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

3

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13

14 **ABSTRACT**

15

16 The macrobenthic fauna in the bay of Bou-Ismail (Mediterranean Sea, Algeria) was studied
17 with the objective of establishing a reference state based on the probable diversity thirty years
18 earlier at the end of the 1980s. A total of 98 points were sampled using a Smith Mac Intyre
19 grab sampler (two replicates each of 0.1 m² and using a 1 mm mesh sieve). A total of 17,120
20 individuals representing 840 taxa (including 723 species) were identified from the sampled
21 material. Seven distinct benthic communities were identified as a function of the sediment
22 characteristics. Four diversity indices (Taxonomic Richness, Shannon, Pielou and ES₍₅₀₎), and
23 two benthic indices (AMBI and BO2A) were calculated for each of the seven benthic
24 communities. Coastal Terrigenous Mud contains the poorest community while Muddy
25 Detritic supports the richest variety. The Shannon index exceeds 6 at the sampling points with
26 the greater diversity, where the number of individuals per 0.2 m² reaches 664. Out of 50
27 organisms collected in a sample, the expected number of species was 35 (ES₅₀). Moreover, <
28 50% of the taxa were found at only one or two stations. Benthic indicators revealed a good
29 and high ecological status. The geographic origin of the 723 species is presented as their
30 reported presence in 13 geographical regions including nine areas of the Mediterranean Sea.
31 Most of the species had an Atlantic origin and are present in the western Mediterranean Sea.

32

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

34

35 1. Introduction

36

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

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

49 Le Danois (1925) was the first researcher to describe the benthic communities of the
50 bay of Bou Ismail in relation to the fishing areas. This work was followed by Dieuzeïde
51 (1950) who published an inventory of the benthic macrofauna making up the soft-bottom
52 communities of the fishing areas in this bay, which was later supplemented by Vaissière and
53 Fredj (1963). Dieuzeïde (1940) described the ‘Gravelle de Castiglione’ (*Branchiostoma*
54 community of Coastal Detritic) associated with maerl substrates, which was compared with
55 the communities of the Marseilles area by Pérès (1952) and later analysed in detail by
56 Falconetti (1970).

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

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

69 Mediterranean and along the Algerian coast because of the natural sea currents (Millot *et al.*,
70 1990; Millot, 1999). However, various questions remained unclarified: what was the pattern
71 of the local biodiversity at the scale of the different benthic communities in the bay, and what
72 was the cause of such diversity especially with respect to the benthic soft-bottom
73 communities?

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

81

82 **2. The main characteristics of the bay of Bou Ismail and the design of the sampling** 83 **procedures**

84

85 *2.1. The main characteristics of the bay of Bou Ismail*

86

87 The general movement of coastal water in the area is characterized by the penetration
88 of surface Atlantic waters through the Strait of Gibraltar, across the Alboran Sea and along
89 the Algerian coast (Millot, 1999). Moving west to east, the Algerian surface current is 50km
90 wide, between 150 and 250m thick and runs at an average speed of 50 cm.s⁻¹. It also exhibits a
91 certain instability caused by the anticyclonic and cyclonic gyres (typically 100-150km in
92 diameter) that are associated with the upwelling of cold deep waters favouring a strong
93 primary productivity (Millot, 1999; Millot and Taupier-Letage, 2005).A branch of this
94 Algerian current penetrates into the bay of Bou Ismail and generates a coastal counter current
95 moving in the western direction.

96 Within the bay, the hydrological factors show large seasonal variations, with strong
97 westerly and north-westerly swells occurring during winter associated with the resuspension
98 of fine particles in shallow waters (Bakalem, 2008). Such resuspension is weak during the
99 spring-summer period (dominated by a north and north-easterly swell) which generates
100 currents along the shore moving from the eastern to the western part of the bay with a
101 consequential redistribution of fine sediment towards the west.The dissolved oxygen
102 concentrations vary between 5.6 and 8.5 mg.L⁻¹ with the lowest values being observed during

103 the summer in the shallower waters. The sea surface temperatures vary from 27°C at the end
104 of summer, falling to 16°C in winter; the thermocline occurs at a depth of 20m depth in June
105 falling to 60 m at the end of the summer. The temperature near the sea bottom beneath the
106 thermocline remains at below 16°C all the year round. The salinity shows weak seasonal
107 changes and ranges between 37 and 38; a weak desalination (36.7-37) is observed near the
108 oueds during the winter due to freshwater inputs. The deposition of suspended fine sediment
109 from these freshwater sources was estimated at 3×10^6 tonnes per year (Grovel, 1961), resulting
110 in the formation of subtidal mud flats in the bay (Dagorne, 1970; Aït Kaci and Pauc, 1983a,b;
111 Braik, 1989; Moulfi, 1995).

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

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

125 Compared to the neighbouring areas along the eastern the bay of Algiers, the bay of
126 Bou Ismail had not been greatly urbanized or industrialized prior at the end of the 1980's
127 (Bakalem, 2008; Grimes, 2010). The area was yet to suffer industrial development, and
128 boasted neither commercial harbour nor a major coastal town and generated negligible
129 wastewater discharges. Today, the population along the 60km stretch of coast is estimated at
130 200,000. The main sources of pollution now result from the large discharge of domestic waste
131 water from coastal urban towns generally lacking any water treatment. The study by
132 Boudjellal *et al.* (1995) on the presence of heavy metals (mercury, lead, copper, chromium,
133 cadmium, zinc, etc.) in shallow sediments (5-20m) showed that the bay of Bou Ismail could
134 still be considered as an unpolluted area when compared to other Algerian coasts. In a study
135 on the content of PAH in sediments, Sellali (1996) concluded that hydrocarbon pollution was
136 very low.

137 The medium and long-term development of coastal areas during the last few decades
138 (general urbanization, construction of sea resorts and marinas), along with the uncontrolled
139 exploitation of sand dunes, have changed the hydrodynamics and sedimentation processes,
140 which, along with coastal erosion, have caused shoreline degradation. These impacts have led
141 mainly to the reduction of areas of seabed in the bay classified as of *Posidonia* meadows
142 because of the increased sedimentation in shallower waters (Molinier and Picard, 1952; Braik,
143 1989; Boumaza, 1995; Bakalem, 2008).

144

145 2.2. Benthic sampling methodology

146

147 The sediments were sampled using a 0.1m² Smith Mc Intyre grab apparatus (three
148 replicates per sampling point, two for the fauna and one for the granulometry) in the period
149 20-30 August 1988. Ninety-eight locations were investigated, these following 15 transects
150 perpendicular to the coast and one parallel to the coastline (Fig. 1). The sediment from the
151 two replicates was sieved through a 1 mm mesh and the collected macrofauna fixed in a 10%
152 buffered formaldehyde solution mixed with seawater. The organisms were then sorted,
153 identified if possible at the species level, and counted in the laboratory using the Magister
154 framework reported by Hassan (1991) and Oulmi (1991).

155 In the laboratory, the sediment samples coming from the third replicate were dried at
156 60°C for 24h, and the particles were then passed through a nineteen-sieve column (2500 to 40
157 µm) into a mechanical sieve shaker. Each fraction was then weighed to calculate the
158 contribution of each fraction to the total weight. Then the Folk (1954, 1965) classification was
159 used to determine the sediment type. As in Hassam (1991) and Oulmi (1991), the benthic
160 community classification followed the previously definitions of Glémarec (1969, 1971, 1973)
161 and Chassé & Glémarec (1976), and those of Pérès & Picard (1964) and Picard (1965) who
162 had classified the biocoenoses (=communities) of the Mediterranean Sea.

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

167

168 2.3. Measurements relating to the retrieved organisms

169

170 The data retrieved from the sampling included the abundances of 840 taxa found at the
171 98 sample points, each representing 0.2m². Among the recorded taxa, 723 species were
172 identified to level of species (86% of the taxa); consequently, the geographical patterns of
173 these 723 species could be documented according to the available literature. The species
174 names were validated by use of the WoRMS database (<http://www.marinespecies.org>;
175 accessed on 4 December 2018).

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

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

196

197 2.4. Benthic indices

198

199 The first step was to classify the species into zoological groups to identify the
200 respective dominant organisms of the macrofauna. Next, three indicators were calculated
201 based strictly on species diversity: the Shannon-Weaver index ($\log_2 H'$), the Pielou measure of
202 evenness (J') and the expected number of species for 50 individuals collected from each of the
203 98 samples (ES_{50}).

204 Furthermore, two indices were calculated based on ecological factors: i) AMBI (the
205 AZTI Marine Biotic Index), which analyses the proportions of five ecological groups (using
206 the species list published on the AZTI website on 22 November 2017) (Borja *et al.*, 2000;
207 Borja and Muxika, 2005), and ii)BO2A (Benthic Opportunistic Annelida Amphipods index),
208 which is based on the principle of taxonomic sufficiency that uses only two well-known
209 zoological groups as indicator species (i.e. the amphipods as sensitive species and the
210 opportunist annelids)(Dauvin *et al.*,2016; De-la-Ossa-Carretero and Dauvin, 2010). In the
211 present study, the five ECOlogical Quality Status (EcoQS) classes suggested by the European
212 Water Framework Directive were used, i.e.: high for unpolluted sites, good for slightly
213 polluted sites, moderate for moderately polluted sites, poor for heavily polluted sites, and bad
214 for extremely polluted or azoic sites. The thresholds are given by Dauvin and Ruellet (2007)
215 and also Dauvin *et al.* (2012, 2016) these references based on that defined by Borja *et al.*
216 (2000) for AMBI, and by Vincent *et al.* (2002) for H' and by De-la-Ossa-Carretero and
217 Dauvin (2010) for BO2A.

