Diversity and geographical distribution of soft-bottom macrobenthos in the bay of Bou Ismail (Algeria, Mediterranean Sea)

Ali Bakalem, Najla Hassam, Yasmina Oulmi, Marine Martinez, Jean-Claude Dauvin

Diversity and geographical distribution of soft-bottom macrobenthos in the bay of Bou Ismail (Algeria, Mediterranean Sea)

Ali Bakalem[a], Najla Hassam[a], Yasmina Oulmi[a], Marine Martinez[b], Jean-Claude Dauvin[b*]

[a]Ecole Nationale Supérieure Agronomique (ENSA), Avenue Hassan Badi, 16200 El Harrach, Algiers, Algeria
[b]Normandie Univ., UNICAEN, Laboratoire Morphodynamique Continentale et Côtière M2C, UMR 6143 M2C, 24 rue des Tilleuls, F-14000 Caen, France

*Correspondence to: Normandie Univ.,Université de Caen Normandie, Laboratoire de Morphodynamique Continentale et Côtière, UMR CNRS 6143 M2C, 24 rue desTilleuls, F-14000 Caen, France.
E-mail address: jean-claude.dauvin@unicaen.fr (Jean-Claude Dauvin).

ABSTRACT

The macrobenthic fauna in the bay of Bou-Ismail (Mediterranean Sea, Algeria) was studied with the objective of establishing a reference state based on the probable diversity thirty years earlier at the end of the 1980s.A total of 98 points were sampled using a Smith Mac Intyre grab sampler (two replicates each of 0.1 m^2 and using a 1 mm mesh sieve). A total of 17,120 individuals representing 840 taxa (including 723 species) were identified from the sampled material. Seven distinct benthic communities were identified as a function of the sediment characteristics. Four diversity indices (Taxonomic Richness, Shannon, Pielou and $ES_{(50)}$), and two benthic indices (AMBI and BO2A) were calculated for each of the seven benthic communities. Coastal Terrigenous Mud contains the poorest community while Muddy Detritic supports the richest variety. The Shannon index exceeds 6 at the sampling points with the greater diversity, where the number of individuals per 0.2 m^2 reaches 664. Out of 50 organisms collected in a sample, the expected number of species was 35 (ES_{50}). Moreover, < 50% of the taxa were found at only one or two stations. Benthic indicators revealed a good and high ecological status. The geographic origin of the 723 species is presented as their reported presence in 13 geographical regions including nine areas of the Mediterranean Sea. Most of the species had an Atlantic origin and are present in the western Mediterranean Sea.

Keywords: Algeria; diversity; ecological status; biogeography; benthic community

1. Introduction

The bay of Bou Ismail (formerly known as the 'Baie de Castiglione') is located on the central part of the Algerian coast in the western part of the bay of Algiers (Fig. 1).It covers an area of about 340km² and is bordered by the Chenoua Massif in the west and the Bouzaréah Massif in the east. The continental shelf narrows down to 2 to 4 km near the massifs, but stretches out to 55 km in the central part of the bay where the seabed falls away at a water depth of around 120 m.

The bay of Bou Ismail had been the object of much pioneering research on macrozoobenthic communities, largely due to the creation of the Castiglione Marine Station in 1921. Over the years, this Station had produced inventories of fauna for the Echinoderms (Seurat, 1932; Dieuzeïde, 1933; Devries, 1957), the Bryozoans (Gauthier, 1955), the Hydozoans (Picard, 1955), and more recently,for the amphipods (Bakalem and Dauvin, 1995; Grimes *et al*., 2009) and the Decapods (Grimes *et al*., 2016).

Le Danois (1925) was the first researcher to describe the benthic communities of the bay of Bou Ismail in relation to the fishing areas. This work was followed by Dieuzeïde (1950) who published an inventory of the benthic macrofauna making up the soft-bottom communities of the fishing areas in this bay, which was later supplemented by Vaissière and Fredj (1963). Dieuzeïde (1940) described the 'Gravelle de Castiglione' (*Branchiostoma* community of Coastal Detritic) associated with maerl substrates, which was compared with the communities of the Marseilles area by Pérès (1952) and later analysed in detail by Falconetti (1970).

In the bay of Bou Ismail, the faunal and floristic characteristics of the marine phanerogams (g. *Cymodocea, g. Zostera* and *Posidonia oceanica*) occurring at a water depth between 0.5 and 25m were described and mapped in the 1950s and 1960s (Dieuzeïde and Goëau-Brissonière, 1951; Molinier and Picard, 1952; Le Gall, 1969; Boumaza, 1995).

Despite these detailed studies in the bay of Bou Ismail, no synoptic studies had been carried out across the whole range of community's soft-bottom organism in prior to 1988. Thus, the bay was sampled intensively in August 1988 (Hassam, 1991; Oulmi, 1991; Dauvin *et al*., 2013), and the collected data used in global analyses of the diversity and ecological status of the Algerian coastal waters in comparison with other coasts along the Mediterranean and Atlantic (Bakalem *et al.* 2009; Dauvin *et al*., 2012, 2016). These results highlighted the very high biodiversity in the bay, probably due to the existence of several sediment types but also due to the presence of numerous Atlantic species, which have penetrated into the western

Mediterranean and along the Algerian coast because of the natural sea currents (Millot *et al.*, 1990; Millot, 1999). However, various questions remained unclarified: what was the pattern of the local biodiversity at the scale of the different benthic communities in the bay, and what was the cause of such diversity especially with respect to the benthic soft-bottom communities?

The current study thus had three main objectives. 1) to describe the pattern of the diversity of the macrofauna at the scale of the bay of Bou Ismail, (i.e., the species diversity and distribution at the end of the 1980's); 2) to assess the ecological status of the bay at the end of the 1980's (i.e., before the start of the period of intense development of the Algerian coastal areas linked to population and industrial growth),and 3),to identify the geographical distribution of the species, enabling some explanation of the especially high diversity of the macrofauna in this area.

2. The main characteristics of the bay of Bou Ismail and the design of the sampling procedures

2.1. The main characteristics of the bay of Bou Ismail

The general movement of coastal water in the area is characterized by the penetration of surface Atlantic waters through the Strait of Gibraltar, across the Alboran Sea and along the Algerian coast (Millot, 1999). Moving west to east, the Algerian surface current is 50km wide, between 150 and 250m thick and runs at an average speed of 50 $cm.s^{-1}$. It also exhibits a certain instability caused by the anticyclonic and cyclonic gyres (typically100-150km in diameter) that are associated with the upwelling of cold deep waters favouring a strong primary productivity (Millot, 1999; Millot and Taupier-Letage, 2005).A branch of this Algerian current penetrates into the bay of Bou Ismail and generates a coastal counter current moving in the western direction.

Within the bay, the hydrological factors show large seasonal variations, with strong westerly and north-westerly swells occurring during winter associated with the resuspension of fine particles in shallow waters (Bakalem, 2008). Such resuspension is weak during the spring-summer period (dominated by a north and north-easterly swell) which generates currents along the shore moving from the eastern to the western part of the bay with a consequential redistribution of fine sediment towards the west.The dissolved oxygen concentrations vary between 5.6 and 8.5 $mg.L^{-1}$ with the lowest values being observed during the summer in the shallower waters. The sea surface temperatures vary from 27°C at the end of summer, falling to 16°C in winter; the thermocline occurs at a depth of 20m depth in June falling to 60 m at the end of the summer. The temperature near the sea bottom beneath the thermocline remains at below16°C all the year round. The salinity shows weak seasonal changes and ranges between 37 and 38; a weak desalinisation (36.7-37) is observed near the oueds during the winter due to freshwater inputs.The deposition of suspended fine sediment from these freshwater sources was estimated at$3x10^6$ tonnes per year (Grovel, 1961), resulting in the formation of subtidal mud flats in the bay (Dagorne, 1970; Aït Kaci and Pauc, 1983a,b; Braik, 1989; Moulfi, 1995).

Previous studies of the seabed of the bay have highlighted the wide diversity of the associated fauna. Nine distinct substratum types have been identified: fine sands, muddy fine sands, sandy muds, gravelly sands, muddy gravels, coarse sands and gravels, pure muds, rocky facies and *Posidonia* meadows (Leclaire, 1972; Bakalem, 2008).Pure muds and muddy gravels were the dominant types. The mud flats were formed mainly in the western part of the bay, whilst the coarse sands and gravels and the gravelly sand sediments,were only present in the eastern part. Rocky facies and *Posidonia* meadows were more prevalent in the western than in the eastern part of the bay (Leclaire, 1972; Bakalem, 2008).

Relative to the whole Algerian coast, the bay of Bou Ismail is an important fishing area and the operation of trawlers dates back over many decades (Le Danois, 1925; Dieuzeïde, 1950, 1954; Dieuzeïde and Roland, 1957). This activity is reflected by the presence of a large fishing fleet and five fishing ports including Bou Haroun, which is a major Algerian fishing port.

Compared to the neighbouring areas along the eastern the bay of Algiers, the bay of Bou Ismail had not been greatly urbanized or industrialized prior at the end of the 1980's (Bakalem, 2008; Grimes, 2010). The area was yet to suffer industrial development, and boasted neither commercial harbour nor a major coastal town and generated negligible wastewater discharges. Today, the population along the 60km stretch of coast is estimated at 200,000. The main sources of pollution now result from the large discharge of domestic waste water from coastal urban towns generally lacking any water treatment. The study by Boudjellal *et al.* (1995) on the presence of heavy metals (mercury, lead, copper, chromium, cadmium, zinc, etc.) in shallow sediments (5-20m) showed that the bay of Bou Ismail could still be considered as an unpolluted area when compared to other Algerian coasts. In a study on the content of PAH in sediments, Sellali (1996) concluded that hydrocarbon pollution was very low.

The medium and long-term development of coastal areas during the last few decades (general urbanization, construction of sea resorts and marinas), along with the uncontrolled exploitation of sand dunes, have changed the hydrodynamics and sedimentation processes, which, along with coastal erosion, have caused shoreline degradation. These impacts have led mainly to the reduction of areas of seabed in the bay classified as of *Posidonia* meadows because of the increased sedimentation in shallower waters (Molinier and Picard, 1952; Braik, 1989; Boumaza, 1995; Bakalem, 2008).

2.2. Benthic sampling methodology

The sediments were sampled using a 0.1m^2 Smith Mc Intyre grab apparatus (three replicates per sampling point, two for the fauna and one for the granulometry) in the period 20-30 August 1988. Ninety-eight locations were investigated, these following 15 transects perpendicular to the coast and one parallel to the coastline (Fig. 1). The sediment from the two replicates was sieved through a 1 mm mesh and the collected macrofauna fixed in a 10% buffered formaldehyde solution mixed with seawater. The organisms were then sorted, identified if possible at the species level, and counted in the laboratory using the Magister framework reported by Hassan (1991) and Oulmi (1991).

In the laboratory, the sediment samples coming from the third replicate were dried at 60°C for 24h, and the particles were then passed through a nineteen-sieve column (2500 to 40 µm) into a mechanical sieve shaker. Each fraction was then weighed to calculate the contribution of each fraction to the total weight. Then the Folk (1954, 1965) classification was used to determine the sediment type. As in Hassam (1991) and Oulmi (1991), the benthic community classification followed the previously definitions of Glémarec (1969, 1971, 1973) and Chassé & Glémarec (1976), and those of Pérès & Picard (1964) and Picard (1965) who had classified the biocoenoses (=communities) of the Mediterranean Sea.

