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The sandy beach macrofauna of Gulf of Gabès (Tunisia)

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Conflict of interest
The authors declare no conflict of interests.

Abstract

This study describes the macrofauna of the three beaches situated in central Gulf of Gabès (Tunisia): Ouderef, Gabès and Zarrat. The Gulf of Gabès has the largest tides in the Mediterranean and the beaches showed a wide intertidal zone. The beaches were sampled once during the spring low tides of June 2005. A transect was extended at each beach, from above the drift line to below the swash line at five sampled levels; at each level six 0.05 m^2 replicates were taken to a depth of 30 cm and sieved through a 1-mm mesh, and the organisms collected and preserved. The three beaches showed a different physical environment. Sediment type was medium sand at the steeper Ouderef beach, fine sands at Gàbes beach, and very fine sands at the flatter Zarrat beach. The total number of species collected was 31: 12 crustaceans, 10 polychaetes, four molluscs and five insects. The supralittoral and mediolittoral zones were very different. The supralittoral zone was dominated by *Talitrus saltator* and insects. The most abundant mediolittoral species were the amphipod crustacean *Bathyporeia guilliamsoniana* at Ouderef beach (23069 ind.m^{-1}), the surf clam *Donax trunculus* at Gabès beach (60711 ind.m^{-1}) and the spionid polychaete *Scolelepis mesnili* at Zarrat beach (18345.6 ind.m^{-1}).

Problem

Sandy beaches are the most widely distributed intertidal habitat along the coastline of Africa, and a great deal of the knowledge on beach ecology arises from the studies of the South African beaches (Bally 1983; McLachlan 1977, 1988; McLachlan *et al.* 1979, 1981; among others). In contrast, research on sandy beaches is scarce on northern Africa, as noted by several authors (Dexter 1992; Deidun *et al.* 2003; Scapini 2003). Baseline studies were carried out in the beaches of Morocco (Bayed 2003) and Egypt (Dexter 1989). With respect to Tunisia, the pioneer studies of Seurat (1924, 1929, 1934) described some biological and physical characteristics of the beaches of the Gulf of Gabès.

Delamare Deboutteville (1954) conducted faunistic surveys of several sand beaches. More recent studies from Tunisian beaches are related to the meiofauna (Hulings 1971), biology and ecology of interstitial polychaetes (Westheide 1970, 1972a,b; Von Soosten *et al.* 1998), arthropods (Charfi-Cheikhrouha *et al.* 2000; ElGtari *et al.* 2000; Colombini *et al.* 2002; Marques *et al.* 2003) and the wedge clam (Dhaoui-Ben Kheder *et al.* 2003).

Tunisia is surrounded on the North and East by the Mediterranean Sea, with 1148 km of coastline, two hundred of them in the Gulf of Gabès. It is a shallow gulf located in the south-western part of the Strait of Sicily, with weak currents, low energy waves, and high salinity (37.5–39.25‰) and temperature (13.2–26.5 °C) (Ktari-Chakroun & Azouz 1971). The Gulf of Gabès has the largest tides in the Mediterranean. These tides are semidiurnal and present a distinct spatial pattern: they are less developed at edges and more developed in the middle of the gulf, in Gabès, with ranges up to 2.3 m at spring low tides (Seurat 1924; Delamare Deboutteville 1954; Sammari *et al.* 2006).

Although there are diverse studies on marine biodiversity, fishery and pollution effects in the Gulf of Gabès (*e.g.* De Gaillande 1970; Ktari-Chakroun & Azouz 1971; Darmoul *et al.* 1980; Darmoul 1988; Louati *et al.* 2001; Hamza-Chaffai *et al.* 2003; Zaghden *et al.* 2005; see literature revision in El Afli *et al.* 2001), data about the macroinfauna on sandy beaches are sparse, and the only information available to date is from Seurat's (1924, 1929, 1934) works.

The aim of this study was to provide the first descriptive information regarding the macroinfauna and habitat characteristics of beaches of Gulf of Gabès. The beaches selected for the present study were chosen because of their situation in the middle of the Gulf, where the highest tides occur.