218

219 **3. Results**

220

221 *3.1. General patterns of the fauna distribution*

222

223 The central region of bay of Bou Ismail is described as mud, whereas the shallower
224 zones were characterized by muddy and fine sand; for both of the western and eastern parts of
225 the bay there was coarser sediment near the rocky headlands (Fig. 1). The fine particles
226 (<63µm) made up between 5 to 95% of the total sediment, whereas carbonate of bioclastic
227 origin represented a large proportion of the total sediment, ranging from 15 to 80%. Based on
228 the results of Hassam (1991) and Oulmi (1991) for the eastern and western parts of the bay
229 respectively, the 98 sample locations could be being classified as one of seven main soft-
230 bottom benthic communities (Fig. 1).

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

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

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

246 Ten sampling points were spread across the bay from shallow to deeper areas but
247 generally at a depth of 17 to 34m depth, (except for one sampling point at 113m). These
248 corresponded to the Muddy Sand (MS) community with a sediment containing between 5 and
249 28% fine particles. This type of community was characterized by two species: the bivalve
250 *Atlantella pulchella* (Lamarck, 1818) and the amphipod *Urothoe grimaldii* Chevreux, 1895
251 (Fig. 3).

252 Thirteen sampling points generally located at between 31 and 52 m depth, (except for
253 two deeper locations at 113 and 136m), corresponded mainly in the western and central parts
254 of the bay. These were classified as Sandy Mud (SM) community types with a sediment
255 containing 55 to 80% fine particles. Two species, the bivalve *Nucula sulcata* Bronn, 1831 and
256 the Ophiuroid *Amphiura chiajei* Forbes, 1843, were abundant in this type of community (Fig.
257 4).

258 Twenty-five sampling locations at depths ranging from 40 to 100m in the central part
259 of the bay corresponded to the Coastal Terrigenous Mud (CTM) community; the
260 corresponding sediments contained with >90% fine particles. The presence of the polychaete
261 *Paraprionospio pinnata* (Ehlers, 1901) and the Holothuroid *Oestergrenia digitata* (Montagu,
262 1815) characterized this type of benthic community (Fig. 4).

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

268 A total of 17,120 individuals representing 840 taxa were counted from samples
269 retrieved from 98 locations covering a total sampling area of ~20m² across a stretch of bay
270 covering 342 km². Taxonomic richness per 0.2m² of sampling area varied from 8 taxa at a

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

277 The polychaetes made up 40.5% of the taxonomic richness, followed by crustaceans
 278 (32.2% and especially amphipods at 21.8%, decapods, 5.6% and isopods, 4.5%) and bivalve
 279 molluscs (10%).

280 In terms of abundance, the polychaetes again dominated with 44.7% of the collected
 281 individuals, followed by the crustaceans (35% including the amphipods which made up
 282 29.3%), and then the echinoderms with 7.6%.

283 The Shannon factor for biodiversity ($\log_2 H'$) varied from 1.73 to 6.03 for the
 284 sampling sites, with a mean of 4.24 and 65% of all the sampling points were over 4.0 (Fig. 6).
 285 The number of individuals per sampling location varied from 9 at a CTM station to 664 at a
 286 CD station, with a mean value of 148. Only four locations showed an abundance greater than
 287 400, and 18 locations had an abundance below 40; among these last group, five sampling
 288 points had an even lower abundance of below 20 (Fig. 6). The expected number of species
 289 for 50 individuals collected in a sample (ES_{50}) varied from 8 to 34 species, with a mean of
 290 21.9; 66% of the values had an ES_{50} of below 20 species (Fig. 6).

291

292 3.2. Distribution pattern of the seven types of benthic community

293

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

302 Considering now the measurement J' (the Pielou measure of evenness): this revealed
 303 no difference in values between the benthic communities, samples corresponding to the type
 304 CTM yielded significantly lower values than those classified as MD, SM or GS (Table 2). The

305 species number (S), and values for ES (50) and H' were all significantly higher in MD
 306 samples than for those classified as CTM or SM (Table 2). SM values were also lower than
 307 those obtained for GS (Table 2).

308 Table 1 sets out the mean values for the measurements of diversity, AMBI and BO2A.
 309 All the seven types of benthic communities were attributed a high or good status; amongst the
 310 98 sampling locations, 34 are classified as high and 64 good for AMBI and 83 high and 15
 311 good in terms of the BO2A measurement.

312

313 *3.3. Biogeographical patterns of the recorded species in the bay of Bou Ismail*

314

315 Full details of the geographical origins of the 723 species identified in the bay of Bou
 316 Ismail, (as well as their presence in 13 previously defined geographical areas) is given in the
 317 appendix. Table 3 summarized these results. Most of the species found in the bay originated
 318 from the Mediterranean or northeast Atlantic, and 655 species (91% of those identified) were
 319 also found at other sites in the north-western Mediterranean Sea. 643 species (89% of the total
 320 found in the bay of Bou Ismail) were also found in the Aegean Sea, and 545 (75%) and 529
 321 (73 %) were also found in the Adriatic Sea and the Ionian Sea, respectively. 469 species (65
 322 %) were also recorded in the Levantine Sea. By contrast, only 306 (42%) and 182 (25%) of
 323 the listed species were also found in the Tunisian and Libyan coastal waters, as well as in the
 324 Alboran Sea. A total of 620 species (86%) were also present in north-eastern Atlantic
 325 European waters. Very few species were shared with the Red Sea or Indo-Pacific regions.
 326 These results confirmed the Atlantic origin of most of the species (81%) found in the bay of
 327 Bou Ismail; only 88 species (12%) were endemic to the Mediterranean Sea, and 6% were
 328 cosmopolitan species. The prepared dendogram (Fig 7) enabled the distinguishing of two
 329 main groups, the first being comprised of common species the areas Indo-Pacific and/or Red
 330 Sea (IP and RS) and the Mediterranean Sea. The second group included species from all the
 331 other biogeographical regions, which itself could be divided into three sub-groups: 1) AL and
 332 BS; 2) TL and AA, and 3) LE, AD, IO, NE, AE, NWM and BI.

333

334 **4. Discussion**

335

336 *4.1. Comparison of the number of species and their abundance in the bay of Bou Ismail with*
 337 *similar sites across the Mediterranean Sea*

338

339 Whilst numerous local and regional studies had been carried out on benthic
340 communities at sites across the Mediterranean Sea, there had been little quantitative sampling
341 of soft-bottom communities at the same time at the scale of a whole site and associated with
342 the identification of all zoological groups. The communities identified in the bay of Bou
343 Ismail (and in most studies concerning the Mediterranean Sea) were organised following the
344 classification of biocoenoses (= communities) proposed by Pérès and Picard (1964). Picard
345 (1965) described the benthic communities in the Gulf of Marseilles, whilst Guille (1970,
346 1971) studied the benthic communities from the French Catalan coast and Desbruyères *et al.*
347 (1973) concentrated on the Spanish Catalan coast. Later, Labrune *et al.* (2006, 2008) and
348 Bonifácio (2015) took account of benthic communities in the Golfe du Lion on the French
349 Mediterranean coast. Quantitative data had also been obtained for other areas of the
350 Mediterranean and Black seas, including the Adriatic (Zavodnik and Vidakovic, 1987 and
351 Zavodnik *et al.*, 1985), the Cretan coast (Karakassis and Eleftheriou, 1997), the Ionian Sea,
352 (Zenetos *et al.*, 1996), the Gulf of Tunis (Ayari and Afli, 2003) and as well as along the
353 Crimean coast (Black Sea) (Revkov and Nikolaenko, 2002). These data could be compared
354 with the results of the current study for the bay of Bou Ismail (Table 4).

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

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

370 The two Well Calibrated Fine Sand and Muddy Detritic benthic communities in the
371 bay of Bou Ismail exhibited the highest taxonomic richness (TR), while the other
372 communities in the bay yielded TR values of the same order of magnitude as those found in

373 other areas of the Mediterranean Sea (Table 4). For soft-bottom communities along the
374 Algerian coast, Dauvin *et al.* (2013) reported a TR of 1,642 taxa from a total sampling surface
375 area of 174 m². Escaravage *et al.* (2009) reported a TR of 1,033 in the Aegean Sea (for a
376 sampling surface-area of 34 m²), which was the second highest value recorded when
377 compared with other areas of the north-eastern Atlantic and the Mediterranean Sea. Using a
378 similar sampling surface-area (7.75 m²), Dauvin *et al.* (2013) highlighted a decrease in TR
379 along the Algerian coast falling from 597 taxa in the western sector to 274 taxa in the eastern
380 sector, with the Bay of Bou Ismail near to the Bay of Algiers showing an intermediate
381 diversity of 407 taxa.