Four environmental parameters were recorded for each sampling location: water depth (ranging between 3 and 135m), seafloor type (varying from rocky to muddy), the percentage of carbonate and the quantity of fine particles (<63µm) in the sediment, the three last parameters were measured from a third replicate sampled by the Smith Mc Intyre grab.

2.3. Measurements relating to the retrieved organisms

The data retrieved from the sampling included the abundances of 840 taxa found at the 98 sample points, each representing $0.2m^2$.Among the recorded taxa, 723 species were identified to level of species (86% of the taxa); consequently, the geographical patterns of these 723 species could be been documented according to the available literature. The species names were validatedby use of the WoRMS database (http://www.marinespecies.org; accessed on 4 December 2018).

The distribution of the 723 identified species was also categorized in terms of the distinct biogeographical regions of the Mediterranean adopted by Coll *et al.* (2010): (i) AD: Adriatic Sea, (ii) AE: Aegean Sea, AL: (iii) Alboran Sea, (iv) IO: Ionian Sea, (v) LE: Levantine Sea,(vi) NWM: north-western Mediterranean, (vii) TL: Tunisian and Libyan continental shelf, (viii) BI: the bay of Bou Ismail (south-western Mediterranean), and (ix) BS: Black Sea. Four other zoographic realms are also selected:(i) NE: North-Eastern Atlantic European waters; (ii) IP: Indo-Pacific; (iii) RS: Red Sea and (iv) AA: African Atlantic Coast (extending from Cap Spartel to Cap Blanc).The purpose of this exercise was to define the origin of the macrofauna species found in the bay of Bou Ismail (either from the Mediterranean or originating further from the Atlantic or other geographical area). The species were then classified into nine groups according to their geographical affinity: (i) eam (Mediterranean, European and African Atlantic), (ii) em (Mediterranean and European Atlantic), (iii) am (Mediterranean and African Atlantic coast), (iv) e (endemic species), (v) mr (Mediterranean and Red Sea species), (vi) c (cosmopolitan species), (vii) emr (Mediterranean, European Atlantic and Red Sea species), (viii) emip (Mediterranean, European Atlantic and Indo-Pacific species) and (ix) mrip (Mediterranean, Red Sea and Indo-Pacific species).

A hierarchical cluster analysis (HCA) was used based on Sorensen’s coefficient for Presence/Absence of the species in the 13 biogeographical regions defined above, and a dendogram was constructed using the group-average algorithm from the PRIMER V6 software (Clarke and Gorley, 2006).

2.4. Benthic indices

The first step was to classify the species into zoological groups to identify the respective dominant organisms of the macrofauna. Next, three indicators were calculated based strictly on species diversity: the Shannon-Weaver index ($\log_2 H'$), the Pielou measure of evenness (J') and the expected number of species for 50 individuals collected from each of the 98 samples (ES_{50}).

Furthermore, two indices were calculated based on ecological factors: i) AMBI (the AZTI Marine Biotic Index), which analyses the proportions of five ecological groups (using the species list published on the AZTI website on 22 November 2017) (Borja *et al.*, 2000; Borja and Muxika, 2005), and ii)BO2A (Benthic Opportunistic Annelida Amphipods index), which is based on the principle of taxonomic sufficiency that uses only two well-known zoological groups as indicator species (i.e. the amphipods as sensitive species and the opportunist annelids)(Dauvin *et al.*,2016; De-la-Ossa-Carretero and Dauvin, 2010). In the present study, the five ECOlogical Quality Status (EcoQS) classes suggested by the European Water Framework Directive were used, i.e.: high for unpolluted sites, good for slightly polluted sites, moderate for moderately polluted sites, poor for heavily polluted sites, and bad for extremely polluted or azoic sites. The thresholds are given by Dauvin and Ruellet (2007) and also Dauvin *et al.* (2012, 2016) these references based on that defined by Borja *et al.* (2000) for AMBI, and by Vincent *et al.* (2002) for H' and by De-la-Ossa-Carretero and Dauvin (2010) for BO2A.

3. Results

3.1. General patterns of the fauna distribution

The central region of bay of Bou Ismail is described as mud, whereas the shallower zones were characterized by muddy and fine sand; for both of the western and eastern parts of the bay there was coarser sediment near the rocky headlands (Fig. 1). The fine particles (<63µm) made up between 5 to 95% of the total sediment, whereas carbonate of bioclastic origin represented a large proportion of the total sediment, ranging from 15 to 80%. Based on the results of Hassam (1991) and Oulmi (1991) for the eastern and western parts of the bay respectively, the 98 sample locations could be being classified as one of seven main soft-bottom benthic communities (Fig. 1).

Four sample points corresponded to the conditions of a Coastal Detritic (CD) community with less than 5% fine particles in the sediment and at a water depth between 16 and 24m. These locations were spread across the bay with one in the western part, two in the centre and the last one in the western zone. This type of community is characterized by two species: the Cephalochordate *Branchiostoma lanceolatum* (Pallas, 1774) and the Ophiuroid *Ophiacantha setosa* (Bruzelius, 1805) (Fig. 2).

Nine sample points were located in the eastern part of the bay, corresponding to the Gravelly Sand (GS) community, with sediments containing between 6 to 47% fine particles at occurring at water depths between 15 and 98m. Two amphipods, *Gammaropsis maculata* and *Othomaera knudseni* (Reid, 1951), were abundant in this type of community (Fig. 2).

Eleven sample points located in shallow (3 to 20m) waters in the western and the eastern parts of the bay corresponded to the Well Calibrated Fine Sand (WCFS) community with sediments containing less than 5% fine particles. Two species were abundant in this type of community: the tanaid *Apseudopsis mediterraneus* (Bacescu, 1961) and the amphipod *Ampelisca brevicornis* (Costa, 1853) (Fig. 3).

Ten sampling points were spread across the bay from shallow to deeper areas but generally at a depth of 17 to 34m depth, (except for one sampling point at 113m). These corresponded to the Muddy Sand (MS) community with a sediment containing between 5 and 28% fine particles.This type of community was characterized by two species: the bivalve *Atlantella pulchella* (Lamarck, 1818) and the amphipod *Urothoe grimaldii* Chevreux, 1895 (Fig. 3).

Thirteen sampling points generally located at between 31 and 52 m depth, (except for two deeper locations at 113 and 136m), corresponded mainly in the western and central parts of the bay. These were classified as Sandy Mud (SM) community types with a sediment containing 55 to 80% fine particles. Two species, the bivalve *Nucula sulcata* Bronn, 1831 and the Ophiuroid *Amphiura chiajei* Forbes, 1843, were abundant in this type of community (Fig. 4).

Twenty-five sampling locations at depths ranging from 40 to 100m in the central part of the bay corresponded to the Coastal Terrigenous Mud (CTM) community; the corresponding sediments contained with >90% fine particles. The presence of the polychaete *Paraprionospio pinnata* (Ehlers, 1901) and the Holothuroid *Oestergrenia digitata* (Montagu, 1815) characterized this type of benthic community (Fig. 4).

Twenty-six sampling points that were mainly in the western and eastern deep zones of the bay (ranging in depth from 26 to 122 m) corresponded to the Muddy Detritic (MD) community type with sediments containing between 15 and 57% fine particles.This benthic community was characterized by the amphipod *Othomaera othonis* (H. Milne Edwards, 1830) as well as the polychaete *Terebellides stroemii* Sars, 1835 (Fig. 5).

A total of 17,120 individuals representing 840 taxa were counted from samples retrieved from 98 locations covering a total sampling area of ~20m² across a stretch of bay covering 342 km^2. Taxonomic richness per 0.2m^2 of sampling area varied from 8 taxa at a

CTM station to 118 taxa at a GS station (Fig. 6). 307 of the taxa (36.5%) were retrieved from a single sampling point, whilst 126 others came from just two further locations (15%) and 176 others from three, four or five stations (21%). Four of the taxa showed an occurrence frequency at over have of all the sampling points: Nemertina, the polychaete *Aponuphis bilineata* (Baird, 1870), the ophiuroid *Amphiura chiajei* Forbes, 1843 and the amphipod *Ampelisca typica* (Spence Bate, 1856).

The polychaetes made up 40.5% of the taxonomic richness, followed by crustaceans (32.2% and especially amphipods at 21.8%, decapods, 5.6% and isopods, 4.5%) and bivalve molluscs (10%).

In terms of abundance, the polychaetes again dominated with 44.7% of the collected individuals, followed by the crustaceans (35% including the amphipods which made up 29.3%), and then the echinoderms with 7.6%.

The Shannon factor for biodiversity ($\log_2$ H') varied from 1.73 to 6.03 for the sampling sites, with a mean of 4.24 and 65% of all the sampling points were over 4.0 (Fig. 6). The number of individuals per sampling location varied from 9 at a CTM station to 664 at a CD station, with a mean value of 148. Only four locations showed an abundance greater than 400, and 18 locations had an abundance below 40; among these last group, five sampling points had an even lower abundance of below 20 (Fig. 6). The expected number of species for 50 individuals collected in a sample (ES_{50}) varied from 8 to 34 species, with a mean of 21.9; 66% of the values had an ES_{50} of below 20 species (Fig. 6).

3.2. Distribution pattern of the seven types of benthic community

The four indices that indicate the abundance and diversity of the macrofauna all showed similar patterns, with low values corresponding the central part of the bay and the highest values found in the eastern and the western parts (Fig. 6). Table 1 gives the mean values (and standard deviation) of these indices for the seven listed types of benthic community. It was clear that samples from sediments described as Coastal Terrigenous Mud showed lower values than other benthic communities. The Muddy Detritic type yielded the highest values, with very high values for H' and $ES_{(50)}$. The five other types of benthic community all showed intermediate values lying between these two extremes.

Considering now the measurement J' (the Pielou measure of evenness):this revealed no difference in values between the benthic communities, samples corresponding to the type CTM yielded significantly lower values than those classified as MD, SM or GS (Table 2). The species number (S), and values for ES (50) and H' were all significantly higher in MD samples than for those classified as CTM or SM (Table 2). SM values were also lower than those obtained for GS (Table 2).

Table 1 sets out the mean values for the measurements of diversity, AMBI and BO2A. All the seven types of benthic communities were attributed a high or good status; amongst the 98 sampling locations, 34 are classified as high and 64 good for AMBI and 83 high and 15 good in terms of the BO2A measurement.

3.3. Biogeographical patterns of the recorded species in the bay of Bou Ismail

Full details of the geographical origins of the 723 species identified in the bay of Bou Ismail, (as well as their presence in 13 previously defined geographical areas) is given in the appendix. Table 3 summarized these results. Most of the species found in the bay originated from the Mediterranean or northeast Atlantic, and 655 species (91% of those identified) were also found at other sites in the north-western Mediterranean Sea. 643 species (89% of the total found in the bay of Bou Ismail) were also found in the Aegean Sea, and 545 (75%) and 529 (73 %) were also found in the Adriatic Sea and the Ionian Sea, respectively. 469 species (65 %) were also recorded in the Levantine Sea. By contrast, only 306 (42%) and 182 (25%) of the listed species were also found in the Tunisian and Libyan coastal waters, as well as in the Alboran Sea. A total of 620 species (86%) were also present in north-eastern Atlantic European waters. Very few species were shared with the Red Sea or Indo-Pacific regions. These results confirmed the Atlantic origin of most of the species (81%) found in the bay of Bou Ismail; only 88 species (12%) were endemic to the Mediterranean Sea, and 6% were cosmopolitan species. The prepared dendogram (Fig 7) enabled the distinguishing of two main groups, the first being comprised of common species the areas Indo-Pacific and/or Red Sea (IP and RS) and the Mediterranean Sea. The second group included species from all the other biogeographical regions, which itself could be divided into three sub-groups: 1) AL and BS; 2) TL and AA, and 3) LE, AD, IO, NE, AE, NWM and BI.