Study Area

Three sandy beaches situated along 40-km coast of central Gulf of Gabès, were sampled during spring tides in June 2005: Ouderef, Gabès and Zarrat (Fig. 1). These beaches represented three sites of the sandy coastline of the Gulf of Gabès, which stretches more or less uninterruptedly from Sfax on the North to Zarzis on the South.

Material and Methods

In the middle of the beach, a transect was extended from above the drift line to below the swash line. The beach division was based on Salvat's (1964, 1967) zonation scheme, and five sampled stations were marked to levels: (1) 2 m above the drift line; (2) drift line; (3) retention; (4) resurgence; and (5) saturation. At each station, six 0.05 m^2 replicates (1 m apart) were taken with plastic cylinders to a depth of 30 cm and sieved through a 1-mm mesh. The residue was preserved in 7% formalin and

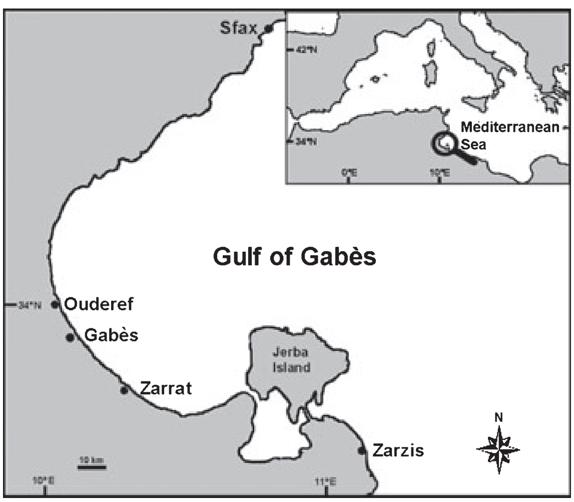

Fig. 1. Map showing the location of the sampled beaches.

stored with rose bengal. A sample of sediment for grain size analysis and organic matter content was collected at each station. Particle size analysis was performed by dry sieving (Buchanan 1984). Trask's (1950) sorting coefficient was calculated. Organic matter content of the fraction of the sediment <0.5 mm was estimated as weight loss of dried samples after combustion (450 °C, 24 h). The beach slope was determined by Emery's (1961) profiling technique.

Species diversity and evenness were measured with the Shannon–Wiener index and Pielou's evenness index respectively. Species dominance and density were calculated for the supralittoral and mediolittoral zones in every beach.

Relationships between benthic assemblages at the three beaches were investigated using non-metric multidimensional scaling (MDS) and similarity cluster dendrograms to produce the best graphical descriptions of faunal similarities between sites. For the analyses, the data matrix, consisting of total abundances of species at each site, was square root transformed and then converted to a symmetric matrix of biotic similarity between pairs of sites using the Bray–Curtis similarity index. The similarity matrix was agglomerately clustured using average linkage. The BIOENV procedure was used to define suites of nine environment variables (beach, sampling level, median grain size, organic matter content, sorting index, pelitic fraction, beach slope, intertidal wide and beach length) that best explain the macroinfauna assemblage structure. The above analyses were performed by the PRIMER software package (Clarke & Warwick 1994).

The specimens of *Donax trunculus* collected were divided into three size groups: (i) recruited individuals (sizes from 1 to 9 mm); (ii) juveniles (sizes from 9 to 15 mm); and (iii) adults (size >15 mm) (Manca Zeichen *et al.* 2002).

Results

The physical characteristics of the three beaches are shown in Table 1. Beach longitude was calculated as the distance between a harbour and a wadi that enclosed the sample point. Zarrat beach, more than 8-km long, has the maximum intertidal wide and the minimum slope of the three beaches. A sedimentary gradient was observed in the three beaches from north to south, ranging from medium sands in Ouderef beach to very fine sands in Zarrat beach. The organic matter content of the sediments was relatively low throughout the beaches and ranged from 1.22% (Zarrat beach) to 1.93% (Ouderef beach) Except for level 1 of Gabès beach, sediment type was similar at all sampled levels of each beach (Fig. 2a). The lowest organic matter content was found in the upper level

Table 1. Summary table describing the locations and the principal characteristics of the beaches.

