexamine spinosa* (Montagu, 1813) (316), *Microdeutopus gryllotalpa* Costa, 1853 (313), *Cymadusa filosa* Savigny, 1816 (171), *Elasmopus rapax* Costa, 1853 (99) and *Leucothoe incisa* Robertson, 1892 (94) (Table 2). Three species were represented only by one individual each, four by two individuals and four by three individuals (Table 2). The species richness is similar between the channels: 31 for CM and CP, 28 for CML and 26 for CK (Table 4). Nevertheless, the number of species is significantly higher in winter (38) than during the three other seasons: 23 in autumn, 24 in summer and 25 in spring (Table 4).

Among the recorded species, five are new for Tunisian waters: *Abludomelita gladiosa* (Bate, 1862), *Maera grossimana* (Montagu, 1808), *Microdeutopus bifidus* Myers, 1977, *Paracaprella pusilla* Mayer, 1890 and *Synchelidium maculatum* Stebbing, 1906.

Table 3. Results of ANOVA tests on environmental parameters: Organic Matter, Temperature, Salinity, pH and depth. CP: Ben Khlaf; CML: Maltine; CK: Kneiss; CM: Kerkennah. Win: winter (January 2017); Aut: autumn (September 2016); Sum: summer (July 2016); Spr: spring (April 2016) (dof: degree of freedom).

	Factors	dof	F	P	Tukey test
Organic Matter	Season	3	9.9	< 0.001	Win≠Spr, Aut, Sum
	Site	3	0.7	0.55	
Temperature	Season	3	433.8	< 0.001	Win≠Spr, Aut, Sum; Spr≠Aut, Sum
	Site	3	0.1	0.95	
Salinity	Season	3	1.8	0.15	
	Site	3	25.1	< 0.001	CML≠CM, CP, CK
pH	Season	3	20.3	< 0.001	Win≠Sum, Spr; Aut≠Sum, Spr
	Site	3	3.5	< 0.05	CM ≠ CK, CML
Depth	Season	3	0.2	0.93	
	Site	3	9.2	< 0.001	CML ≠ CK, CM
	Σ	95			

Table 4. Results of ANOVA tests on amphipod abundance and species richness. CP: Ben Khlaf; CML: Maltine; CK: Kneiss; CM: Kerkennah; Win: winter (January 2017); Aut: autumn (September 2016); Sum: summer (July 2016); Spr: spring (April 2016) (dof: degree of freedom).

		dof	F	P	Tukey test
Abundance	Season	3	6.1	< 0.001	Winter ≠ Autumn & Summer
	Site	3	7.0	< 0.001	CML ≠ CM, CK & CP
	Σ	95			
Species richness	Season	3	5.8	< 0.001	Winter ≠ Spring, Summer & Autumn
	Site	3	1.1	0.36	
	Σ	95			

Out of the 106 samples, six yielded no amphipods and six others showed only one individual each. These samples correspond mainly to those collected in spring and at gravel stations in the four channels. Nine samples showed abundances smaller than 100 individuals/0.4 m², with a maximum at the station CML2 in winter (610 individuals/0.4 m²).

There are significant differences in abundances between seasons (Table 4): 2,318 individuals were collected during the winter (53 % of collected individuals), and fewer during spring (1,057), autumn (541) and summer (462). The CML abundances (2,328) are significantly higher than in the three other channels (CP: 842, CK: 749, CM: 459; Table 4).

Among the 45 species, 2 are plant detritus feeders, 16 deposit-suspension feeders, 4 herbivores, 16 omnivores and 7 suspension feeders. Nevertheless, 65.1% of the specimens are deposit-suspension feeders, 12.0% herbivores, 8.8% plant detritus feeders, 7.9% omnivores and 6.1% suspension feeders.

Spatial pattern

Figure 2 shows the species richness and the mean abundance per 0.4 m² for each station at each of the four channels. Three main patterns can be clearly seen: higher abundances at the CML stations (except CML3), a low species richness at some stations with shell and gravel (CK4, CM4 and CP2), and an increase of the species richness in CML from shallow to deeper stations.

