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Spatial distribution and structure of benthic polychaete communities of Essaouira intertidal rocky shores (Atlantic coast of Morocco)

CHOUIKH Nor-eddine[1], GILLET Patrick[2], LANGSTON W. J.[3], CHEGGOUR Mohamed[4], MAAROUF Abdelmalek[1], MOUABAD Abdelfattah[1, *]

[1] *Laboratory "Aliments, Environnement et santé", Faculty of Sciences and Technics, B. P. 549, Cadi Ayyad University, Marrakech 40000, Morocco*

[2] *Mer Molécules Santé, Department of Biology Environment, Faculty of Sciences UCO, Angers 49008, France*

[3] *Marine Biological Association, the Laboratory, Citadel Hill, Plymouth PL1 2PB, United Kingdom*

[4] *Department of Biology, Ecole Normale Supérieure, B. P. 2400, Cadi Ayyad University, Marrakech 40000, Morocco*

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Abstract Polychaetes are one of the most important groups of macrobenthic organisms in coastal and marine environments, in terms of diversity and abundance, and play an important role in the functioning of ecosystem. This study aims to describe the structure and spatial distribution of polychaete communities along Essaouira's rocky shoreline (Atlantic coast of Morocco) in relation to the major environmental variables such as granulometry, salinity, temperature, pH, and intertidal range. Twelve sites from these intertidal rocky shores were sampled using a quadrat method during the summer 2016. A total of 4 435 individuals belonging to 34 taxa were recorded. Among the families, Sabellaridae (24%) and Nereididae (23%) were ranked first in terms of abundance of individuals. *Sabellaria alveolata* (24%) and *Perinereis cultrifera* (13%) were the dominant species. Diversity (H') values varied from 2.28 to 3.95. Pielou's index (J') varied between 0.62 and 0.89. This was essentially due to the low dominance of few species. Cluster analysis was used to characterise Essaouira's rocky shores on the basis of benthic polychaete communities. SIMPER analysis confirmed the presence of three distinct communities. According to canonical correspondence analysis, the structure and distribution of faunal assemblages of benthic polychaetes was mainly related to topographical complexity, water temperature, hydrodynamic conditions and upwelling. We conclude that these rocky shores show typically high benthic polychaete diversity compared to the taxonomic list of other rocky coasts. In addition, these results constitute a baseline data for the development of a sustainable network for long-term monitoring of benthic polychaete community changes due to ecological factor influences and anthropogenic activity impacts.

Keyword: polychaetes; taxonomic diversity; Essaouira; rocky shore; faunal assemblage

1 INTRODUCTION

Among marine invertebrates, polychaete annelids are one of the most diverse and abundant benthic groups: more than 12 000 species of polychaetes are reported worldwide (Appeltans et al., 2012). They colonize a wide variety of marine habitats, from soft to hard substrates, from the intertidal zone to the hadal zone (Serrano Samaniego, 2012). Polychaetes are one of the most characteristic groups of benthic communities (Labrune et al., 2007) and one of the richest benthic taxa in terms of specific richness (Arvanitidis et al., 2002). This group often dominates benthic macrofauna and can be considered as a good proxy to describe the distribution of macrobenthic communities (Olsgard and Somerfield, 2000) when it is the main component of macrofauna (Mackie et al., 1995). Thus, in most cases, assemblages of polychaetes show similar variation in distribution

* Corresponding author: a.mouabad@uca.ma

patterns as the totality of benthic fauna (Fauchald, 1973) and can therefore be considered as representatives of marine biodiversity (Olsgard et al., 2003). Moreover, polychaetes are considered as appropriate indicators of biodiversity trends in biogeographic studies (Gobin and Warwick, 2006) because unlike other taxa, their taxonomy is relatively well described (although this point is still debated because of many synonymies that make the systematics of polychaetes still unstable (Rouse and Pleijel, 2001)). They also encompass several trophic levels and life histories. They are often represented by a good number of species and families in ecological samples (Hutchings, 1998; Cole and Chapman, 2007). Several factors are known to influence the distribution and abundance of polychaetes, including substrate nature, amount of organic matter contained in sediments, depth, salinity and temperature (Hutchings, 1998), many of which are reported here.