beach	sampling date	location		L	W	slope (%)	Md (±SD)	sediment type	So (±SD)	Pf (±SD)	OM (±SD)
Ouderef	22/06/2005	34°01′ N	10°02′ E	11890	56.4	1.7	340 (17)	medium sands	1.26 (0.05)	2.18 (1.28)	1.44 (0.24)
Gabès	23/06/2005	33°53′ N	10°07′ E	1060	98.4	1.3	250 (53)	fine sands	1.38 (0.14)	1.63 (0.86)	1.93 (0.30)
Zarrat	21/06/2005	33°43′ N	10°19′ E	8060	131.5	0.24	120 (30)	very fine sands	1.24 (0.1)	1.7 (0.24)	1.22 (0.44)

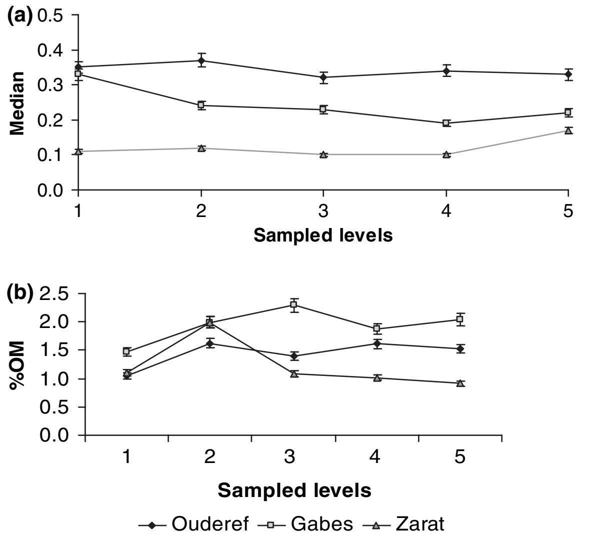

Fig. 2. a: Median grain size (mm) at sampled levels in the three beaches. b: Organic matter content (%) at sampled levels in the three beaches.

Table 2. Number of species and individuals.

	Ouderef	Gabès	Zarrat
species no.			
Crustacea	8	5	8
Polychaeta	5	3	7
Insecta	4	4	3
Mollusca	3	2	4
total	20	14	22
individuals			
Crustacea	716	27	37
Polychaeta	9	19	462
Insecta	18	30	55
Mollusca	50	1030	278
total	793	1106	832
diversity (H′)	1.46	0.46	1.48
evenness (J′)	0.49	1.17	0.46

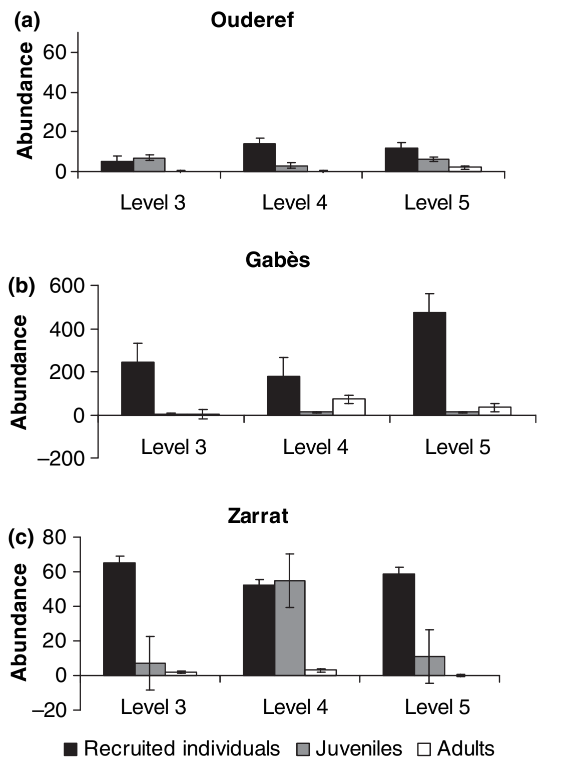

Fig. 3. Size distribution of *Donax trunculus* at sampled levels in the three beaches. Note the different scale on the y-axis.

of all three beaches. Against what is usual, there was no relationship between grain size and organic matter content. Zarrat, the beach with finest sediments also had the lowest organic matter content (Fig. 2b).