The dendrogram based on abundance data (Fig. 3) shows that the stations are mainly grouped by channel, with a clear distinction of the Kerkennah channel from the three others, the highly individual nature of the Maltine Channel and a similar amphipod fauna in both the Ben Khlaf and Kneiss channels.

BEST analysis shows that the environmental variables that best match with the observed community patterns are: temperature, pH, presence of seagrasses and sediment fraction >500 μm (Spearman ρ = 0.308; *p* < 0.01).

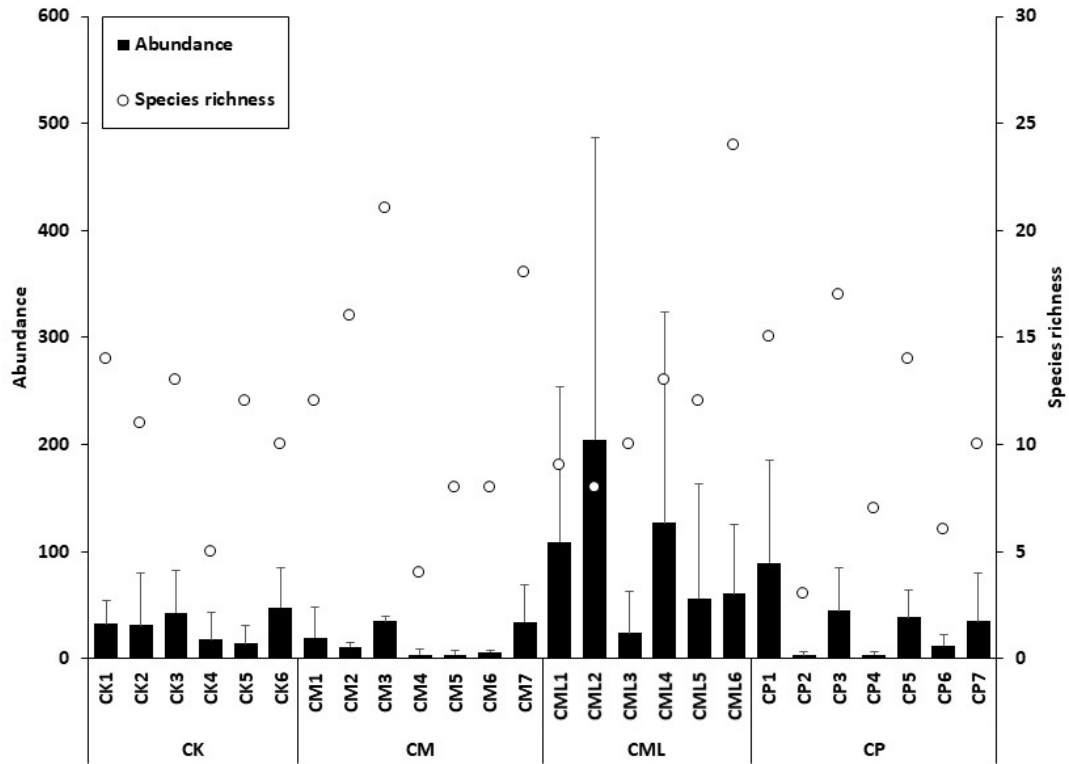


Fig. 2: Mean amphipod abundance, and total species richness at the 26 stations of the four channels sampled four times from spring 2016 to winter 2017. CP: Ben Khlaf; CML: Maltine; CK: Kneiss; CM: Kerkennah. Error bar: standard deviation on abundances, white circles: species richness.