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

387 The high TR was associated with low abundances of the organism as well as very high
388 values for the Shannon-Weaver index ($\log_2 H'$), Pielou evenness (J') and the expected number
389 of species for 50 individuals ($ES_{(50)}$) (Table 1) reflected in the presence of diversified
390 communities in the Bay of Bou Ismail, these values were amongst the highest recorded in the
391 literature for soft-bottom communities (Dauvin *et al.*, 2013). The Muddy Detritic community
392 appeared to be the most diversified while the Coastal Terrigenous Mud community was the
393 least diversified. The benthic indicators AMBI and BO2A yielded a High and Good
394 ecological quality status for all the seven benthic communities recorded. Similarly, as inferred
395 from the diversity indices, the Muddy Detritic community was classified as High EcoQS,
396 whilst the Coastal Terrigenous Mud and Sandy-Mud communities were associated with a
397 Good EcoQS. This applied to the Well Calibrated Fine Sand community at the scale of the
398 Mediterranean Sea (Dauvin *et al.*, 2017a), while a degraded EcoQS was attributed to the
399 benthic communities in Algerian harbours, particularly in the case of Algiers (Dauvin *et al.*,
400 2017b).

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

405

406 *4.2. Geographical patterns*

407

408 It was clear that the species present in the seven benthic communities around the bay
409 of Bou Ismail related mainly to the influence of the north-eastern Atlantic and Mediterranean
410 Sea (Tables 3, Figure 7 and Appendix.). Dauvin *et al.* (2013) highlighted a fall in the number
411 of Atlantic species from west to east along the Algerian coast. This decline was also
412 recognized when moving from the western to the eastern basin of the Mediterranean Sea.
413 Nevertheless, in the Levantine basin in the East, numerous Lessepsian migrant species
414 originating from the Red Sea or having Indo-Pacific origin had colonized this part of the
415 Mediterranean and contributed to the enrichment of the local biodiversity. The number of
416 Non-Native Species (NNS) arising from migration through the Suez Canal was very low in
417 the bay of Bou Ismail, with only two polychaete species found: *Metasychis gotoi* (Izuka, 1902)
418 and *Pista unibranchia* Day, 1963. With respect to the invertebrates, Grimes *et al.* (2018)
419 reported 18 NNS in the marine communities along the Algerian coast including five species
420 of Indo-Pacific or Red Sea origin. Those NNS corresponding to Lessepsian migrant species
421 were more numerous in other parts of the eastern basin of the Mediterranean Sea (Coll *et al.*,
422 2010, 2012; Zenetos *et al.*, 2017).

423 When comparing the species diversity in different marine areas, a broad bias due to the
424 variable sampling methods was noted. It was clear that studies in the Alboran Sea were biased
425 towards a low number of species in common with work done in the bay of Bou Ismail (Table
426 3 and Appendix), probably due to the small number of studies in this area of the
427 Mediterranean Sea. Conversely, the low number of species in common between the bay of
428 Bou Ismail and the virtually isolated Black Sea reflected the low diversity of the latter with
429 particular physico-chemical characteristics in relation to hypoxic and anoxic conditions.

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

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

438 The adjoining Adriatic and Ionian seas displayed closer similarities than between other
439 Mediterranean areas of the second defined group (Fig. 7). The AE, NWM and BI areas in the
440 Mediterranean Sea all showed strong similarities with the European North-Eastern Atlantic

441 and African Atlantic coasts. The bay at Bou Ismail also displayed a close similarity with the
442 NWM area, which was to be expected since both areas correspond to the western
443 Mediterranean basin.

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

449

450 *4.3. Towards a conservation status for the benthic communities of the bay of Bou Ismail*

451

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

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

472 This approach should be developed in other areas of the Mediterranean Sea where
473 biodiversity hotspots had been identified. The soft-bottom communities in the bay of Bou
474 Ismail could be a good candidate to apply this methodology. The main human pressure on the

475 soft-bottom communities of this part of the Algerian coastline rose from the intensive trawling
 476 activity. Moreover, a study of the structure of the seven identified soft-bottom communities
 477 should be undertaken to re-evaluate the first synoptic mapping of these benthic communities
 478 carried out at the end of the 1980s. Furthermore, the ecological status of two special
 479 communities, i.e. *Posidonia oceanica* meadows and 'gravelle de Castiglione' (*Branchiostoma*
 480 community of the Coastal Detritic with maerl), should be updated as soon as possible to
 481 facilitate measures for the immediate preservation of this exceptional soft-bottom
 482 macrobenthos in the bay of Bou Ismail.

483

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485

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492

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- 677

678 **Figure captions**

679

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

682

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

686

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

691

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

695

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

698

699 Fig. 6. The spatial distribution of indices of diversity at the 98 sampling points across the bay
700 of Bou Ismail: the number of taxa per 0.2 m², the abundance per 0.2 m², the Shannon-Wiener
701 diversity, the ES₍₅₀₎, the AMBI and BO2A.

702

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

2°25.920'E

2°33.600'E

2°41.280'E

2°48.960'E

N

Benthic habitats

- Muddy Detritic
- Gravelly Sand
- Coastal Detritic
- Muddy Sand
- Well Calibrated Fine Sand
- Sandy Mud
- Coastal Terrigenous Mud