A total of 31 species/morphs of macrofauna were recorded in the beaches of the Gulf of Gabès. Crustaceans were the most diverse group (with 12 species), followed by polychaetes (10 species), insects (five species/morphs) and molluscs (four species). Table 2 shows the number of species, abundance, diversity, and evenness in the three beaches. Crustaceans at Ouderef beach and polychaetes at Zarrat beach were the most abundant and diverse. The highest density for a macrofauna species at the Gulf was reached by *Donax trunculus* at Gabès beach. Although this species was present in all three beaches, Gabès was the beach with the most newly recruited individuals (Fig. 3).

The MDS analysis in Fig. 4 performed by pooling the five sampling levels on each beach, suggested that the macrofauna communities could be grouped into two broad categories: Group I, on the left, containing the supralittoral levels (levels 1 and 2, above the drift line and drift line respectively) and Group II, on the right,

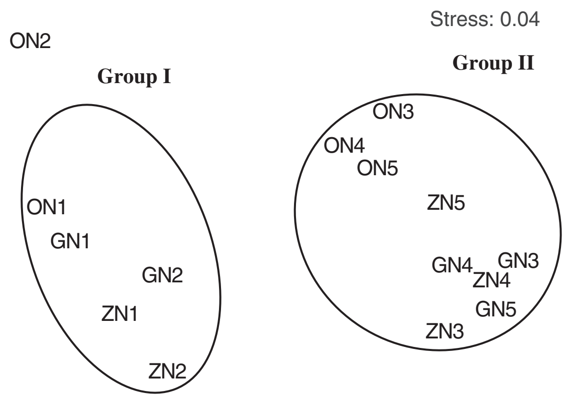

Fig. 4. Multidimensional scaling plot of the samples according to species abundance. Codes: O, Ouderef; G, Gabès; Z, Zarrat; N1, level 1; N2, level 2; N3, level 3; N4, level 4; N5, level 5.

with the mediolittoral or intertidal levels (level 3, retention; level 4, resurgence; and level 5, saturation). The low stress value (S = 0.04) gives a potentially useful two-dimensional picture. The combination with clustering analysis can be an effective way of obtaining additional information about the overall structure of these two categories.

Cluster analysis (Fig. 5) shows that Group II could be divided into two subgroups with a similarity close to 70%, one containing the mediolittoral levels of Gabès beach (Group IIa) and other with the mediolittoral levels of Ouderef beach (Group IIb).

Supralittoral levels are inhabited by seven species. Table 3 shows their density and dominance at Ouderef, Gabès and Zarrat beaches. The amphipod *Talitrus saltator* was the most abundant species, present in the three beaches studied, with the highest densities in Ouderef beach. In this beach, *Tylos europeaus* was also abundant. Insects were important at these beach levels, with *Hypocaccus* sp. as the only taxa found in all three beaches. One unidentified species of Staphilinidae was abundant only at Zarrat beach.

A total of 24 intertidal species were collected: 10 Polychaeta, 10 Crustacea and four Mollusca (Table 4). In Ouderef beach, with 14 intertidal species, the most dominant species were *Bathyporeia guilliamsoniana* (78.8%), *Donax trunculus* (9.4%), *Gastrosaccus mediterraneus* (6.8%) and *Cumopsis fagei* (1.4%). In Gabès beach, the bivalve *Donax trunculus* accounted for 96.7% of the total individuals collected; 90% of these were newly recruited individuals (Fig. 3). At this beach, nine intertidal species were collected, with the spionid polychaete *Scolelepis mesnili* as the only other dominant species. The highest number of intertidal species (18 species) was collected at Zarrat beach, with *Scolelepis mesnili* (54.7%), *Donax trunculus* (33.2%), *Glycera tridactyla* (3.7%), *Bathyporeia guilliamsoniana* (2.3%), *Neverita josephinia* (1.5%) and *Gastrosaccus mediterraneus* (1.0%) as dominant species.

The biological differences observed between the three beaches could be explained by differences in the physical parameters. BIOENV analysis showed that the combinations of environmental variables which produced the highest degree of correlation between the biotic and environmental data matrices (Table 5) were beach (site), median grain size, organic matter content and sorting index for the mediolittoral levels. BIOENV failed to find any significant correlation with any of the environmental variables at supralittoral levels.