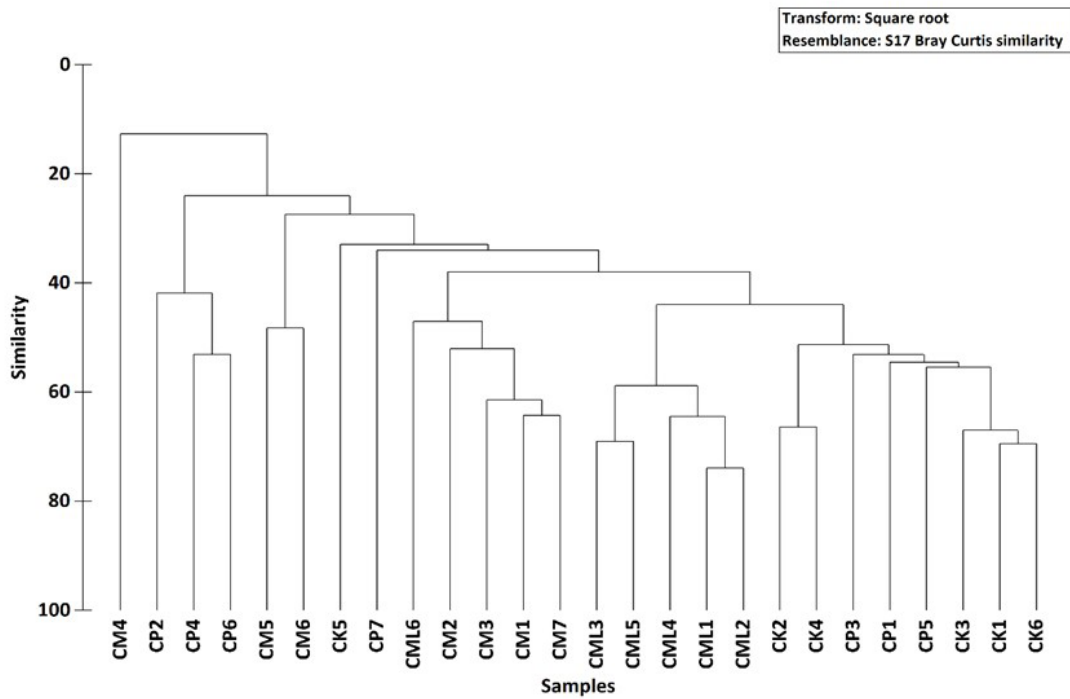


Fig. 3: Cluster dendrogram showing the distribution of the 26 stations (mean abundances for the four seasons of each station) according to the Bray-Curtis similarity after square-root transformation of the abundances of the 45-amphipod species.

Seasonal pattern

Figure 4 shows the seasonal variation in species richness and mean abundance of amphipods for the four channels (i.e. four seasons × four channels). There is a clear pattern of species enrichment in the four channels in winter; a very low abundance throughout the year in CM, low abundances in CK and CP, with higher abundances in winter than during the other seasons in both channels, and high abundances in spring and winter in CML; in

summer and autumn, however, the abundances are of the same order of magnitude as those observed in the three other channels.

When similarity among channels is plotted in a dendrogram based on abundance data (Fig. 5), the Kerkennah channel is clearly discriminated from the other channels. Kerkennah is the only channel not displaying seasonal changes in amphipod community structure: the other three channels show definite clustering of samples according to the time factor rather than spatial location.