4. Discussion

4.1. Comparison of the number of species and their abundance in the bay of Bou Ismail with similar sites across the Mediterranean Sea

Whilst numerous local and regional studies had been carried out on benthic communities at sites across the Mediterranean Sea, there had been little quantitative sampling of soft-bottom communities at the same time at the scale of a whole site and associated with the identification of all zoological groups. The communities identified in the bay of Bou Ismail (and in most studies concerning the Mediterranean Sea) were organised following the classification of biocoenoses (= communities) proposed by Pérès and Picard (1964). Picard (1965) described the benthic communities in the Gulf of Marseilles, whilst Guille (1970, 1971) studied the benthic communities from the French Catalan coast and Desbruyères *et al.* (1973) concentrated on the Spanish Catalan coast. Later, Labrune *et al*. (2006, 2008) and Bonifácio (2015) took account of benthic communities in the Golfe du Lion on the French Mediterranean coast. Quantitative data had also been obtained for other areas of the Mediterranean and Black seas, including the Adriatic (Zavodnik and Vidakovic,1987 and Zavodnik *et al*., 1985), the Cretan coast (Karakassis and Eleftheriou, 1997), the Ionian Sea, (Zenetos *et al*.,1996),the Gulf of Tunis (Ayari and Afli, 2003) and as well as along the Crimean coast (Black Sea) (Revkov and Nikolaenko, 2002), These data could be compared with the results of the current study for the bay of Bou Ismail (Table 4).

Several authors (including Escaravage *et al*., 2009 and Dauvin *et al*., 2013) had established that the Taxonomic Richness (TR) depended on the sampling method and the number of different benthic communities in a given area. Thus, with 840 taxa, the TR for the bay of Bou Ismail indicated that this was one of the most diversified communities (Table 4). Two other areas,the bay of Marseilles and the French Catalan coast (both in the western basin of the Mediterranean Sea),also showed a high diversity. The other cited areas across the Mediterranean generally yielded lower TR values.

It now well knows that the biodiversity is higher in the western basin of the Mediterranean Sea than in the eastern regions (Coll *et al*., 2010, 2012). This contrast was recognized by Arvanditis *et al*. (2002) for the polychaetes, which displayed a low diversity in the oligotrophic Levantine Sea. A total of 12.5% of the invertebrates reported in the Mediterranean Sea were also recorded in the bay of Bou Ismail. The diversity of the four most diverse zoological groups (Polychaetes, Crustaceans, Molluscs and Echinoderms) that were found in the bay of Bou Ismail represented, respectively, 26%, 12.5%, 5% and 19.5% of the total Mediterranean diversity of these four groups.

The two Well Calibrated Fine Sand and Muddy Detritic benthic communities in the bay of Bou Ismail exhibited the highest taxonomic richness (TR), while the other communities in the bay yielded TR values of the same order of magnitude as those found in other areas of the Mediterranean Sea (Table 4). For soft-bottom communities along the Algerian coast, Dauvin *et al*. (2013) reported a TR of 1,642 taxa from a total sampling surface area of 174 m². Escaravage *et al*. (2009) reported a TR of 1,033 in the Aegean Sea (for a sampling surface-area of 34 m²), which was the second highest value recorded when compared with other areas of the north-eastern Atlantic and the Mediterranean Sea. Using a similar sampling surface-area (7.75 m²), Dauvin *et al*. (2013) highlighted a decrease in TR along the Algerian coast falling from 597 taxa in the western sector to 274 taxa in the eastern sector, with the Bay of Bou Ismail near to the Bay of Algiers showing an intermediate diversity of 407 taxa.

The seven soft-bottom communities in the bay of Bou Ismail showed low abundances of between 545 and 1380 individuals per m² (Table 4). These values were similar to those recorded along the French Catalan coast by Guille (1970), higher than those found by Bonifacio (2015) for the same area, but lower than those recorded in the current study for the Ionian Sea and the Gulf of Tunis (Table 4).

The high TR was associated with low abundances of the organism as well as very high values for the Shannon-Weaver index ($\log_2$H'), Pielou evenness (J') and the expected number of species for 50 individuals ($ES_{(50)}$) (Table 1) reflected in the presence of diversified communities in the Bay of Bou Ismail, these values were amongst the highest recorded in the literature for soft-bottom communities(Dauvin *et al*., 2013). The Muddy Detritic community appeared to be the most diversified while the Coastal Terrigenous Mud community was the least diversified. The benthic indicators AMBI and BO2A yielded a High and Good ecological quality status for all the seven benthic communities recorded. Similarly, as inferred from the diversity indices, the Muddy Detritic community was classified as High EcoQS, whilst the Coastal Terrigeneous Mud and Sandy–Mud communities were associated with a Good EcoQS. This applied to the Well Calibrated Fine Sand community at the scale of the Mediterranean Sea (Dauvin *et al*., 2017a), while a degraded EcoQS was attributed to the benthic communities in Algerian harbours, particularly in the case of Algiers (Dauvin *et al*., 2017b).

Finally, this study established a reference status for benthic communities in the bay of Bou Ismail at the end of the 1980s, which were characterized by high diversity and high EcoQS indicating low perturbation of this particular benthic soft-bottom environment at this time.

4.2. Geographical patterns

It was clear that the species present in the seven benthic communities around the bay of Bou Ismail related mainly to the influence of the north-eastern Atlantic and Mediterranean Sea (Tables 3, Figure 7 and Appendix,).Dauvin *et al*. (2013) highlighted a fall in the number of Atlantic species from west to east along the Algerian coast. This decline was also recognized when moving from the western to the eastern basin of the Mediterranean Sea. Nevertheless, in the Levantine basin in the East, numerous Lessepsian migrant species originating from the Red Sea or having Indo-Pacific origin had colonized this part of the Mediterranean and contributed to the enrichment of the local biodiversity. The number of Non-Native Species (NNS) arising from migration through the Suez Canal was very low in the bay of Bou Ismail, with only two polychaete species found:*Metasychis gotoi* (Izuka, 1902) and *Pista unibranchia* Day, 1963. With respect to the invertebrates, Grimes *et al.* (2018) reported 18 NNS in the marine communities along the Algerian coast including five species of Indo-Pacific or Red Sea origin. Those NNS corresponding to Lessepsian migrant species were more numerous in other parts of the eastern basin of the Mediterranean Sea (Coll *et al*., 2010, 2012; Zenetos *et al*., 2017).

When comparing the species diversity in different marine areas, a broad bias due to the variable sampling methods was noted. It was clear that studies in the Alboran Sea were biased towards a low number of species in common with work done in the bay of Bou Ismail (Table 3 and Appendix), probably due to the small number of studies in this area of the Mediterranean Sea. Conversely, the low number of species in common between the bay of Bou Ismail and the virtually isolated Black Sea reflected the low diversity of the latter with particular physico-chemical characteristics in relation to hypoxic and anoxic conditions.

The Tunisian-Libyan region was distinguished from the other Mediterranean areas (sub-group 3 in Fig. 7), and was well separated from the African Atlantic Ocean probably due to the subtropical conditions in both areas.

The locations LE, AD, IO, NE, AE, NWM, and BI all corresponded to geographical areas sharing strong connections; however, within this group,the Levantine Sea (LE) represented specific areas of the eastern Mediterranean Sea influenced by species originating from the Red Sea and Indo-Pacific (via the Suez Canal). Within the Mediterranean Sea as a whole, a large number of NNS had been found in the Levantine Sea (Zenetos *et al*., 2017).

The adjoining Adriatic and Ionian seas displayed closer similarities than between other Mediterranean areas of the second defined group (Fig. 7). The AE, NWM and BI areas in the Mediterranean Sea all showed strong similarities with the European North-Eastern Atlantic and African Atlantic coasts. The bay at Bou Ismail also displayed a close similarity with the NWM area, which was to be expected since both areas correspond to the western Mediterranean basin.

Finally, the range of Mediterranean fauna displayed strong similarities with that in the Atlantic (both the European and African coasts); moreover, the fauna found in the bay of Bou Ismail was closer to that found in European rather than African coasts. Overall, the western Mediterranean (except the Alboran Sea) shared more than 60% of species with the eastern Mediterranean Sea.

4.3. Towards a conservation status for the benthic communitiesof the bay of Bou Ismail

It is worth revisiting the Bay of Bou Ismail with a similar sampling design, in order to assess the changes with time in this highly diversified sea soft-bottom environment in the context of the effect of climate change and increase of human activities on the shallow coastal ecosystems of the Mediterranean Sea. Moreover, in spite of the high diversity of marine organisms, only a few Marine Protected Areas had been recognized in the Mediterranean Sea, most of them being found off the coasts of European countries. Nevertheless, in the framework of the Barcelona convention, efforts had been made in recent years to map key marine habitats across the Mediterranean Sea and to promote their conservation through the establishment of Specially Protected Areas of Mediterranean Importance (SPAMI)(http://rac-spa.org/medkeyhabitats). The targeted habitats correspond mostly to hard substratum, bio-constructed formations and seagrass meadows, particularly *Posidonia oceanica* beds. Such policies have been implemented, for example, in the western sector of the Algerian coast around the Habibas and Rachgoun Islands (http://www.racspa.org/sites/default/files/doc_mkh/algeria/ile_de_rachgoun_cartographie_habitats_marins_cles.pdf).

An objective approach was proposed by Altobelli *et al*. (2017) which was to identify Ecologically or Biologically Significant Marine Areas (EBSA) associated with a biodiversity hotspot off the coast of Sicily (Italy) that was under threat. The related methodology took into account the biological and ecological value of a community using the presence/absence indicators relating to the Convention on Biological Diversity (CBD) and human pressures.

This approach should be developed in other areas of the Mediterranean Sea where biodiversity hotspots had been identified. The soft-bottom communities in the bay of Bou Ismail could be a good candidate to apply this methodology. The main human pressure on the soft-bottom communities of this part of the Algerian coastline rose from the intensive trawling activity. Moreover, a study of the structure of the seven identified soft-bottom communities should be undertaken to re-evaluate the first synoptic mapping of these benthic communities carried out at the end of the 1980s. Furthermore, the ecological status of two special communities, i.e. *Posidonia oceanica* meadows and 'gravelle de Castiglione' (*Branchiostoma* community of the Coastal Detritic with maerl), should be updated as soon as possible to facilitate measures for the immediate preservation of this exceptional soft-bottom macrobenthos in the bay of Bou Ismail.

Acknowledgements

The authors would like to thank the crew of the oceanographic vessel, the M.S. Benyahia for their help during the sampling campaigns. The authors also wish to acknowledge the contribution received from S. Alizier, T. Ruellet and S. Andres with respect to setting up the database, data analyses and preparation of the figures. Finally, the authors are grateful to Michel Carpenter for his correction of the original English manuscript and Colin Burton for his correction on the last version of the text.