36°44.160'N

36°36.480'N

Sidi Fredj

Zeralda

Bou Ismail

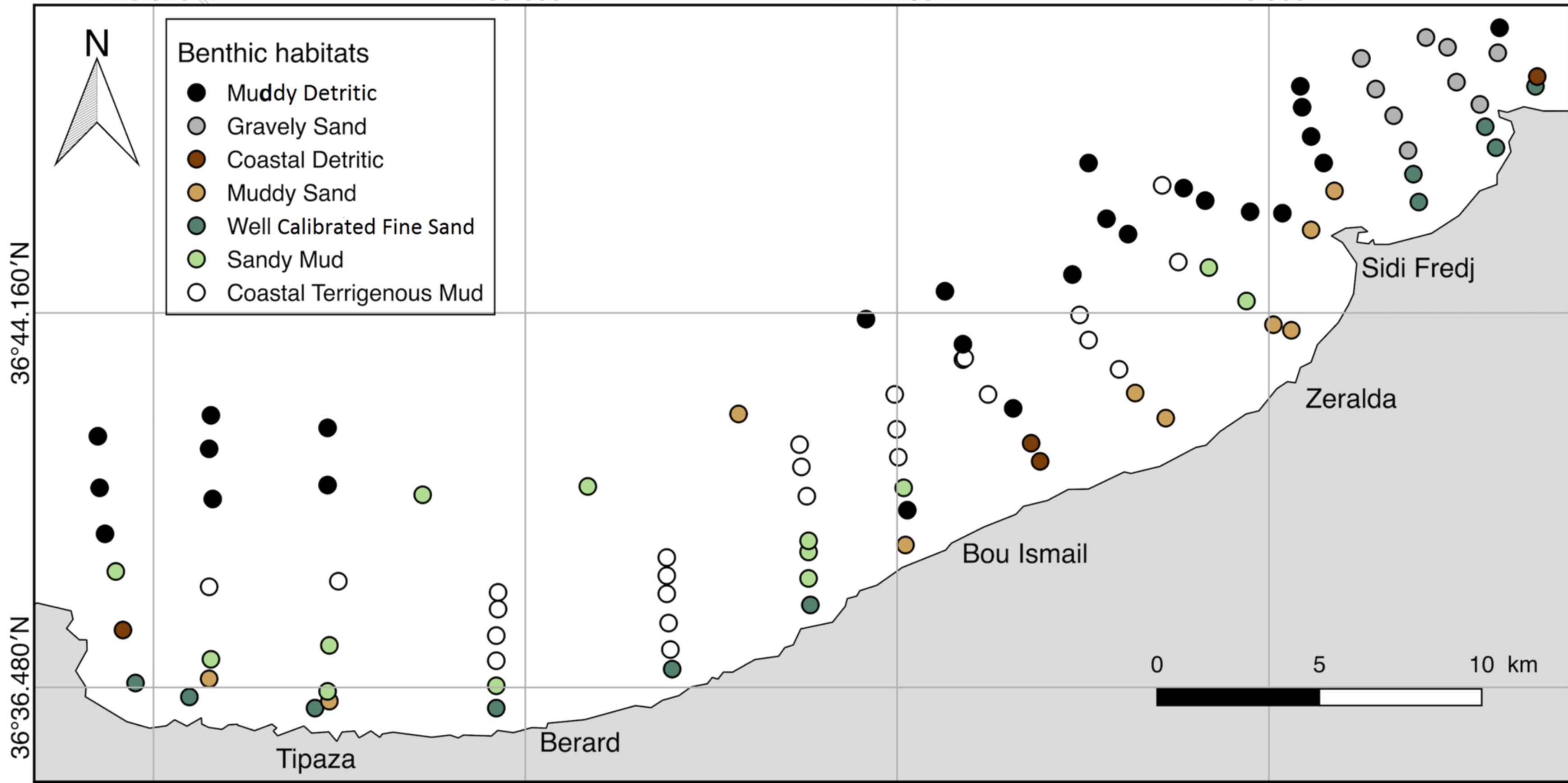
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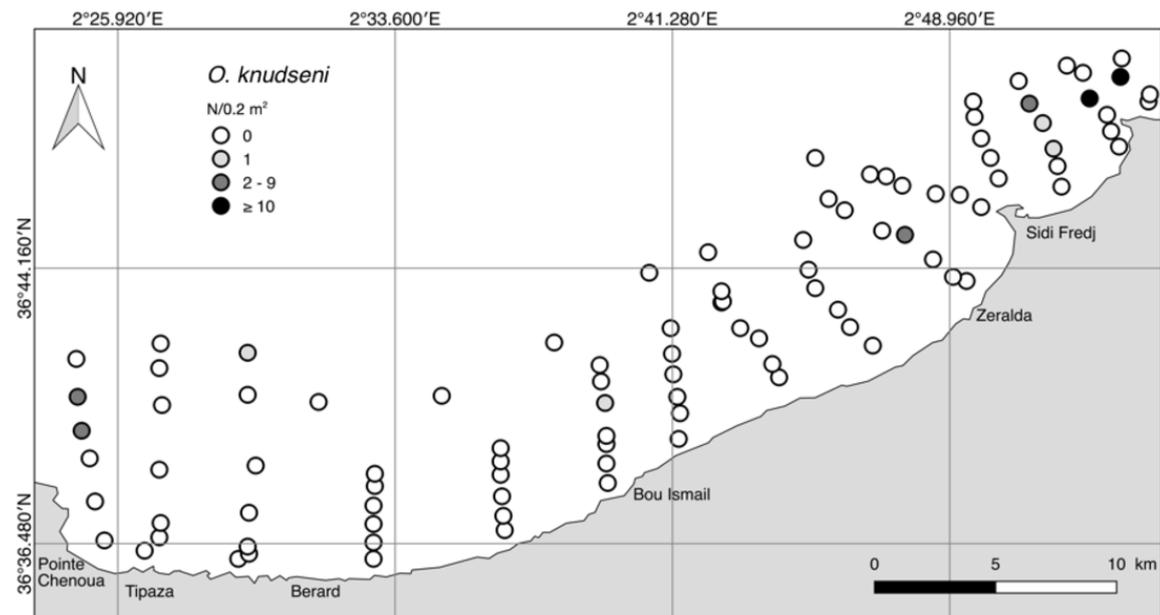
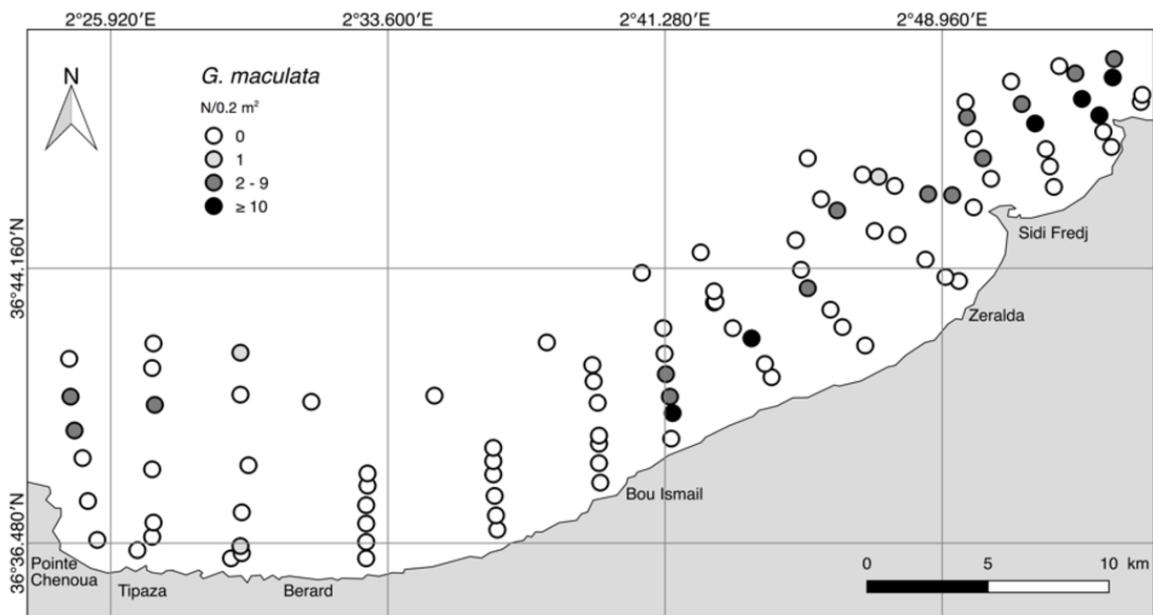
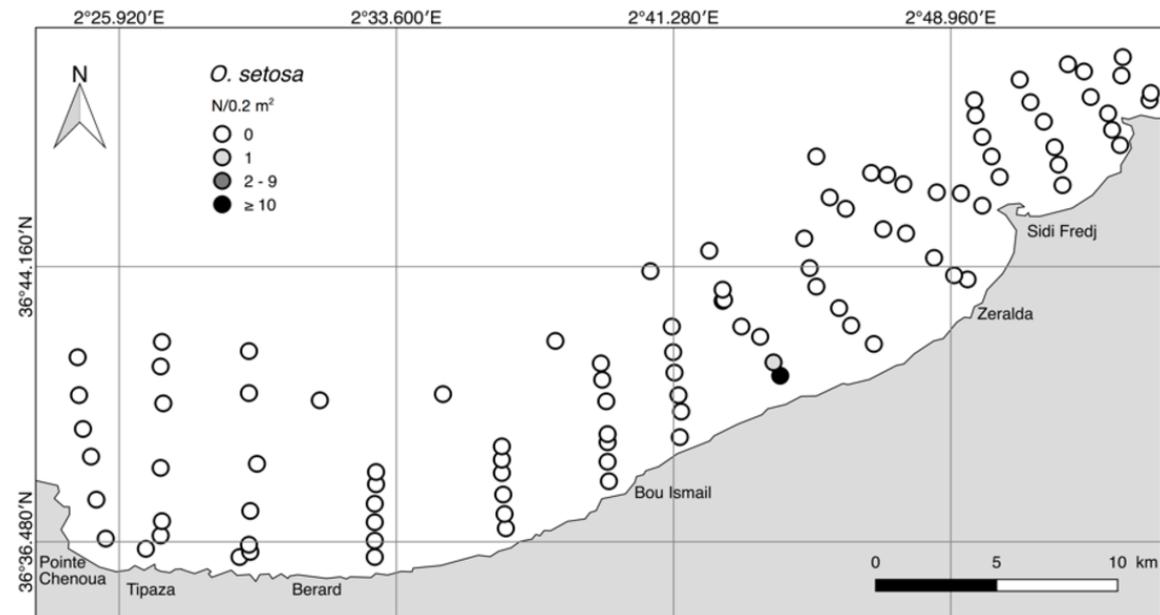