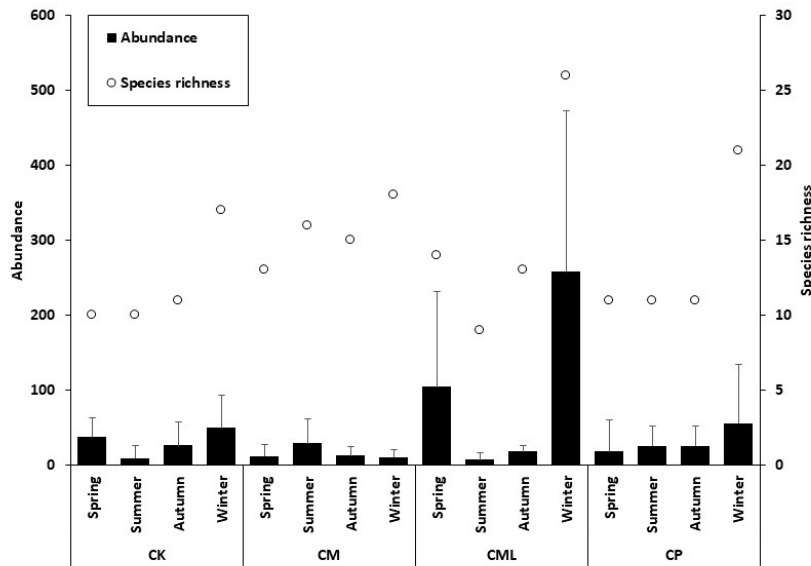


Fig 4: Mean amphipod abundance and total species richness in the four channels sampled during the four sampling seasons from spring 2016 to winter 2017. CP: Ben Khlaf; CML: Maltine; CK: Kneiss; CM: Kerkennah. Error bar: standard deviation on abundances, white circles: species richness.

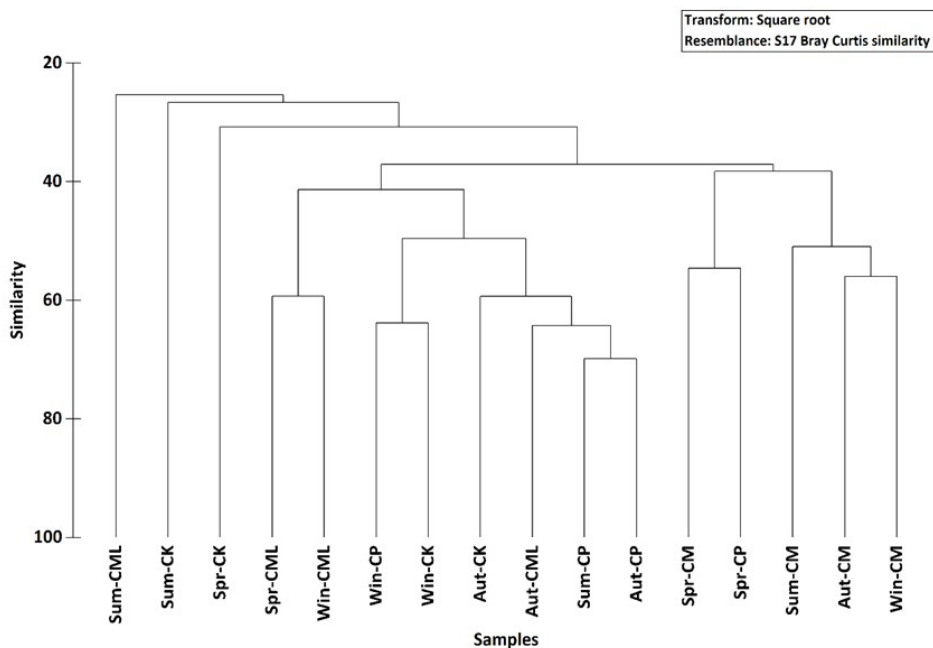


Fig. 5: Cluster dendrogram showing the distribution of the four channels in the four seasons according to the Bray-Curtis similarity (mean abundances of stations sampled in each channel), after square-root transformation of the abundance of amphipod species. CP: Ben Khlaf; CML: Maltine; CK: Kneiss; CM: Kerkennah. Win: winter; Aut: autumn; Sum: summer; Spr: spring.

Nevertheless, the structure of amphipod fauna is more closely similar between autumn and winter than between spring and summer, but still not showing any clear pattern.

BEST analysis reveals that the environmental variables showing the best match with the observed community temporal changes are salinity, pH and sediment fraction >500 μm (Spearman $\rho = 0.281$; $p < 0.01$).

New species for Tunisian waters

In the collection of amphipods from the tidal channels of the Gulf of Gabès, five species are newly recorded for Tunisian waters (compare with the list of Tunisian amphipods by Zakhama-Sraieb *et al.*, 2017), including a species non-native to the Mediterranean Sea.