References

Aït Kaci, A.D., Pauc, H., 1983a. La couverture sédimentaire récente en baie de Bou- Ismaïl. Nature et structure. Pelagos 28, 203 - 204.

Aït Kaci, A.D., Pauc, H., 1983b. La sédimentation en baie de Bou - Ismaïl et les apports en suspension de l'oued Mazafran. Variations saisonnières. Pelagos 28, 255 - 256.

Altobelli, C., Perzia, P., Falautano, M., Consoli, P., Canese, S., Romeao, T., Andoloro, F., 2017. Mediterranean banks in EBSA area: Hospots of biodiversity under threat. Mar. Env. Res. 131, 57-68.

Arvanitidis, C., Bellan, G., Drakopoulos, P., Valavanis, V., Dounas, C., Koukouras, A., Eleftheriou, A., 2002. Seascape biodiversity patterns along the Mediterranean and the Black Sea: lessons from the biogeography of benthic polychaetes. Mar. Ecol. Progr. Ser. 244, 139-152.

Ayari, R., Afli, A., 2003 Bionomie benthique du petit golfe de Tunis. Bull. Inst. Natn. Scien. Tech. Mer de Salammbô, 30, 79-90.

Bakalem, A., 2008. Les peuplements des sables fins de la côte Algérienne. Thèse de Doctorat d'Etat, option Océanographie Biologique, Faculté des Sciences Biologiques, Université des Sciences et de la Technologie Houari Boumediene (USTHB), Alger, Algérie (www.unicaen.fr/m2c/IMG/pdf/bakalem_ali_these_2008.pdf).

Bakalem, A., Dauvin, J.C., 1995. Inventaire des Crustacés Amphipodes (Gammaridea Caprellidae, Hyperiidea) des côtes d'Algérie : Essai de synthèse. Mésogée 54, 49-62.

Bakalem, A., Ruellet, T., Dauvin, J.C., 2009. Benthic indices and ecological quality of shallow Algeria fine sand community. Ecol. Ind. 9, 395-408.

Bonifácio, P., 2015. Study of the present state and of recent temporal changes in the benthic macrofauna composition of Gulf of Lions soft-bottom macrobenthic communities, NW Mediterranean. PhD Université de Bordeaux, France.

Borja, A., Franco, J., Perez, V., 2000. A marine biotic index to the establish ecology quality of soft-bottom benthos within European estuarine coastal environments. Mar. Poll. Bull. 40, 1100-1114.

Borja, A., Muxika, I., 2005. Guidelines for the use of AMBI (AZTI's Marine Biotic Index) in the assessment of the benthic ecological quality. Mar. Poll. Bull. 50, 787-789.

Boudjellal, B., Ferhat, N., Djillali, M., Azzouz, M., 1995. Heavy metals in the superficiel sediments of Bou Ismail Bay. Rapp. Comm. Inter. Mer Medit., 33, 134

Boumaza S., 1995. Phénologie, biomasse, lépidochronologie et production de l'herbier à *Posidonia oceanica* (L) Delile de l'Anse de Kouali, Tipaza (Algérie). Thèse de Magistère, ISMAL, Alger.

Braik, D., 1989. Etude de la dynamique sédimentaire devant Bou-Ismaïl. Sédimentologie, morphologie. Problème d'érosion du littoral. Aménagement. Thèse de Magistère, IST, USTHB, Alger, Algérie.

Chassé, C., Glémarec, M., 1976. Principes généraux de la classification des fonds pour la cartographie biosédimentaire. J. Rech. Oceanogr., 1, 1-12.

Clarke, KR, Gorley, RN., 2006. PRIMER V6: User Manual/Tutorial. PRIMER-E. Plymouth.

Coll, M., Piroddi, C., Steenbeek, J., Kaschner, K., Ben Rais Lasram, F. et al. 2010. The Biodiversity of the Mediterranean Sea: Estimates, Patterns, and Threats. PLoS ONE 5(8):e11842. doi:10.1371/journal.pone.0011842.

Coll, M., Piroddi, C., Albouy, C., Ben Rais Lasram, F., Cheung, W.W.L., Christensen, V., Karpouzi, V.S., Guilhaumon, F., Mouillot, D., Paleczny, M., Palomares, M.L., Steenbeek, J., Trujillo, P., Watson, R., Pauly, D., 2012. The Mediterranean Sea under siege: spatial overlap between marine biodiversity, cumulative threats and marine reserves. Global Ecol. Biogeogr. 21, 465-480.

Dagorne, A., 1970. Remarques préliminaires sur la sédimentation prélittorale en Baie de Bou-Ismail. Ann. Alger. Géog., 7, 73- 78.

de-la-Ossa-Carretero, J.A., Dauvin, J.C., 2010. A comparison of two biotic indices, AMBIand BOPA/BO2A, for assessing the Ecological Quality Status (EcoQS) of benthic macro-invertebrates. Transit. Waters Bull. 4, 12-24.

Dauvin, J.C, Alizier, S., Rolet, C., Bakalem, A., Bellan, G., Gomez Gesteira, J.L., Grimes, S., De-La-Ossa-Carretero, J.A., Del-Pilar-Ruso,Y., 2012. Response of the different indices to the diverse human pressures. Ecol. Ind. 12, 143-153.

Dauvin, J.C., Grimes, S., Bakalem, A., 2013.Marine Biodiversity on the Algerian Continental Shelf (Mediterranean Sea).J. Nat. Hist.47, 1745-1765.

Dauvin, J.C., Andrade, H., de-la-Ossa-Carretero, J.A., Del Pilar Ruso, Y., Riera, R., 2016. Polychaete/Amphipod ratios: an approach to validating simple benthic indicators. Ecol. Ind. 63, 89-99.

Dauvin, J.C., Bakalem, A., Baffreau, A., Bellan, G., Lardicci, C., Sarda, R., Grimes, S., 2017a. The well sorted fine sand community from the western part of the Mediterranean Sea: a marine habitat under diverse human pressures. Environ. Poll. 224, 336-351.

Dauvin, J.C., Bakalem, A., Baffreau, A., Grimes, S., 2017b. Benthic ecological status of Algerian harbours. Mar. Poll. Bull. 125, 378-388.

Desbruyères, D., Guille, A., Ramos, J., 1973. Bionomie benthique du plateau continental de la côte catalane espagnole. Vie et Milieu 23, 335-363.

Devries, A., 1957. Sur quelques Echinides Réguliers de la baie de Castiglione. Bull. Stat. Aquic. Pêche, Castiglione n.s. 9, 73-100.

Dieuzeïde, R., 1933. Les Echinides réguliers de la baie de Castiglione. Bull. Stat. Aquic. Pêche, Castiglione 2, 73-79.

Dieuzeïde, R., 1940. Etude d'un fond de pêche d'Algérie : la gravelle de Castiglione.Bull. Stat. Aquic. Pêche, Castiglione n.s., 1, 37-57.

Dieuzeïde, R., 1950. La faune du fond chalutable de la baie de Castiglione. Bull. Sta. Aquic. et Pêche, Castiglione n.s. 2, 11-85.

Dieuzeïde, R., 1954. Recherche sur les fonds chalutables de la région d'Alger. Notes faunistiques sur la zone méso-abyssale. Comité Local d'Océanographie et d'Etude des côtes d'Algérie, 78-81.

Dieuzeïde, R., Roland, J., 1957. Répartition bathymétrique de la faune des fonds chalutables des côtes d'Algérie. Bull. Sta. Aquic. Pêche, Castiglione n.s. 9, 50-69.

Dieuzeïde, R., Goëau-Brissonière, W., 1951. Les prairies de zostères naines et de Cymodocées (mattes) aux environs d'Alger. Bull. Stat. Aquic. Pêche, Castiglione n.s. 3, 11-53.

Escaravage, V., Herman, P.M.J., Merckx, B., Wlodarska-Kowalczuk, M., Amouroux, J.M., Degraer, S., Grémare, A., Heip, C.H.R., Hummel, H., Karakassis, I., Labrune, C., Willems, W., 2009. Distribution patterns of macrofaunal species diversity in subtidalsoft sediments: biodiversity–productivity relationshipsfrom the MacroBen database. Mar Ecol Prog Ser. 382, 253-264.

Falconetti, C., 1970. Etude faunistique d'un faciès : la ''Gravelette'' ou maërl de Castiglione (Algérie). Tethys 1, 1057-1096.

Folk, R.L., 1954. The distinction between grain size and mineral composition in sedimentary rock nomenclature. J. Geol., 62, 344-356.

Folk, R.L., 1965. Petrology of sedimentary rocks. Hemphill's, Austin, Texas, USA.

Gauthier, Y., 1955. Bryozoaires de Castiglione. Bull. Stat. Aquic. Pêche, Castiglione n.s, 7,223-271.

Glémarec, M., 1969. Les peuplements benthiques du plateau continental Nord Gascogne. Thèse Doc. Etat, Sci. Nat., Univ. Paris, France.

Glémarec, M., 1971. L'endofaune du plateau continental Nord-Gascogne. Etude des facteurs écologiques. Vie Milieu, suppl. 22, 93-108.

Glémarec, M., 1973. The benthic communities of the European north Atlantic continental shelf. Oceanogr. Mar. Biol. Ann. Rev., 11, 263-289.

Grimes, S., Dauvin, J.C., Ruellet, T., 2009. New records of marine amphipod fauna (Crustacea: Peracarida) on the Algerian coast. J. Mar. Biol. Ass. UK 2 – Mar. Biodiv. Rec. e134, 1-9.

Grimes, S. 2010. Les peuplements macrobenthiques des substrats meubles algériens: organisation et structure. Thèse de Doctorat d'Etat, Université Es Sénia, Oran, Algeria.

Grimes, G., Bakalem, A., Dauvin, J.C., 2016.Annotated checklist of marine Algerian Crustacean Decapods. Mediter. Mar. Sci. 17, 384-395.

Grimes, S., Benardi, M., Bbali, N., Refes, W., Boudjellal-Kaidi, N., Seridi, H., 2018. Biodiversity changes along the Algerian coast (Southwestern Mediterranean basin) from 1834 to 2017. First assessment of introduced species. Med. Mar. Sci. 19, 146-179.

Grovel A., 1961. Recherches sédimentologiques en baie d'Alger. Thèse 3e cycle, Université d'Alger.

Guille, A., 1970. Bionomie benthique du plateau continental de la côte catalane française. II. Les communautés de la macrofaune. Vie et Milieu 21, 137-280.

Guille, A., 1971. Bionomie benthique du plateau continental de la côte catalane française. IV- Densité, biomasses et variations saisonnières de la macrofaune. Vie et Milieu, 22, 93-158

Hassam, N., 1991. Contribution à l'étude des peuplements macrobenthiques de la baie de Bou-Ismail : le secteur Est. Thèse de Magistère en océanographie Biologique, ISMAL, Alger, Algérie.

Karakassis, I., Eleftheriou, A., 1997. The continental shelf of Crete: structure of macrobenthic communities. Mar. Ecol. Prog. Ser. 160, 185-196

Labrune, C., Amouroux, J.M., Sarda, R., Dutrieux, E., Thorin, S., Rosenberg, R., Grémare, A., 2006. Characterization of the ecological quality of the coastal Gulf of Lions (NW Mediterranean). A comparative approach based on three biotic indices. Mar. Pollut. Bull.52, 34-47.