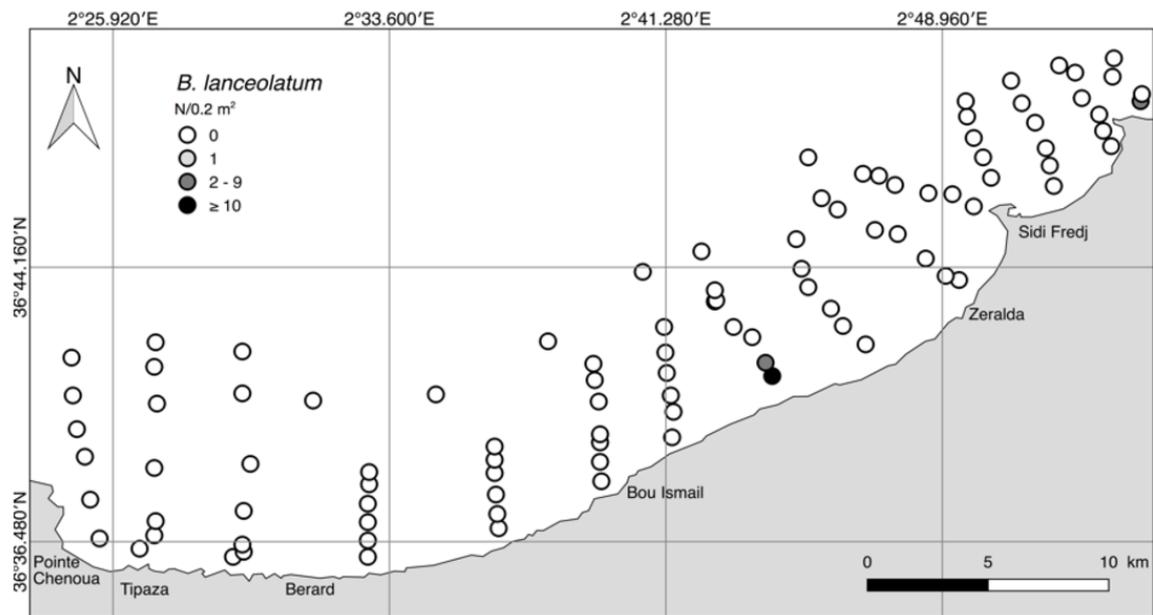
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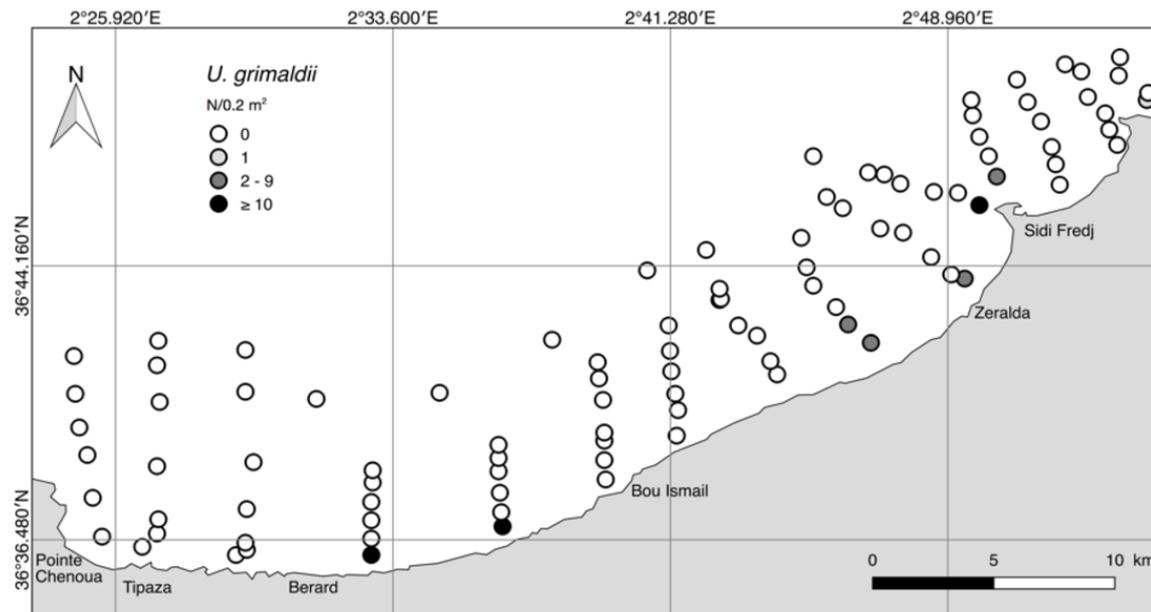
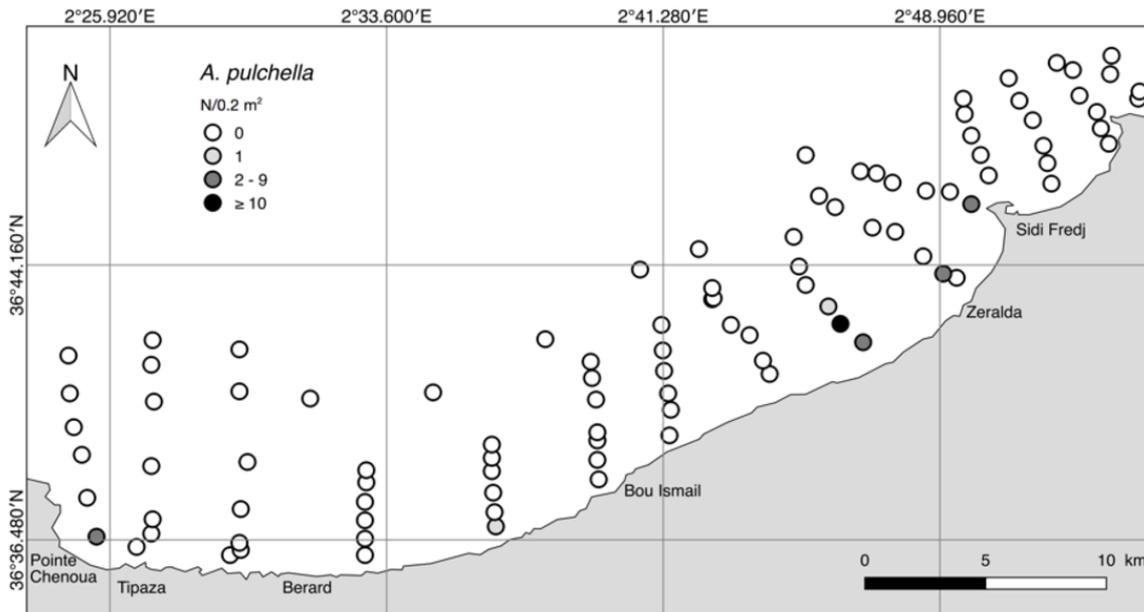
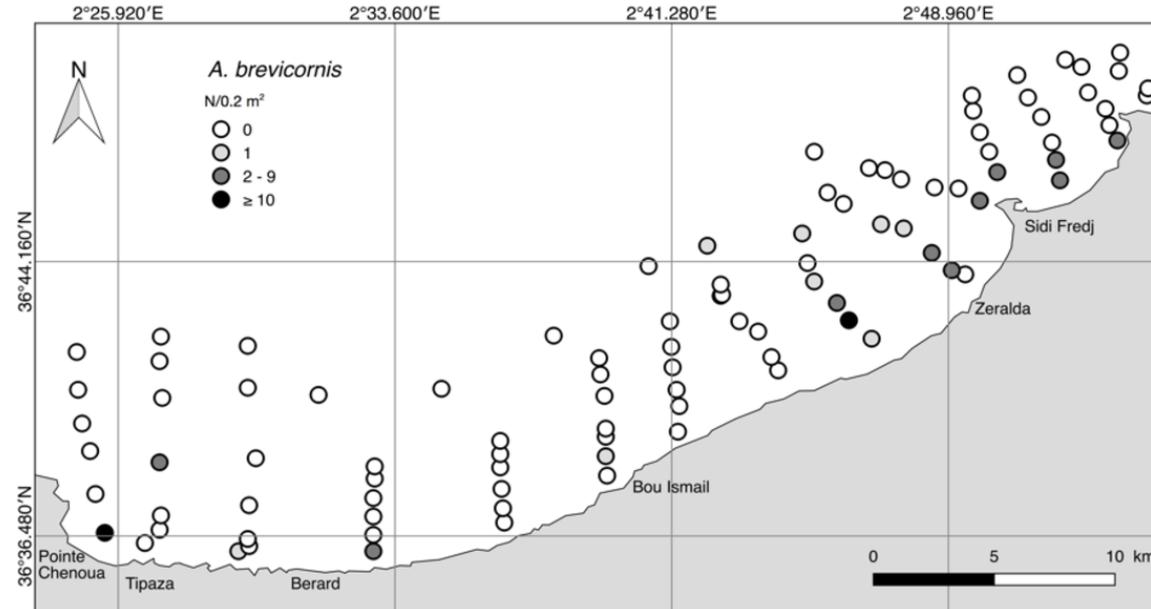
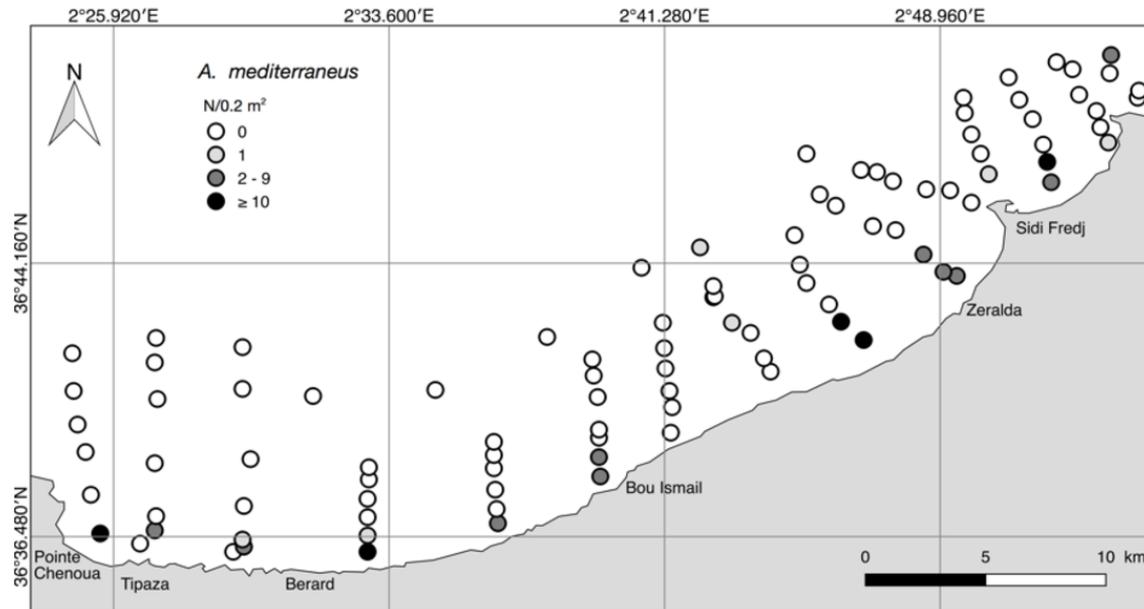