Discussion

The coast along the Gulf of Gabès is a continuous sandy habitat interrupted by harbours and wadis. Compared to other Mediterranean coast, tides are exceptionally important in this Gulf. This fact, associated with very flat slope, results in a wider intertidal zone than that observed at mesotidal beaches. An inventory of the macrofauna parameters shows clear differences between the beaches of the Gulf of Gabès and those in the rest of Mediterranean Sea (Table 6). The number of species by beach and the macroinfauna density are more similar to those of the NE

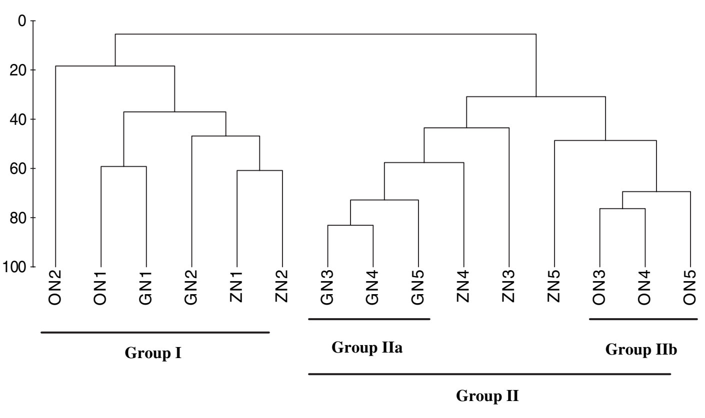

Fig. 5. Dendrogram of similarity of samples according to species abundance. Codes: O, Ouderef; G, Gabès; Z, Zarrat; N1, level 1; N2, level 2; N3, level 3; N4, level 4; N5, level 5.

Table 3. Density and dominance of supralittoral species in the three beaches of the Gulf of Gabès.

	Ouderef			Gabès			Zarrat		
supralittoral species	density (ind.m^{-2})	density (ind.m^{-1})	dom (%)	density (ind.m^{-2})	density (ind.m^{-1})	dom (%)	density (ind.m^{-2})	density (ind.m^{-1})	dom (%)
Talitrus saltator	370.3	9988.0	78.0	16.6	440.0	27.7	8.3	766.7	8.3
Tylos europaeus	77.6	2156.0	16.8						
Coleoptera, larvae				16.6	440.0	27.7	8.3	766.7	8.3
Carabidae, larvae	3.3	88.0	0.6	1.6	44.0	2.7			
Hypocaccus sp. A	12.0	528.0	4.1	23.3	616.0	38.8	6.6	613.3	6.6
Xanthomus sp. A	1.6	44.0	0.3	1.6	44.0	2.7			
Staphilinidae spp.							76.6	7053.3	76.6
total	465.0	12804	100.0	60.0	1672.0	100.0	100.0	10273.3	100.0

Table 4. Density and dominance of mediolittoral species in the three beaches of the Gulf of Gabès.