Labrune, C., Grémare, A., Amouroux, J.M., Sardá, R., Gil, J., Taboada, S., 2008. Structure and diversity of shallow soft-bottom benthic macrofauna in the Gulf of Lions (NW Mediterranean). Helgol. Mar. Res. 62, 201-214.

Le Danois, E., 1925. Recherches sur les fonds chalutables des côtes de Tunisie et d'Algérie en 1924. Mém. Off. Sci. Techn. Pêches marit. 3, 1655.

Le Gall, J.Y., 1969. Etude de l'endofaune des pelouses de Zostéracées superficielles de la baie de Castiglione. Téthys 1, 395-420.

Leclaire, L., 1972. La sédimentation holocène sur le versant méridional du bassin algéro-baléares (Précontinent algérien).Mém. Mus. Natn. Hist. Nat., Paris, C 24, 1-391.

Millot, C., 1999. Circulation in the western Mediterranean Sea. J. Mar. Syst. 20, 423-442.

Millot, C., Taupier-Letage, I., Benzohra, M., 1990. The Algerian eddies. Earth-Sci. Reviews 27, 203-209.

Millot, C, Taupier-Letage, I., 2005. Additional evidence of LIW entrainment across the Algerian subbasin by mesoscale eddies and not by a permanent westward flow. Prog. Oceanogr. 66, 231-250.

Molinier, M., Picard, J., 1952. Etudes biologiques sur les herbiers de Phanérogames marines à l'Ouest d'Alger. Bull. Stat. Aquic. Pêche, Castiglione n.s. 4, 335-362.

Moulfi, A., 1995. Les mécanismes de la sédimentation et les propriétés géotechniques des dépôts récents de la partie occidentale de la baie de Bou-Ismail (Ouest Algérois). Thèse de Magistère, IST, USTHB, Alger.

Oulmi, Y., 1991. Contribution à l'étude des peuplements macrobenthiques de la baie de Bou-Ismail : le secteur Ouest. Thèse de Magistère en océanographie Biologique, ISMAL, Alger, Algérie.

Pérès, J.M., 1952. Notes sur les fonds de gravelle dans la région de Marseille comparés à ceux d'Algérie. Vie et Milieu 2 (Suppl.), 208-216.

Pérès, J.M., Picard, J., 1964. Manuel de bionomie benthique de la mer Méditerranée. Rec. Trav. Stat. Mar. Endoume, 31, 5-137.

Picard, J., 1955. Hydraires des environs de Castiglione. Bull. Stat. Aquic. Pêche, Castiglione n.s. 7, 179-199.

Picard, J., 1965. Recherches qualitatives sur les biocénoses marines des substrats meubles dragages de la région marseillaise. Rev. Trav. Stat. Mar. Endoume 36, 1-160.

Revkov, N.K., Nikolaenko, T.V. 2002. Biodiversity of Zoobenthos in the Coastal Zone of the South Coast of Crimea (Laspi Bay Area) Russ. J. Mar. Biol. 28, 151-162.

Sellali, B., 1996. La pollution par les hydrocarbures pétroliers en Méditerranée Sud. Occidentale : niveaux de contamination de l'eau et du sédiment superficiel des régions littorales Centre et Ouest de l'Algérie. Thèse de Magistère, ISMAL, Bou Ismail, Alger, Algérie.

Seurat, L.G., 1932. Sur la présence de l'*Astropartus arborecescens* Rond. dans la baie de Castiglione. Bull. Stat. Aquic. Pêche Castiglione 2, 135-142.

Vaissière, R., Fredj, G., 1963. Contribution à l'étude de la faune benthique du plateau continental de l'Algérie. Bull. Inst. Océanogr. Monaco 60, 5-83.

Vincent, C., Heinrich, H., Edwards, A., Nygaard, K., Haythornthwaite, J., 2002. Guidance on typology, references conditions and classification systems for transitional and coastal waters, CIS Working Group 2.4 (Coast) Common Implementation Strategy of the Water Framework Directive, European Commission, pp. 119.

Zavodnik, D., Vidakovic, J., 1987. Report on bottom fauna in two northern Adriatic areas presumed to be influenced by inputs. FAO Fish. Rep., 352 (suppl.), 263-279.

Zavodnik, D., Vidakovic, J., Amoureux L., 1985. Contribution to sediment macrofauna in the area of Rovinj (North Adriatic Sea). Cah. Biol. Mar. 26, 431-444.

Zenetos, A., Christianidis, S., Pancucci, M.A., Simboura, N., Tziavos, C., 1996. Oceanology study of an open coastal area in the Ionian Sea with emphasis on its benthic fauna and some zoogeographical remarks. Oceanol. Acta 20, 2, 437-451.

Zenetos, A., Çinar, M.E, Crocetta, F., Golani, D., Rosso, A., Servello, G., Shenkar, N., Turon, X., Verlaque, M. 2017. Uncertainties and validation of alien species catalogues:the Mediterranean as an example. Estuar. Coast. Shelf Sci. 191, 171-187.

Figure captions

Fig. 1. The spatial distribution of the seven benthic communities identified in the bay of Bou Ismail.

Fig. 2. The spatial distribution of *Branchiostoma lanceolatum* (Pallas, 1774), *Ophiacantha setosa* (Bruzelius, 1805) for the Coastal Detritic community, and *Gammaropsis maculata* and *Othomaera knudseni* (Reid, 1951) for the Gravely Sand community.

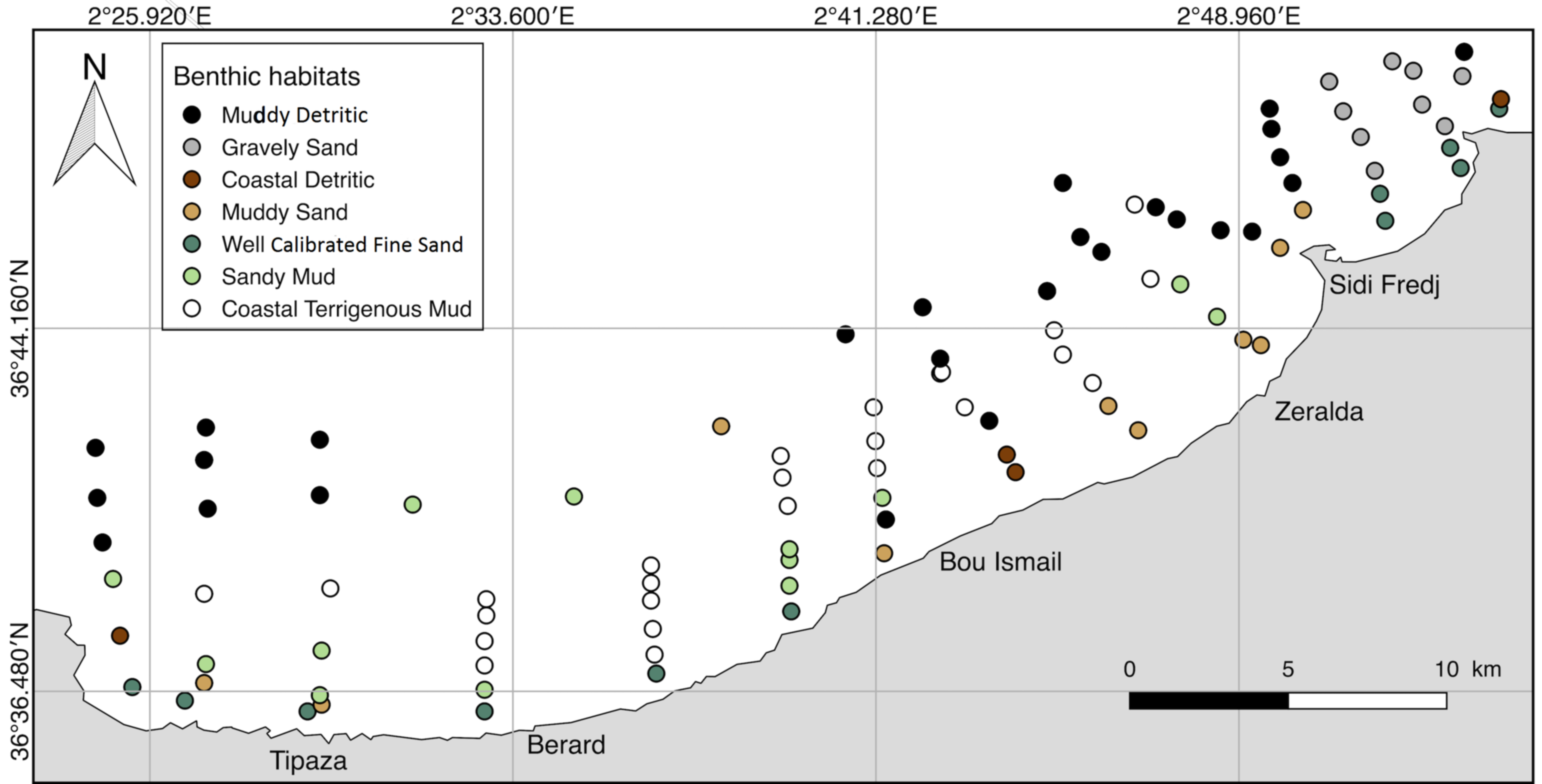
Fig. 3. The spatial distribution of *Apseudopsis mediterraneus* (Bacescu, 1961), *Ampelisca brevicornis* (Costa, 1853) for the Well Calibrated Fine Sand community,and *Atlantella pulchella* (Lamarck, 1818) and *Urothoe grimaldii* Chevreux, 1895 for the Muddy Sand community.