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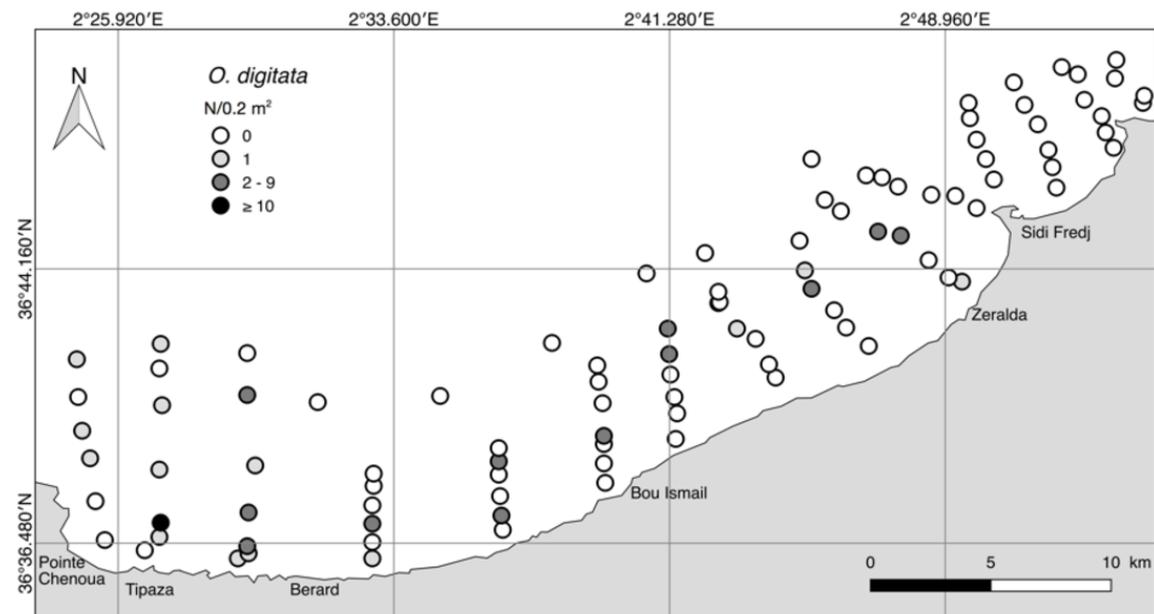
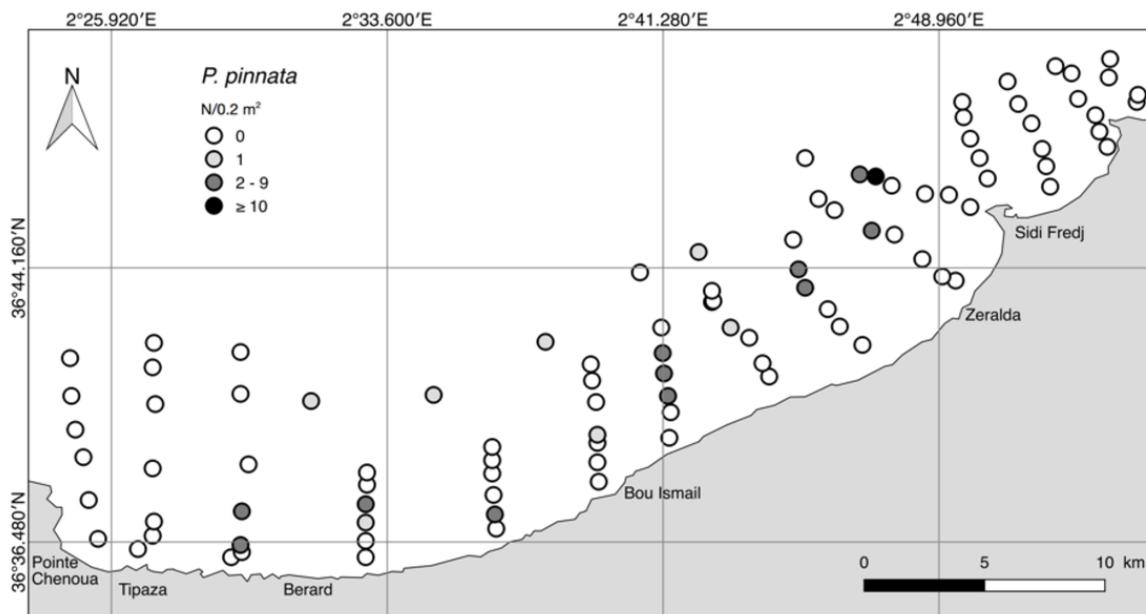
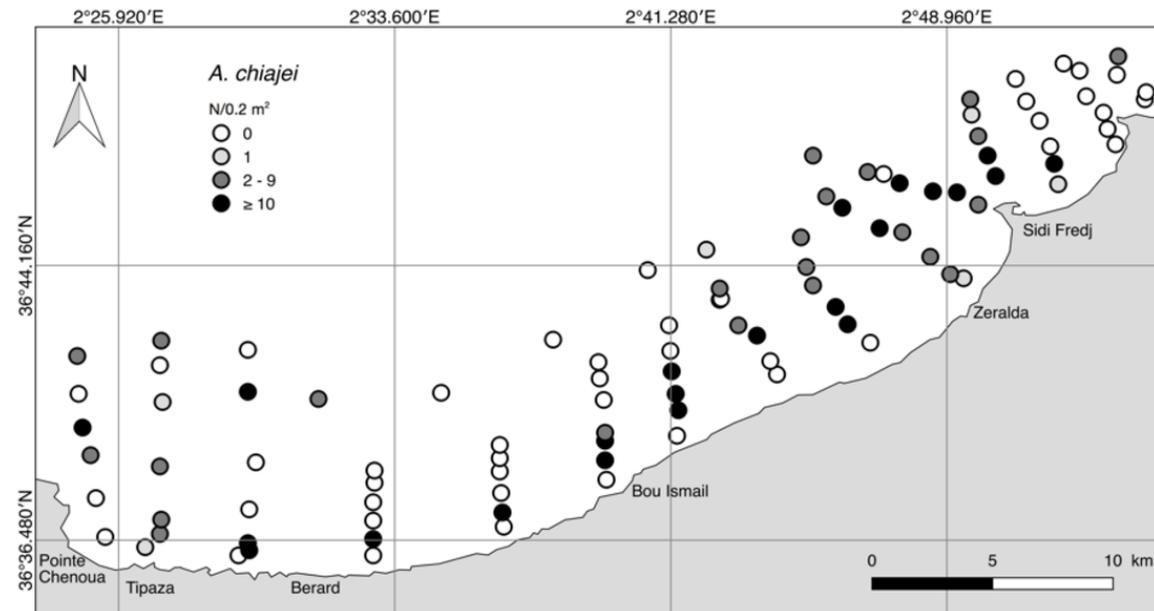
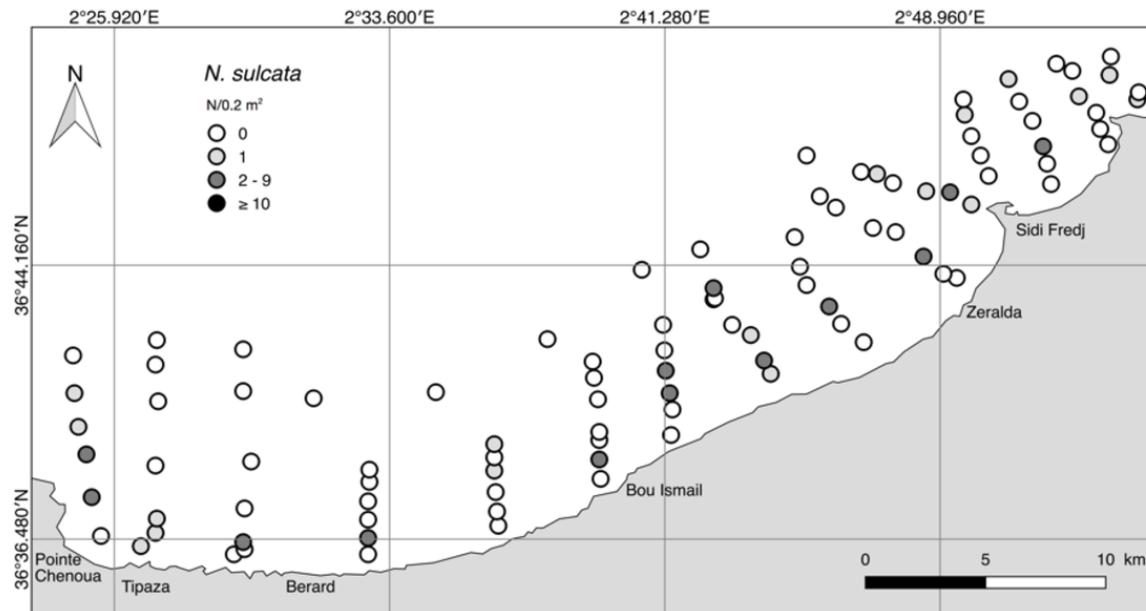
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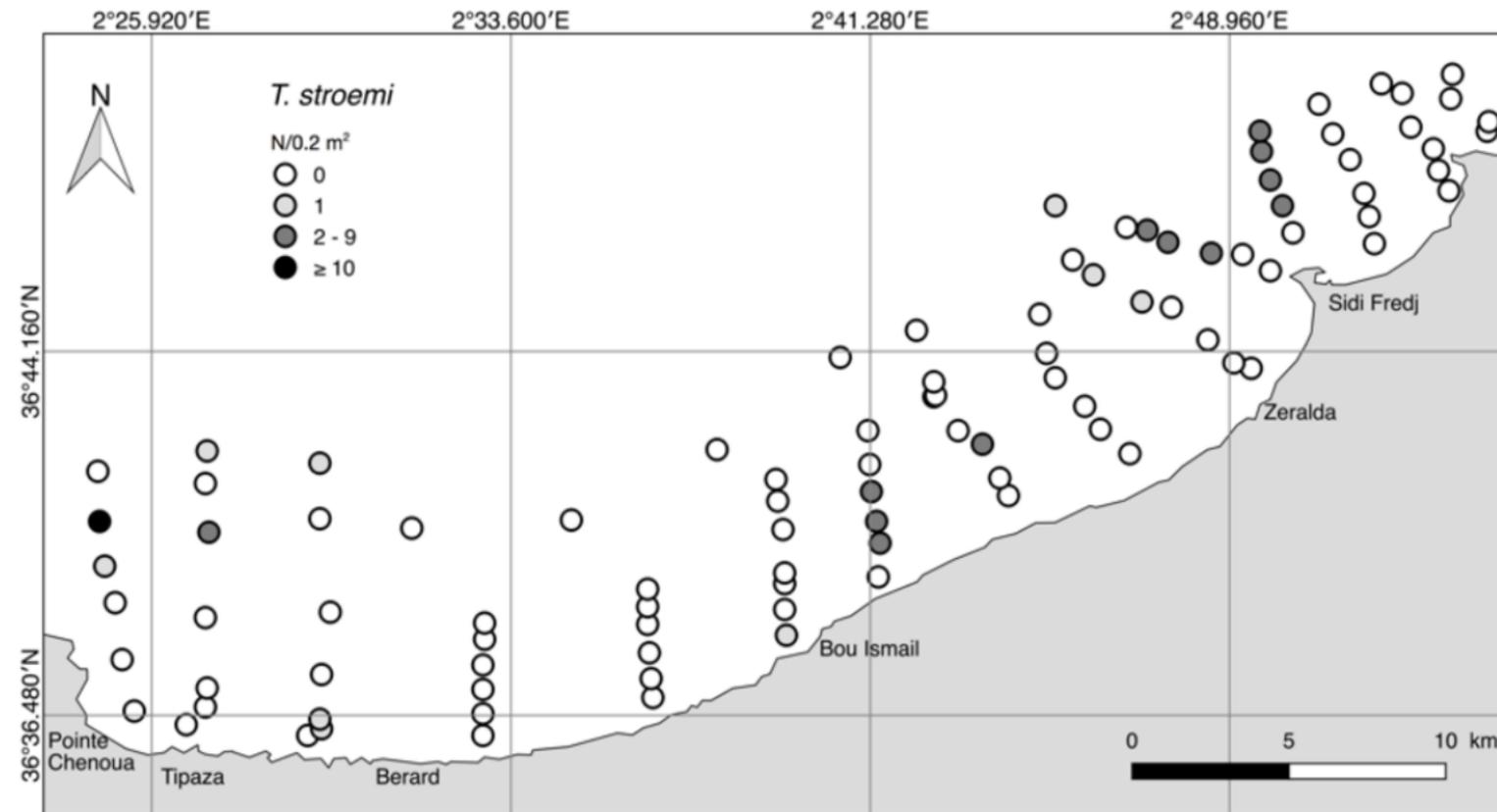