	Ouderef			Gabès			Zarrat		
mediolittoral species	density (ind.m^{-2})	density (ind.m^{-1})	dom (%)	density (ind.m^{-2})	density (ind.m^{-1})	dom (%)	density (ind.m^{-2})	density (ind.m^{-1})	dom (%)
Capitella capitata				4.4	236.0	0.3	1.1	43.9	0.1
Diopatra neapolitana							3.3	131.7	0.3
Glycera alba	4.4	2.1	0.8						
Gycera tridactyla	2.2	1.2	0.4	4.4	236.0	0.3	32.2	1272.8	3.7
Hediste diversicolor							2.2	87.8	0.2
Lumbrinereis impatiens	1.1	59.0	0.2						
Nephtys assimilis							2.2	87.8	0.2
Nephtys cirrosa									
Nephtys hombergi	1.1	59.0	0.2						
Nephtys kersivalensis							2.2	87.8	0.2
Scolelepis mesnili	1.1	59.0	0.2	12.2	649.0	1.0	470.0	18345.6	54.7
Chamelea gallina				5.5	59.0	0.1	3.3	131.7	0.4
Donax trunculus	52.2	2773.0	9.4	1143.3	60711.0	96.7	285.5	11279.4	33.2
Neverita josephinia	2.2	118.0	0.4				13.3	526.7	1.5
Sphaeronassa mutabilis	1.1	59.0	0.2				6.6	263.3	0.7
Carcinus estuarii				1.1	59.0	0.1	1.1	43.9	0.1
Liocarcinus vernalis							1.1	43.9	0.1
Atylus massiliensis							1.1	43.9	0.2
Bathyporeia guilliamsoniana	434.4	23069	78.8	7.7	413.0	0.6	20.0	746.1	2.3
Corophium acherusicum							1.1	43.9	0.1
Eurydice affinis	1.1	59.0	0.2	2.2	118.0	0.2			
Eurydice spinigera	3.3	177.0	0.6						
Idotea baltica	1.1	59.0	0.2						
Cumopsis fagei	7.7	413.0	1.4				1.1	43.9	0.1
Gastrosaccus mediterraneus	37.7	2006.0	6.8	5.5	295.0	0.4	8.8	351.1	1.0
total	551.1	29618	100.0	1186.6	62776.0	100.0	857.8	33544.3	100.0

Atlantic beaches than to other Mediterranean beaches. The low macrofauna diversity and density of the Mediterranean beaches (Dexter 1986/1987, 1989; Deidun *et al.* 2003) are clearly related to the tidal range, and the highest amplitude of this range at the Gulf of Gabès provokes an increase in macrofaunal parameters.

The beaches sampled in Tunisia show a clear zonation pattern for each beach: (i) a supralittoral zone, (Sampled levels of dry sand and drift line) with insects and air-breathing crustaceans and (ii) more diverse middle and lower zones (sampled levels of retention, resurgence and saturation) with intertidal species. Several authors distinguished different zones along the intertidal beach (McLachlan & Jaramillo 1995) but the sharp boundaries in macrofaunal zonation were not found at the Gulf of Gabès beaches. There is no clear separation between levels

Table 5. Results of BIOENV analyses.

no. variables	correlation	selections
4	0.82	beach, median grain size, organic matter and sorting index
2	0.82	beach and sorting index
3	0.81	beach, median grain size and sorting index
3	0.81	beach, organic matter and median grain size
1	0.79	beach
2	0.78	beach and median grain size
3	0.78	beach, organic matter and sorting index
2	0.77	beach and organic matter
5	0.75	beach, median grain size, organic matter, pelitic fraction, sorting index, beach slope, intertidal wide, beach length
4	0.74	beach, median grain size, organic matter, pelitic fraction
3	0.73	sorting index, beach slope, intertidal wide, beach length
2	0.73	sorting index, intertidal wide

of retention, resurgence and saturation. As was shown by the cluster and MDS analyses, the most important factor to explain the distribution of the intertidal macrofauna is the factor 'beach (site)' rather than the factor 'level'. This division of the beach into two main zones, supralittoral and mediolittoral, has also been also described for beaches of Scotland (Raffaelli *et al.* 1991) and N Spain (Rodil *et al.* 2006).

Although the three beaches are considered dissipative (*sensu* Short & Wright 1983), the physical environment does not remain constant along the entire Gulf. The northernmost beach, Ouderef, was steeper and has coarser sediments than the southernmost flat and fine-grained beach of Zarrat. The observed differences in faunal composition can be explained in term of differences in the physical parameters of the three beaches. Studies have shown that species richness and density are inversely related to sediment grain size and beach slope (Defeo *et al.* 1992; McLachlan *et al.* 1993; McLachlan & Jaramillo 1995), but the contrary is also possible (Veloso & Cardoso 2001).

The most abundant species of the supralittoral zone, *Talitrus saltator* and *Tylos europaeus*, are commonly found along the Mediterranean and Atlantic sandy shores of Europe and North Africa. Cited as characteristic of the 'biocenose des laisses a dessication rapide sur sable supralittoral' (Pérès & Picard 1964), both species are scavengers that feed on decaying wrack. This fauna, associated with the drift line, was impacted by beach cleaning, which occurred at Gabès at the time of sampling and thus it is not surprising that this beach has the lowest density of the supralittoral assemblage. The only occurrence of *T. europaeus* at Ouderef beach was probably related to the type of sediment. According to Kensley (1974), *Tylos europaeus* avoids fine sand beaches inhabiting instead coarse-sand beaches. Relationships between this species and the granulometric parameters have been cited by other authors (Fallaci *et al.* 1996; Gonçalves *et al.* 2005).