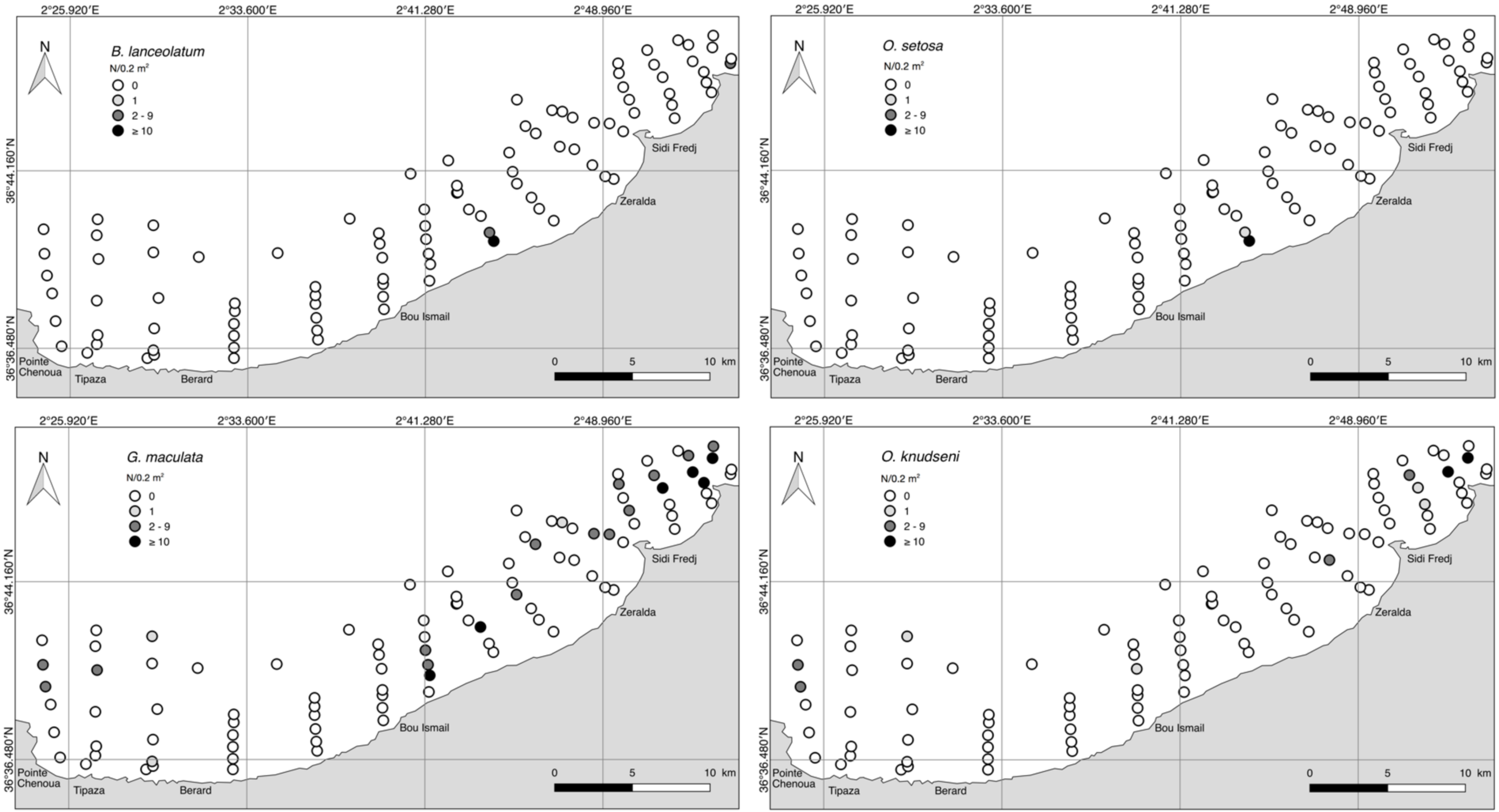
Fig 4. The spatial distribution of *Nucula sulcata*Bronn, 1831, *Amphiura chiajei* Forbes, 1843 for the Sandy Mud community,and *Paraprionospio pinnata* (Ehlers, 1901)and *Oestergrenia digitata* (Montagu, 1815) for the Coastal Terrigenous Mud community.

Fig. 5. The spatial distribution of *Othomaera othonis* (H. Milne Edwards, 1830) and *Terebellides stroemii* Sars, 1835 for the Muddy Detritic community.

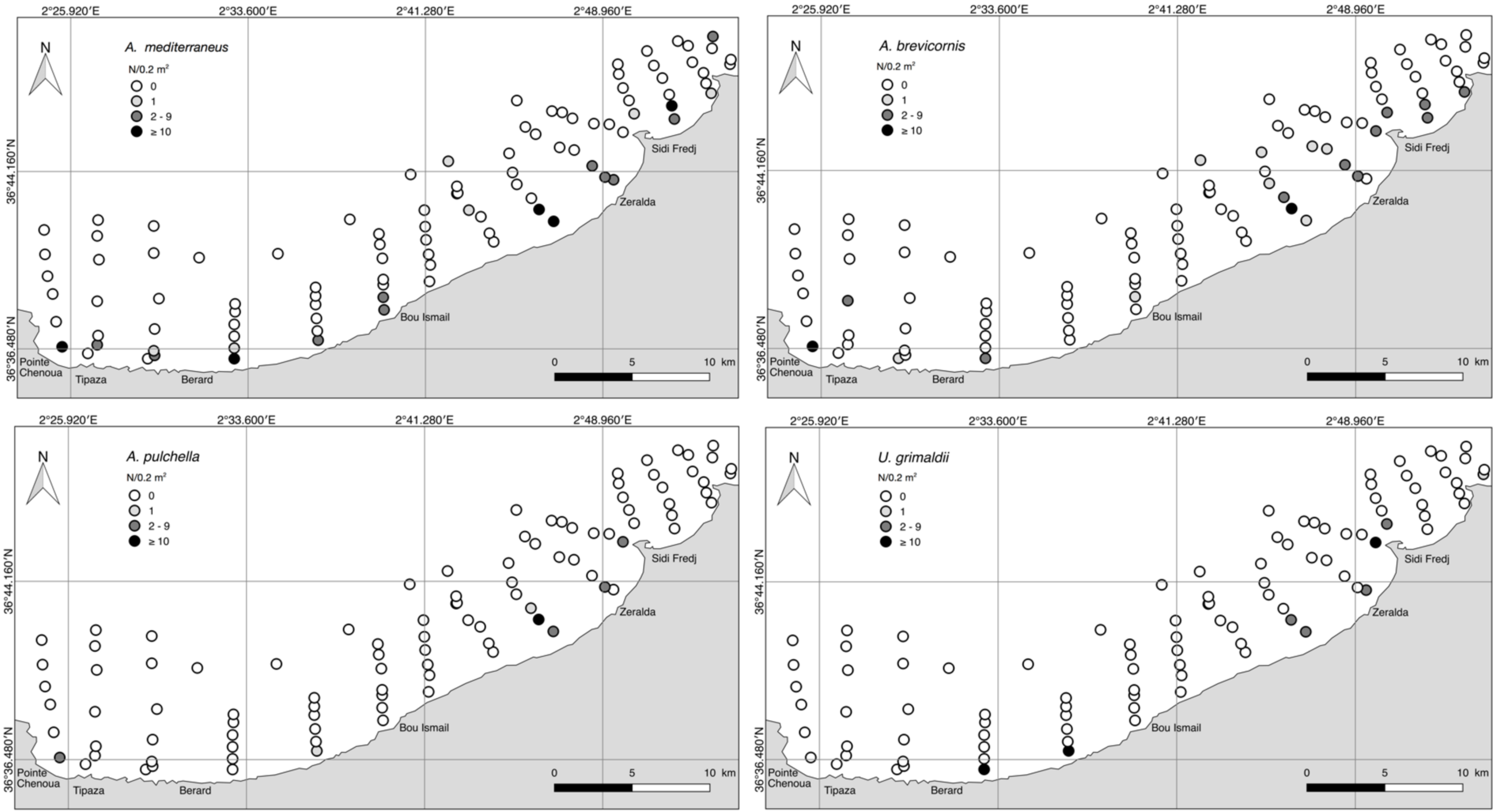
Fig. 6. The spatial distribution of indices of diversity at the 98 sampling points across the bay of Bou Ismail: the number of taxa per 0.2 m^2, the abundance per 0.2 m^2, the Shannon-Wiener diversity, the $ES_{(50)}$, the AMBI and BO2A.

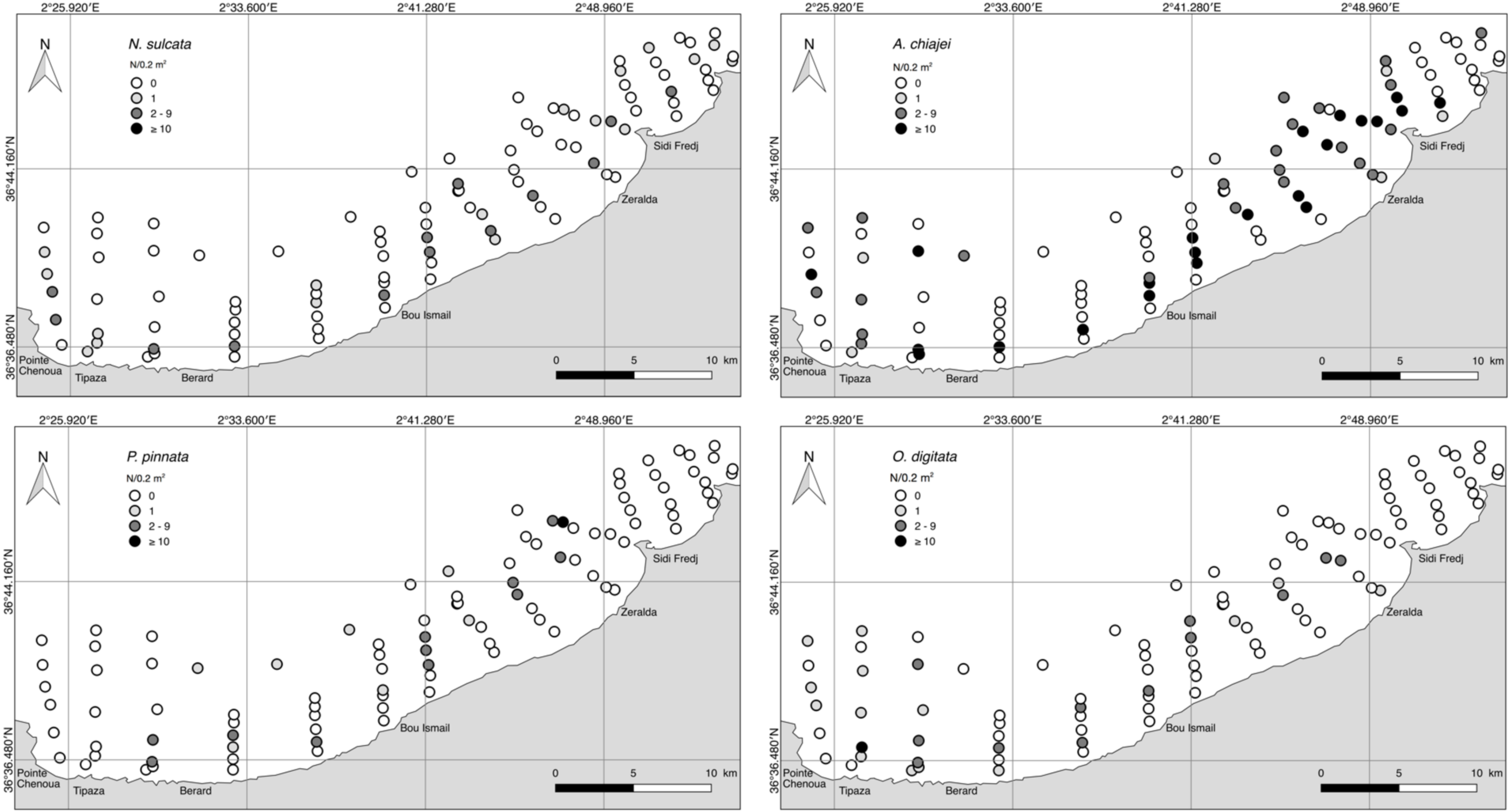
Fig. 7. Results of a cluster analysis (based on the Sørensen similarity) on species present and absence, in 13 geographical coastal regions.AD: Adriatic Sea, AE: Aegean Sea, AL: Alboran Sea, IO: Ionian Sea, LE: Levantine Sea, NWM: North-western Mediterranean, TL: Tunisian and Libyan continental shelf, BI: the bay of Bou Ismail, BS: Black Sea, NE: North-eastern Atlantic European waters; IP: Indo-Pacific; RS: Red Sea and AA: African Atlantic Coast (extending from Cap Spartel to Cap Blanc).