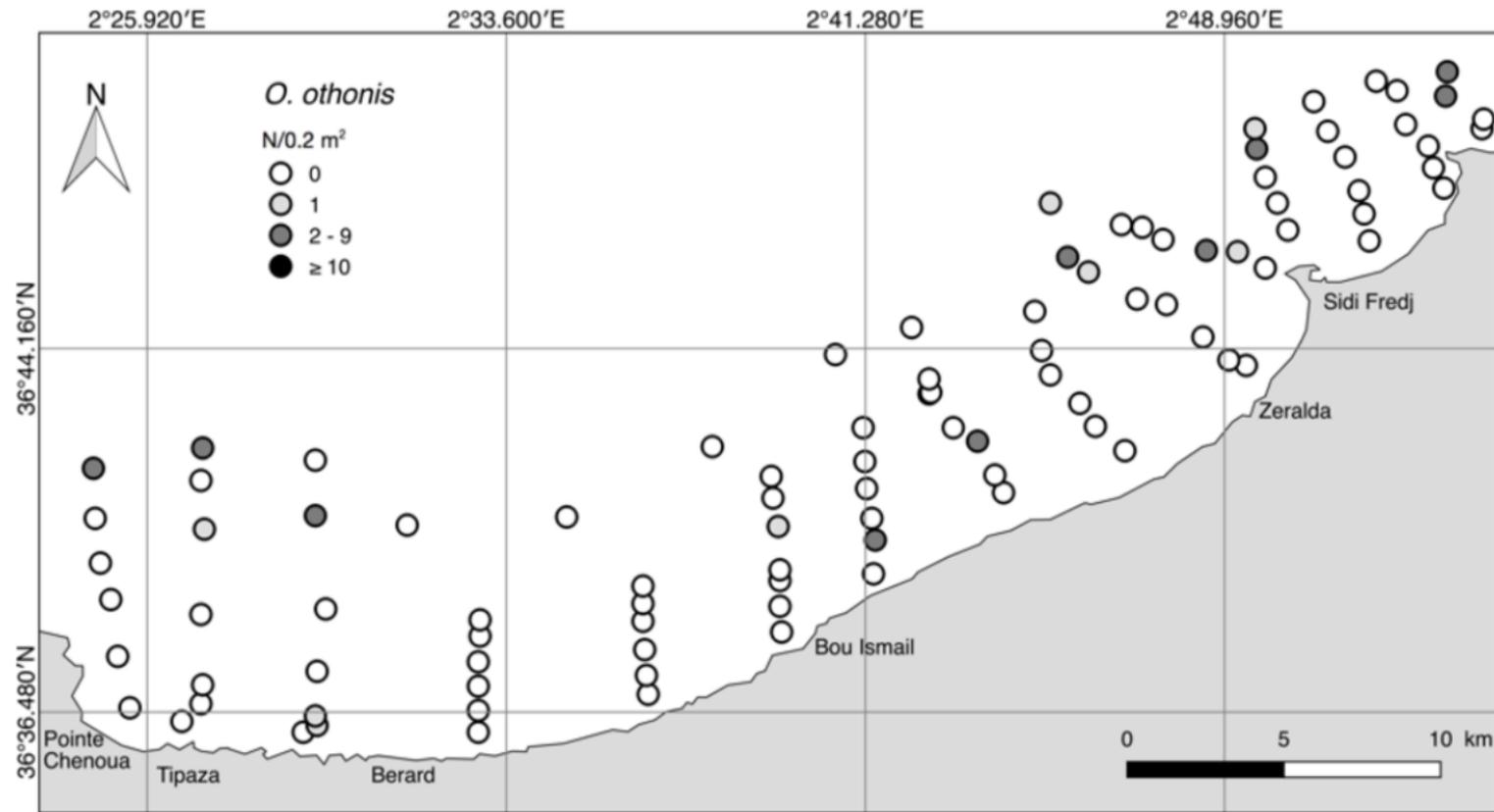
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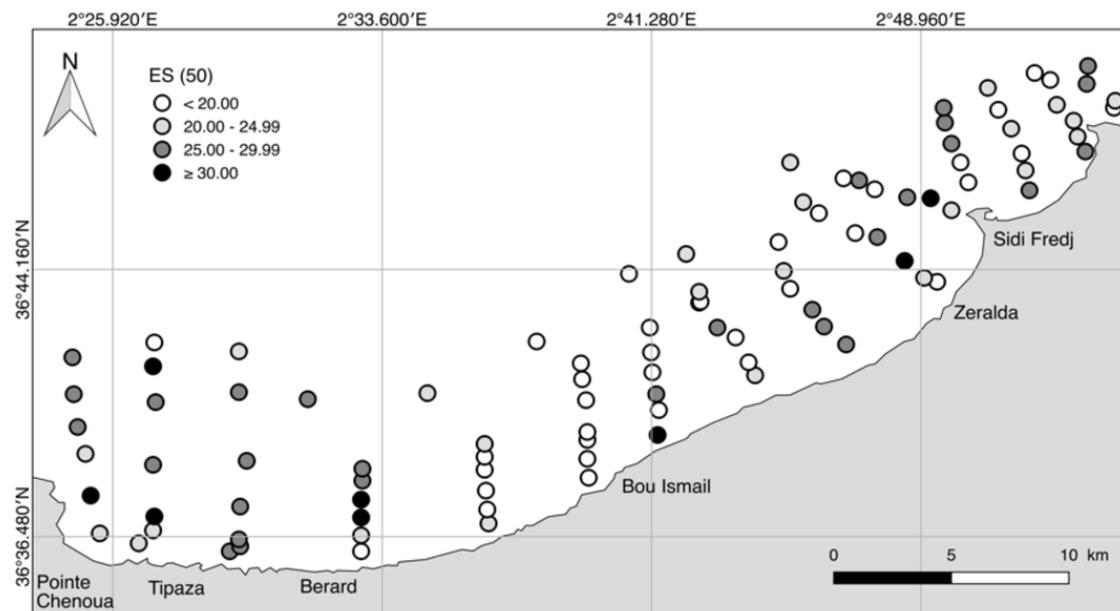
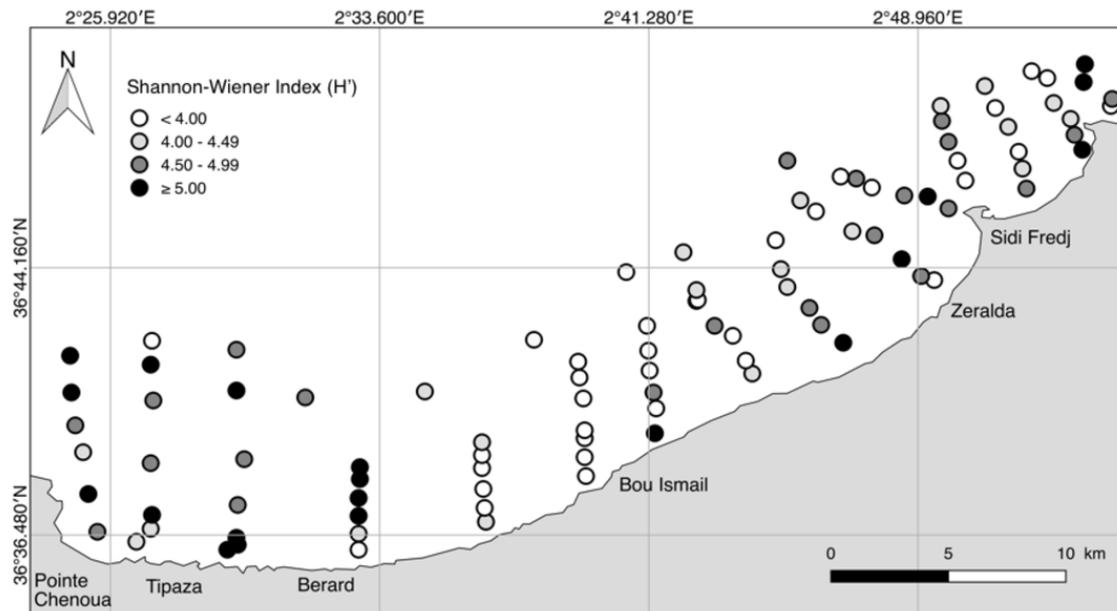
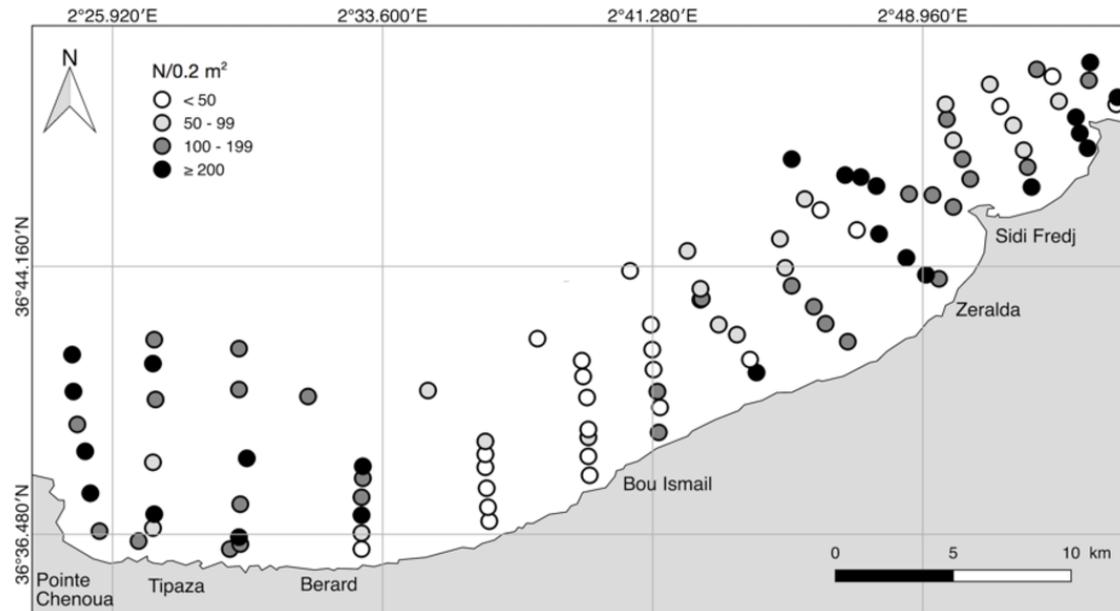
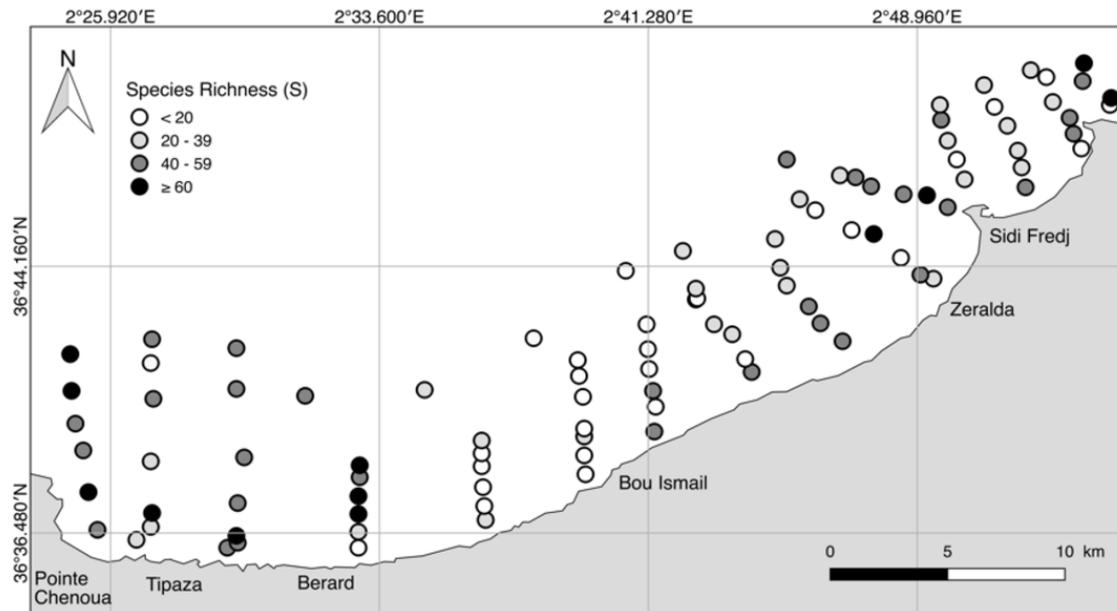