Two *Leucothoe* species have been identified, *L. incisa* Robertson, 1892, recently recorded for the Gabès Gulf (Mosbahi *et al.*, 2015b), and *L. denticulata* A. Costa, 1851. The latter has been often misidentified in the past as *L. spinicarpa* (Abilgaard, 1789), but the occurrence of this North Sea species in the Mediterranean was questioned by Krapp-Schickel & Menioui (2005). The identity of specimen identified as *L. spinicarpa* in Tunisian waters (Zakhama-Sraieb *et al.*, 2017) should be carefully re-assessed.

Abludomelita gladiosa (Bate, 1862)

Only one individual was sampled at CP7, in autumn. This Atlanto-Mediterranean species is widely distributed in the western Mediterranean Sea (Algeria, France, Tyrrhenian Sea), as well as the Adriatic Sea (Ruffo, 1982). This occurrence of *A. gladiosa* is the easternmost for this species in the central Mediterranean Sea (Christodoulou *et al.*, 2013). *Abludomelita gladiosa* is found from the intertidal zone to water depths of 60 m, mainly on coarse sediment.

Maera grossimana (Montagu, 1808)

Nine individuals were identified: two in CM3 and five in CP5 in spring, one in CK8 in summer and the last one in CM3 in winter. This Atlanto-Mediterranean species is widely distributed in the western and eastern Mediterranean Sea (Ruffo, 1982; Christodoulou *et al.*, 2013). It is commonly reported from hard-bottom or coarse sand, rarely on muddy bottoms, in water depths of 20-100 m.

Microdeutopus bifidus Myers, 1977

Six individuals were collected, all in winter: one at CM3, two at CP1, two at CM6 and the last one at CK2. This endemic Mediterranean species was described from Sicily (Catania, amongst infralittoral algae) (Ruffo, 1982). It has also been recorded from the Central Mediterranean Sea and the Aegean Sea (Christodoulou *et al.*, 2013).

Paracaprella pusilla Mayer, 1890

Eight individuals were identified by José Manuel Guerra-García (personal communication): five at CK5 in summer and three at CP9 in winter; the collection was represented by male and female adults.

Along with *Caprella scaura* Templeton, 1836, *Paracaprella pusilla* is a tropical western Atlantic species representing the second non-native caprellid so far found in the Mediterranean Sea. Its introduction was reported in association with maritime traffic (Ros & Guerra-García, 2012; Ros *et al.*, 2013, 2014). The species has been reported from the Balearic Islands in the western part of the Mediterranean Sea (Ros *et al.*, 2013) and on the southern coast of Israel in the eastern Mediterranean Sea (Ros *et al.*, 2016). Therefore, the present occurrence is the third report of this species in the Mediterranean Sea. It is probable that the species may be present at other localities in the Mediterranean, due to the large distances between the Balearic Islands, the Gulf of Gabès and Israel.

Synchelidium maculatum Stebbing, 1906

Three individuals were collected, all during the winter, with two sampled at CP1 and one at CP9. This Atlanto-Mediterranean species has been reported from the western and eastern Mediterranean Sea (Ruffo, 1993, Christodoulou *et al.*, 2013). *Synchelidium maculatum* is reported living in soft-bottom communities mainly on sandy mud, from the intertidal zone to depths of 100 m.

Discussion

The Mediterranean Sea is one of the most important hot spots of amphipod diversity in the world ocean, with more than 500 species recorded (Ruffo, 1998; Väinölä *et al.*, 2008; Coll *et al.*, 2010; Koukouras, 2010; Ruffo, 2010; Christodoulou *et al.*, 2013; Dauvin *et al.*, 2013). Thus, despite the recent studies of Rym Zakhama-Sraieb and Nawfel Mosbahi, mainly for the shallow waters of northern Tunisia (Zakhama-Sraieb *et al.*, 2006a, b, 2008, 2009, 2010, 2011, 2017; Zakhama-Sraieb, 2011; Mosbahi *et al.*, 2015a, b), amphipods from coastal waters in southern Tunisia, including the Gulf of Gabès, remain relatively poorly studied.