2°25.920′E
2°33.600′E
2°41.280′E
2°48.960′E
36°44.160′N
36°36.480′N
N
Benthic habitats
Muddy Detritic
Gravely Sand
Coastal Detritic
Muddy Sand
Well Calibrated Fine Sand
Sandy Mud
Coastal Terrigenous Mud
Sidi Fredj
Zeralda
Bou Ismail
Berard
Tipaza
0
5
10 km

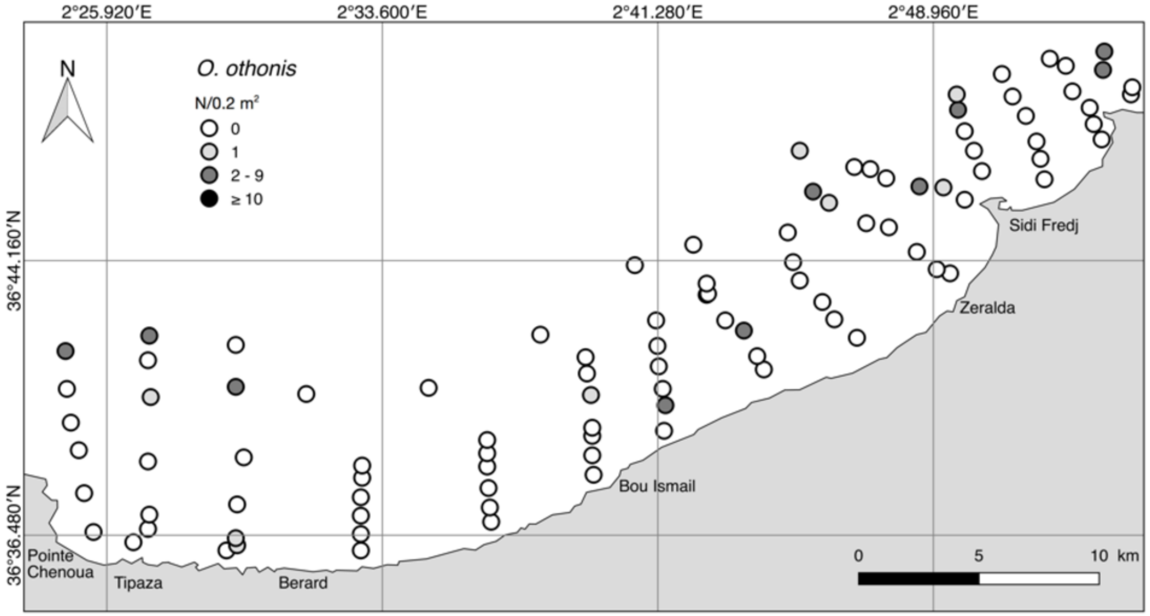


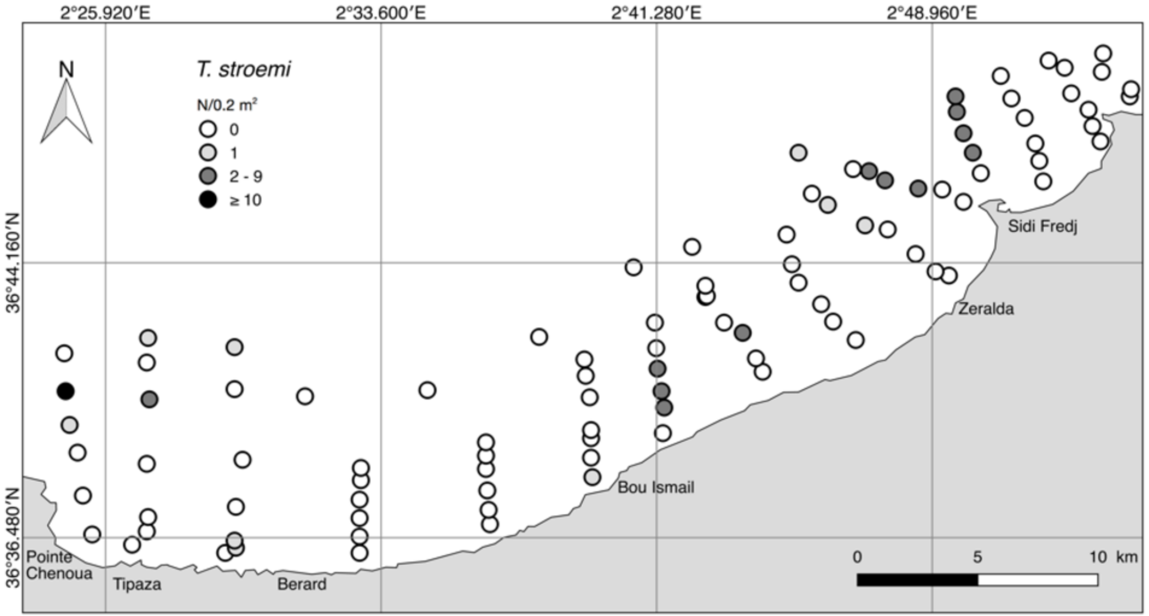
B. lanceolatum
O. setosa
G. maculata
O. knudseni
N/0.2 m²
0
1
2 - 9
≥ 10
N
2°25.920′E
2°33.600′E
2°41.280′E
2°48.960′E
36°44.160′N
36°36.480′N
Sidi Fredj
Zeralda
Bou Ismail
Pointe Chenoua
Tipaza
Berard
0
5
10 km

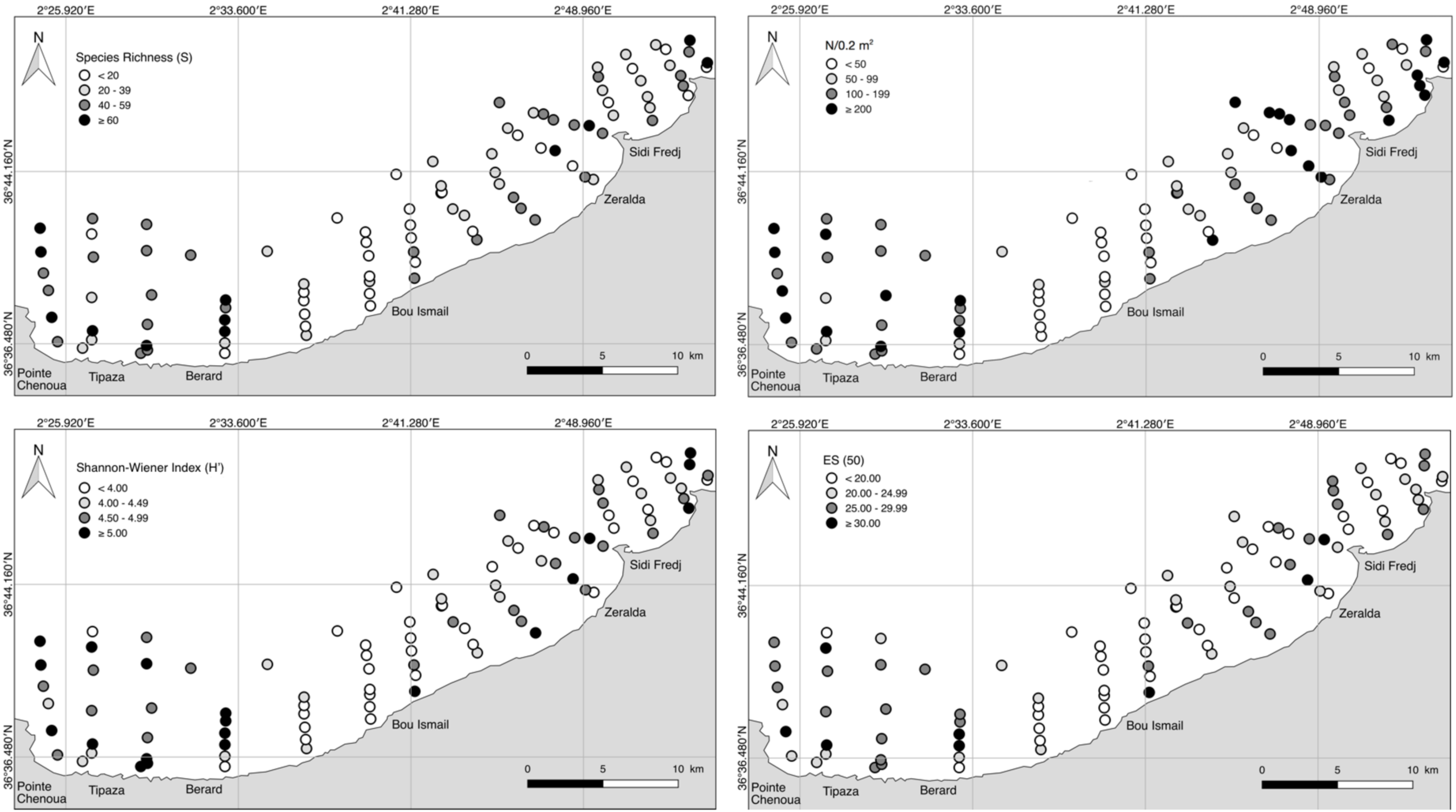

A. mediterraneus
A. brevicornis
A. pulchella
U. grimaldii
N/0.2 m²
0
1
2 - 9
≥ 10
N
2°25.920′E
2°33.600′E
2°41.280′E
2°48.960′E
36°44.160′N
36°36.480′N
Sidi Fredj
Zeralda
Bou Ismail
Pointe Chenoua
Tipaza
Berard
0
5
10 km



2°25.920′E
2°33.600′E
2°41.280′E
2°48.960′E
36°44.160′N
36°36.480′N
N. sulcata
A. chiajei
P. pinnata
O. digitata
N/0.2 m²
0
1
2 - 9
≥ 10
N
Sidi Fredj
Zeralda
Bou Ismail
Pointe Chenoua
Tipaza
Berard
0
5
10 km


2°25.920′E
2°33.600′E
2°41.280′E
2°48.960′E
N
O. othonis
N/0.2 m²
0
1
2 - 9
≥ 10
36°44.160′N
36°36.480′N
Sidi Fredj
Zeralda
Bou Ismail
Pointe Chenoua
Tipaza
Berard
0
5
10 km


2°25.920′E
2°33.600′E
2°41.280′E
2°48.960′E
N
T. stroemi
N/0.2 m²
0
1
2 - 9
≥ 10
36°44.160′N
36°36.480′N
Sidi Fredj
Zeralda
Bou Ismail
Pointe Chenoua
Tipaza
Berard
0
5
10 km


2°25.920′E
2°33.600′E
2°41.280′E
2°48.960′E
36°44.160′N
36°36.480′N
N
Species Richness (S)
< 20
20 - 39
40 - 59
≥ 60
Sidi Fredj
Zeralda
Bou Ismail
Pointe Chenoua
Tipaza
Berard
0
5
10 km
N/0.2 m²
< 50
50 - 99
100 - 199
≥ 200
Shannon-Wiener Index (H')
< 4.00
4.00 - 4.49
4.50 - 4.99
≥ 5.00
ES (50)
< 20.00
20.00 - 24.99
25.00 - 29.99
≥ 30.00