presence/abs
Group average

Resemblance: S8 Sorensen

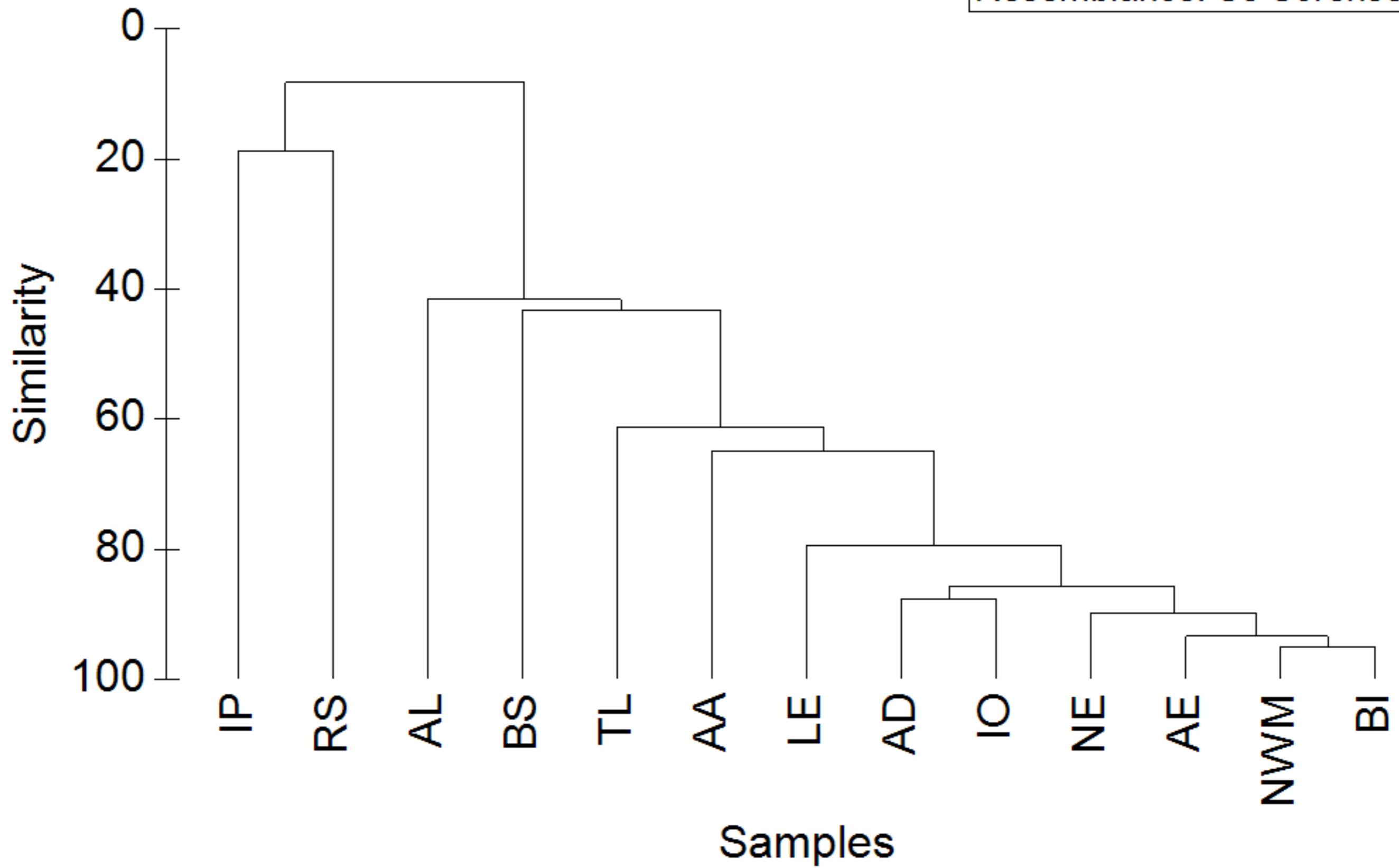


Table 1. Mean values of species richness (S), abundance (N), diversity indices (Shannon-Wienerr, Pielou' evenness J', and $ES_{(50)}$) for 0.2 m²; mean values of AMBI and BO2A and their corresponding Ecological Statuses for the seven habitats of the Bay of Bou Ismail. All values are given with their 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
Gravelly 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 m ²	TTN	Number of species and/or abundance per 1 m ² 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	-