Each new study on benthic communities, particularly when it is focused on the taxonomy of amphipods, reveals the presence of new species previously unrecorded in Tunisian waters. This was the case for two species (*Leucothoe incisa* and *Lysianassa pilicornis*) recently recorded from the intertidal zone of the Kneiss Island by Mosbahi *et al.* (2015b). The present study adds five more species to the list of Tunisian amphipod fauna: *Abludomelita gladiosa*, *Maera grossimana*, *Microdeutopus bifidus*, *Paracaprella pusilla* and *Synchelidium maculatum*. Therefore, the marine amphipod fauna of Tunisia currently accounts for 143 species. It is clear that this amphipod inventory is not complete since most of the recent sam-

pling cover lagoons, intertidal and shallow environments and there is insufficient knowledge of the deeper marine fauna.

This species richness (143) is of the same order of magnitude as the amphipod diversity of the Libyan coast (125 species; Ortiz & Petrescu, 2007) and the Iberian Mediterranean coast (152 species; De-la-Ossa-Carretero *et al.*, 2010). However, the species richness of Tunisian amphipods is lower than that observed on the Algerian coast (332 species; Bakalem & Dauvin, 1995; Grimes *et al.*, 2009; Bakalem *et al.*, 2014), the Italian coast (365 species; Ruffo, 2010), and the French Mediterranean coast (299 species; Dauvin & Bellan-Santini, 2002), but the sampling efforts and the length of the coastal line in these areas are higher than on the Tunisian coast.

For the intertidal zone of the Kneiss Islands, Mosbahi *et al.* (2015a, 2016) reported the presence of 17 amphipod species. Among these species, six are not recorded in the present study: *Ampelisca serraticaudata* Chevreux, 1888, *Dexamine spiniventris* (Costa, 1853), *Gammarus insensibilis* Stock, 1966, *Lysianassa pilicornis* (Heller, 1866), *Monocorophium insidiosum* (Crawford, 1937) and *Orchestia gammarellus* (Pallas, 1766). Conversely, 34 species are found only in the subtidal tidal channels, where the amphipod diversity is higher than that observed in the intertidal zone.

This study on amphipods from the shallow tidal channels of the Gulf of Gabès shows that the fauna is dominated by a small number of species such as *Microdeutopus anomalus*, *Monocorophium acherusicum*, *Dexamine spinosa*, *Microdeutopus gryllotalpa*, *Cymadusa filosa* and *Elasmopus rapax*. These species are characteristic of areas with detritus accumulation, associated with the occurrence of *Zostera*, *Halophila*, *Cymodocea* seagrass meadows. The amphipod fauna studied here displays a close similarity with the one from shallow algae and seagrasses in the Bizerte lagoon, described by Zaabar *et al.* (2015). These authors reported dominance of *Gammarus aequicauda*, accompanied by most of the prevalent species found in the present study from the tidal channels of the Gulf of Gabès, except for *Microdeutopus anomalus*. However, in the Bizerte lagoon, the temporal pattern of abundances is opposite to that observed in the Gulf of Gabès, with maximum abundances during spring (April) and at the beginning of autumn (September), falling to a minimum in winter (January). The distribution of amphipods in the Bizerte lagoon appears mainly linked to temperature and salinity, algae concentration and detritus availability. Similarly, most of the amphipod species recorded in the Bizerte Lagoon are also present in the Tunis lagoon (Diawara *et al.*, 2008). The amphipod fauna of these Tunisian lagoons is rather similar to that reported from several Italian lagoons (e.g. Diviacco & Bianchi, 1987; Procaccini & Scipione, 1992; Basset *et al.*, 2006), with several shared species (*G. aequicauda*, *C. acherusicum*, *M. gryllotalpa*, *E. brasiliensis* and *E. rapax*), and with the Karavasta lagoon system (Albania), where *G. aequicauda*, *C. acherusicum*, and *M. gryllotalpa* show