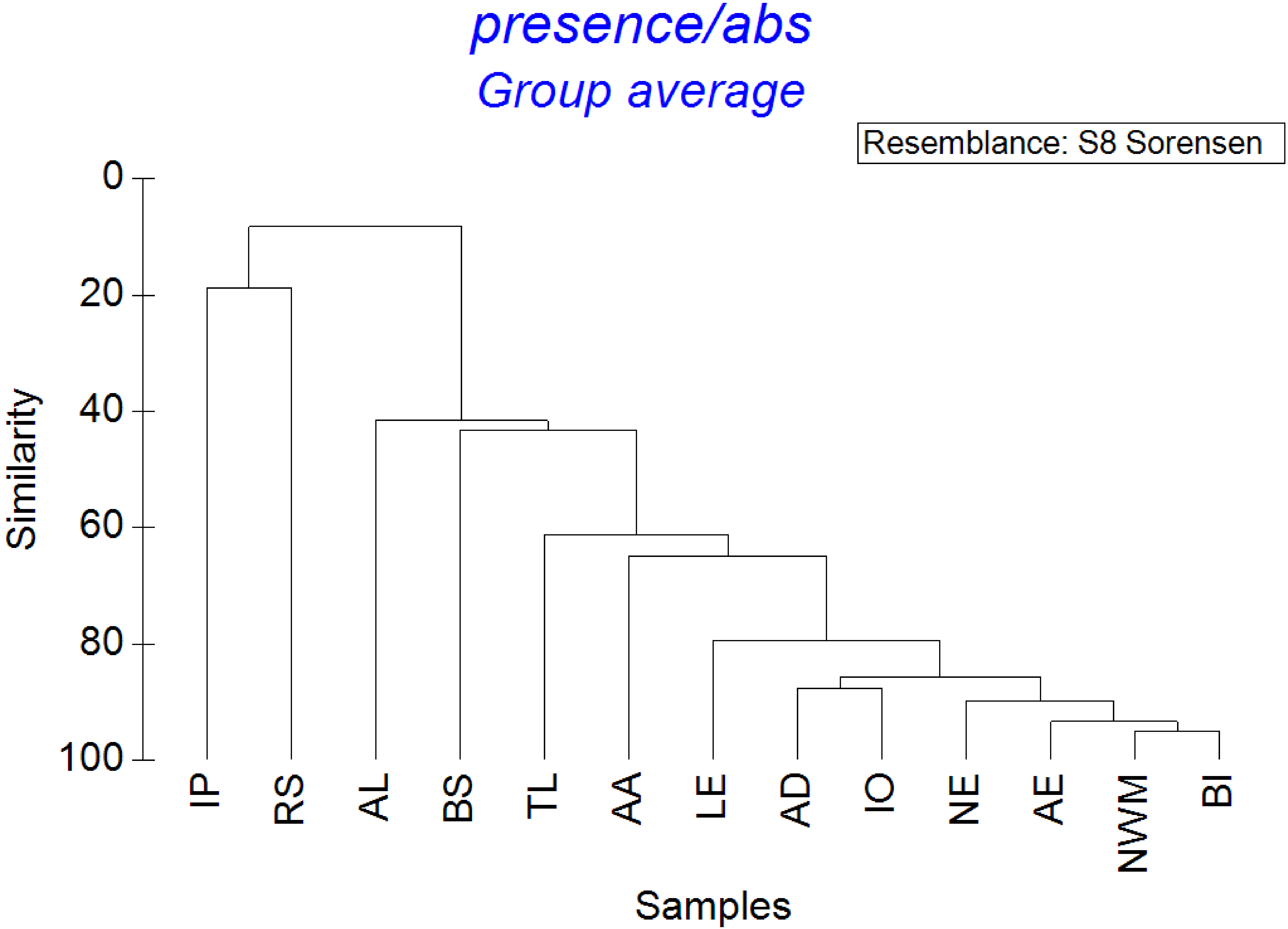

presence/abs
Group average
Resemblance: S8 Sorensen
Similarity
0
20
40
60
80
100
IP
RS
AL
BS
TL
AA
LE
AD
IO
NE
AE
NWM
BI
Samples

Table 1. Mean values of species richness (S), abundance (N), diversity indices (Shannon-Wienerr, Pielou' evenness J', and ES$_{(50)}$) for 0.2 m^2; mean values of AMBI and BO2A and their corresponding Ecological Statuses for the seven habitats of the Bay of Bou Ismail. All values are given with their SD (standard deviation). EcoQS: Ecological Quality Status from Borja et al. (2000) for AMBI and Dauvin et al., (2016) for BO2A.

Benthic habitats	**S ± SD**	**N ± SD**	**H'(log2) ± SD**	**J' ± SD**	**ES$_{(50)}$ ± SD**	**AMBI ± SD**	**EcoQS**	**BO2A ± SD**	**EcoQS**
Muddy Detritic	59.27 ± 18.84	206.12 ± 81.25	4.98 ± 0.46	0.86 ± 0.04	26.92 ± 3.32	1.17 ± 0.27	High	0.009 ± 0.006	High
Gravely Sand	44.33 ± 30.81	200.33 ± 169.31	4.20 ± 0.93	0.80 ± 0.10	21.22 ± 5.45	0.95 ± 0.34	High	0.003 ± 0.004	High
Coastal Detritic	56.25 ± 28.91	268.25 ± 278.00	4.50 ± 0.97	0.80 ± 0.07	23.89 ± 5.51	1.45 ± 0.30	Good	0.009 ± 0.009	High
Muddy Sand	51.10 ± 27.54	240.80 ± 138.45	4.18 ± 1.15	0.76 ± 0.17	21.74 ± 6.51	1.26 ± 0.35	Good	0.008 ± 0.005	High
Well Calibrated Fine Sand	35.82 ± 17.20	109.18 ± 48. 53	4.21 ± 0.87	0.84 ± 0.08	22.71 ± 6.94	1.14 ± 0.25	High	0.008 ± 0.009	High
Sandy Mud	31.15 ± 13.32	109.46 ± 47.82	3.93 ± 1.03	0.80 ± 0.15	20.30 ± 6.62	1.578 ± 0.51	Good	0.024 ± 0.21	Good
Coastal Terrigenous Mud	20.80 ± 12. 27	51.72 ± 38.96	3.65 ± 0.77	0.88 ± 0.07	17.14 ± 6.51	1.72 ± 0.39	Good	0.027 ± 0.021	Good

Table 2. Results of the ANOVA test. CD: Coastal Detritic; MD: Muddy Detritic; GS: Gravelly Sand; WCFS: Well Calibrated Fine Sand; SM: Sandy Mud; MS: Muddy Sand; CTM: Coastal Terrigenous Mud

	Factors	Chi-Squared	df	p-value	Post-hoc test
N	Benthic habitats	46.92	6	< 0.001	CTM ≠ MD, SM, GS
S	Benthic habitats	45.44	6	< 0.001	MD ≠ CTM, SM
ES(50)	Benthic habitats	30.89	6	< 0.001	MD ≠ CTM, SM
H'	Benthic habitats	33.20	6	< 0.001	MD ≠ CTM, SM
J'	Benthic habitats	13.23	6	> 0.05	-
AMBI	Benthic habitats	40.08	6	< 0.001	CTM ≠ MD, WCFS, GS ; SM ≠ GS
BO2A	Benthic habitats	33.98	6	< 0.001	CTM ≠ MD, WCFS, GS ; SM ≠ GS

Table 3. Number of species per sampling area classified according to their biogeographical origin. AD: Adriatic Sea, AE: Aegean Sea, AL: Alboran Sea, IO: Ionian Sea, LE: Levantine Sea, NWM: north-western Mediterranean, TL: Tunisian and Libya shelf, BI: Bou Ismail Bay in the south-western Mediterranean, BS: Black Sea, NE: North-Eastern Atlantic European waters, IP: Indo-Pacific; RS: Red Sea and AA: African Atlantic Coast (from Cap Spartel to Cap Blanc). eam (Mediterranean, European and African Atlantic species), em (Mediterranean and European Atlantic species), am (Mediterranean and African Atlantic coast species), e (endemic species), mr (Mediterranean and Red Sea species), c (cosmopolitan species), emr (Mediterranean, European Atlantic and Red Sea species), emip (Mediterranean, European and Indo-Pacific species) and mrip (Mediterranean, Red Sea and Indo-Pacific species).

Species origin	AA	NE	AL	**BI**	NWM	IO	AD	TL	AE	LE	BS	RS	IP
eam	289	289	103	**289**	273	245	247	158	276	223	89	-	-
em	-	286	42	**286**	245	191	200	89	246	147	60	-	-
am	12	-	8	**12**	11	9	10	4	10	9	4	-	-
e	-	-	15	**88**	83	47	47	20	65	52	9	-	-
mr	-	-	-	**1**	-	-	-	-	1	-	-	1	-
c	33	41	14	**42**	39	35	38	32	41	36	20	14	32
emr	-	3	-	**3**	3	1	3	3	3	1	1	3	-
emip	-	1	-	**1**	1	1	-	-	1	1	1	-	1
mrip	-	-	-	**1**	-	-	-	-	-	-	-	1	1
Total number	334	620	182	**723**	655	529	545	306	643	469	184	19	34

Table 4. Comparison of TTN: Total Taxonomic Number (in bold type) and abundance per 1m² for the seven benthic communities found in the Bay of Bou Ismail and other areas of the Mediterranean Sea. SS: Sampling Surface area; QS: Qualitative Samples, unknown sampling surface area. MD: Muddy Detritic. GS: Gravelly Sand; CD: Coastal Detritic; MS: Muddy sand; WCFS: Well Calibrated Fine Sand; SM: Sandy Mud and CTM: Coastal terrigenous mud. Bold: number of species; plain: abundance per m².

Author	Area	SS in m²	TTN	Number of species and/or abundance per 1 m² per community						
				WCFS	CD	MD	CTM	MS	SM	GS
This study	Bou Ismail Bay, Algeria	19.6	**840**	**303** 545	**216** 1380	**479** 1030	**226** 258	**337** 1200	**213** 547	**266** 1000
Picard, 1965	Marseilles, France	QS	**607**	**128**	**328**	**176**	**109**	-	-	-
Guille, 1970	French Catalan coast	QS + 6	**715**	**205** 508	-	-	**175** 227	**269** 529	**161** 626	**326** 242
Desbruyères et al., 1973	Spanish Catalan coast	14.4	**501**	**199** 1960	-	-	**281** 510	**140** 820		**274** 1438
Zavodnik and Vidakovic, 1987	North Adriatic	3	**156**	-	-	-	**119** 844	**122** 1090	**56** 100	-
Zavodnik et al., 1985	North Adriatic	7.4	**167**	**84** 2115	**112** 1790	**97** 960	-	-	-	-
Karakassis and Eleftheriou, 1997	Cretan, Greece	9.9	**547**	-	-	-	**132** 219	-	-	**390** 1560
Zenetos et al.,1996	Ionian Sea, Greece	5.5	**351**	-	-	-	-	-	**138** 1584	**104** 1030-7830
Revkov and Nikolaenko, 2002	Lapsi Bay, Black Sea	2.64	**131**	**122** 2783	-	-	49 1391	-	-	-
Ayari and Afli, 2003	Gulf of Tunis, Tunisia	6	**214**	**16** 620	-	-	**91** 4685	**149** 2855	-	-
Bonifacio, 2015	Banyuls Bay, France	19	**448**	**16-58** 41-613	-	-	**53-110** 186-723	**30-105** 153-796	**48-108** 171-837	-
Bonifacio, 2015	French Catalan coast	27.3	**474**	**242** 156	-	-	**176** 142	-	**281** 281	-