In each different beach, the most characteristic species, accounting for more than 50% of the intertidal macrofauna, belonged to a different taxonomic group of the

Table 6. Macrofaunal parameters found in other studies in sandy beaches in the Atlantic and Mediterranean Sea.

	no. beaches	area sampled by beach (m^2)	no. species by beach	no. species (total)	density ($ind.m^{-2}$)	maximun tidal range (m)	reference
NE Atlantic							
the Netherlands	9	0.5	5–28	49	222–4166	2.4	Jansen & Mulder (2005)
N Spain	19	3	9–29		31–409	4.8	Rodil *et al.* (2006)
NW Spain[a]	18	1.5	15–26	60	98–1698	4.1	Junoy *et al.* (2005)
Morocco	15	1.7–2.2	4–24	36	40–1333	3	Bayed (2003)
Mediterranean							
Egypt	18		0–5	10	10		Dexter (1989)
Israel	3	0.3	3–4	7		0.3	Dexter (1986/1987)
Malta[b]	10	0.2–0.3	0–7	17	supralittoral: 24 mediolittoral: 160	0.2	Deidun *et al.* (2003)
Gulf of Gabès	3	1.5	14–22	31	supralittoral: 60–465 mediolittoral: 551–1186	2.3	this study

[a]Before the Prestige oil spill.
[b]Only core sampling considered.

three most abundant macrofaunal taxa on sandy beaches worldwide (Pichon 1967; McLachlan 1983): crustaceans, molluscs and polychaetes.

The amphipod *Bathyporeia guilliamsoniana* dominated the Ouderef beach. The sediment characteristics would be responsible for its high abundance; the optimal sediment type for the species is median grain size (Degraer *et al.* 2006). Two other crustaceans reach their highest densities at this beach, *Cumopsis fagei* and *Gastrosaccus mediterraneus*. This mysid was the most abundant and widely distributed sandy beach animal along the Mediterranean beaches of Egypt (Dexter 1989).

The bivalve *Donax trunculus* reached a very high abundance at Gabès beach. This beach had fine sands, a sedimentary type preferred by this species (Degiovanni & Mouëza 1972; Guillou & Le Moal 1978, 1980; Guillou 1982; Bayed & Guillou 1985; Dhaoui-Ben Kheder *et al.* 2003). The exceptional dominance of the *D. trunculus* was due to new recruited individuals at the three mediolittoral levels. According to Dhaoui-Ben Kheder *et al.* (2003), the spawning activity in beaches of Northeast Gulf of Tunis begins in January and continues until July or August and a similar period can be presumed for the species in Gabès. Thus, the major contribution of recruits could be expected at the time of sampling. As expected (Ansell & Lagardère 1980; Bayed & Guillou 1985; Mazé & Laborda 1988), the youngest individuals occurred in the highest levels of the beach, retention and resurgence, and the oldest individuals concentrated in the saturation level, close to the low water.

The spionid polychaete *Scolelepis mesnili* dominates in the finer sediments of Zarrat beach. This species was described by Bellan & Lagardère (1971) in the Atlantic beaches of Europe. Only its cogeneric species, *Scolelepis squamata,* is usually cited as inhabiting these beaches. Both species are sympatric at the same beach at least in the Atlantic coast of France (Bellan & Lagardère 1971), Spain (Junoy & Viéitez 1990, 1992; Pérez Edrosa & Junoy 1991) and Morocco (Bayed 2003). At these beaches, the two species showed a spatial segregation with S. *squamata* occupying the upper intertidal levels of resurgence and retention and *S. mesnili,* a smaller form, occupying the low level of saturation. Only *S. mesnili* was present in the beaches of Gulf of Gàbes; both species are present in the Mediterranean coast of Italia (Lardicci 1989).

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