high occurrences (Monnis Marzano *et al.*, 2010). In the Fusaro coastal lagoon (central Tyrrhenian Sea), the abundances reach their maximum in March and a minimum in June-July (Procaccini & Scipione, 1992). Some species, such as *M. gryllotalpa*, but also *Corophium insidiosum* and *Gammarus insensibilis*, show a winter distribution. Vegetal components also play a fundamental role controlling the distribution and abundances of amphipods in this lagoon, where the amphipod community is typical of euryhaline lagoons influenced by hydrodynamic factors.

The amphipods are generally described as relatively independent of abiotic factors, mainly regarding the grain-size sediment (Zakhama-Sraieb, 2011). In fact, amphipods are able to occupy several layers of the benthic habitats, with some species burrowing into sediment (such as *Bathyporeia* and *Urothoe*) or living on the interface between the substrate and seawater, or attached to algae and invertebrate sessile species such as bryozoans and hydrozoans.

A comparison with the amphipod populations of *Posidonia oceanica* meadows along the Tunisian coast, and more generally with such habitats elsewhere, shows that the amphipod population is richer and more abundant in seagrass meadows (Zakhama-Sraieb *et al.*, 2006a, b, 2011 and references therein). Among the 44 species found in *Posidonia* meadows along the Tunisian coast, 14 are in common with the inventory given in the present study. Similarly, in the Bizerte lagoon, macroalgae offer a favourable support for amphipods (Zaabar *et al.*, 2015). Unfortunately, our survey provides no information about the detritus lying above the sediment; it is clear that the amphipod population structure and spatio-temporal patterns are better explained by detritus accumulation rather than organic matter content in the sediment or grain-size. As the amphipod populations of the tidal channels are largely dominated by herbivores, grazers and detritus feeders living mainly on algae and seagrasses, we propose that the accumulation of macro-particulate detritus should be estimated in such channels, where detritus is trapped in spite of tidal currents. Accumulation could be located in an area with no net tidal transport (null point), corresponding to the turbidity maximum zone associated with the sedimentation of fine particles in megatidal estuaries (Allen *et al.*, 1980).

This wide variety of amphipod habitats can explain the lack of any correlations between amphipod populations of the Gulf of Gabès and environmental factors such as sediment characteristics or organic matter content in the sediment. Nevertheless, in the Gulf of Gabès, the amphipods show three main patterns:

(1) An increase in species richness from the shallower to the deeper zones of the tidal channels.

(2) Seasonal changes in species richness and abundance, which are higher in winter than during the three other seasons. The winter season appears favourable for the accumulation of algae and detritus in the channels after the period of macro-algae growth and reproduction. Thus, the large amount of such food items available in

winter appears to favour dominance by amphipods that clearly feed on detritus and macrophytes.

(3) The Maltine channel shows higher abundances of herbivores and grazers than the three other channels, which could be linked to the more extensive development of seagrasses and macroalgae at this site (see Table 1). Moreover, in terms of species richness and abundance, we can recognize the following spatial pattern: the Maltine channel has the richest fauna, while the Mimoun channel in the Kerkennah Islands has the poorest, with the Ben Khlaf and Kneiss channels showing intermediate values. Excluding the few stations with no amphipods, the poorest stations include two stations in the Ben Khlaf channel and two stations in the Mimoun channel. The low numbers of amphipods at these stations cannot be directly linked with phosphogypsum pollution (El Zrelli *et al.*, 2018), as low-abundance amphipod populations are found both near and at some distance from the industrial outfall.

In the near future, the amphipod population characteristics and spatio-temporal patterns described here will be compared with the results obtained for the two other dominant groups of macrofauna found in the tidal channels, namely the polychaetes and the molluscs.

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