In Morocco, the earliest studies on polychaetes began at the beginning of the 20th century with Charrier (1921) who compiled a list of 21 species from the region of Tangier. With the Vanneau expedition, Fauvel (1928) added two new species: *Cirratulus dollfusi* and *Prionospio elhersi*. The second oceanographic cruise of the Vanneau described by Fauvel (1936) was an important contribution to the knowledge of polychaetes with 226 species, 142 genera, and 30 families recorded. This study by Fauvel presents the two species first described in 1928 and 4 new species: *Cirrineris incertus*, *Mastobranchus dollfusi*, *Melinna monoceroïdes*, and *Lysippe vanelli*. Subsequently, Bellan (1959) studied the polychaetes collected during the Calypso cruise in the Sea of Alboran and in the Ibero-Moroccan bay. In 1968, he noted the presence of *Dispio uncinata* along the coast of Morocco. Subsequently, with their survey from the Sahara to the mouth of the Oued Draa, Rullier and Amoureux (1969) completed the list of polychaetes of Morocco with 13 further species including a species new to science *Panousea africana*. Amoureux and Elkaïm (1972) later described the species *Alkmaria romijni*, a new Ampharetian for the Moroccan coast. Boucher and Glémarec (1974) made a new study of the benthos along the Southern coastline of Morocco. In the Gibraltar strait, Amoureux (1972, 1976a, b) studied a collection of Neridians and described a new species *Nereis moroccensis*. During the BIOMAR project, Bayed and Glémarec (1987) estimated the number of polychaetes in Moroccan waters at 333 species. This inventory was completed by the inclusion of polychaetes from sandy beaches of the littoral zone (Bayed, 2003; Bazaïiri et al., 2003).

The first studies on polychaetes in Moroccan estuaries were conducted by Elkaïm (1972, 1974, 1976a, b, 1977) in the Bou Regreg estuary. Among the 89 species found in this estuary, Gillet (1986, 1988) found four species new to the region: *Arenicola claparedii*, *Nereis succinea*, *Phyllodoce macrphthalma* and *Streblospio dekhuyzeni*. In the mouth of the Oued Souss, Gillet et al. (2003), and Aït Alla et al. (2006) recorded *Arenicola marina*, *Glycera tridactyla*, and *Hediste diversicolor*. Other records include the lagoons of Temara, close to Rabat, (Amoureux and Gantès, 1976), Moulay Bousselham (Bazaïiri, 1999), Marja Zerga (Bazaïiri et al., 2005) and Smir (Chaouti and Bayed, 2005). More recently, the polychaetes of the Khnifiss lagoon in the Sahara were studied by Lefrere (2012). A study of the rocky shore near Safi, describes *Boccardia polybranchia* the latest addition to the Moroccan polychaete inventory (Goumri et al., 2017) which, to date includes 321 species instead of 333 species, because some species reported as new had already been recorded previously and other species were synonymous.

To date, there has been no research into taxonomic diversity of benthic polychaetes on Essaouira intertidal rocky shores; therefore the present study aims to quantify polychaete diversity in this Atlantic coastal area of Morocco. The objective is also to describe, the structure and spatial distribution of polychaete communities in the intertidal rocky shores of Essaouira in relation to the major environmental variables (granulometry, salinity, temperature, pH, intertidal range). Hence, the question of this work is: among the measured environmental parameters, which ones can influence mainly the structure and distribution pattern of polychaetes along these intertidal rocky shores?

2 MATERIAL AND METHOD

2.1 Study area

The study area is located along the Atlantic coast of Essaouira province, Morocco. It lies between longitudes 9°20′W and 9°90′W and between latitudes 31°10′N and 31°50′N (Fig.1). This coastal zone has a diverse climate because of its geographical location between the Sahara desert and Atlantic Ocean. This is typical of the North African Atlantic coast (warm, humid and with high mean temperatures).

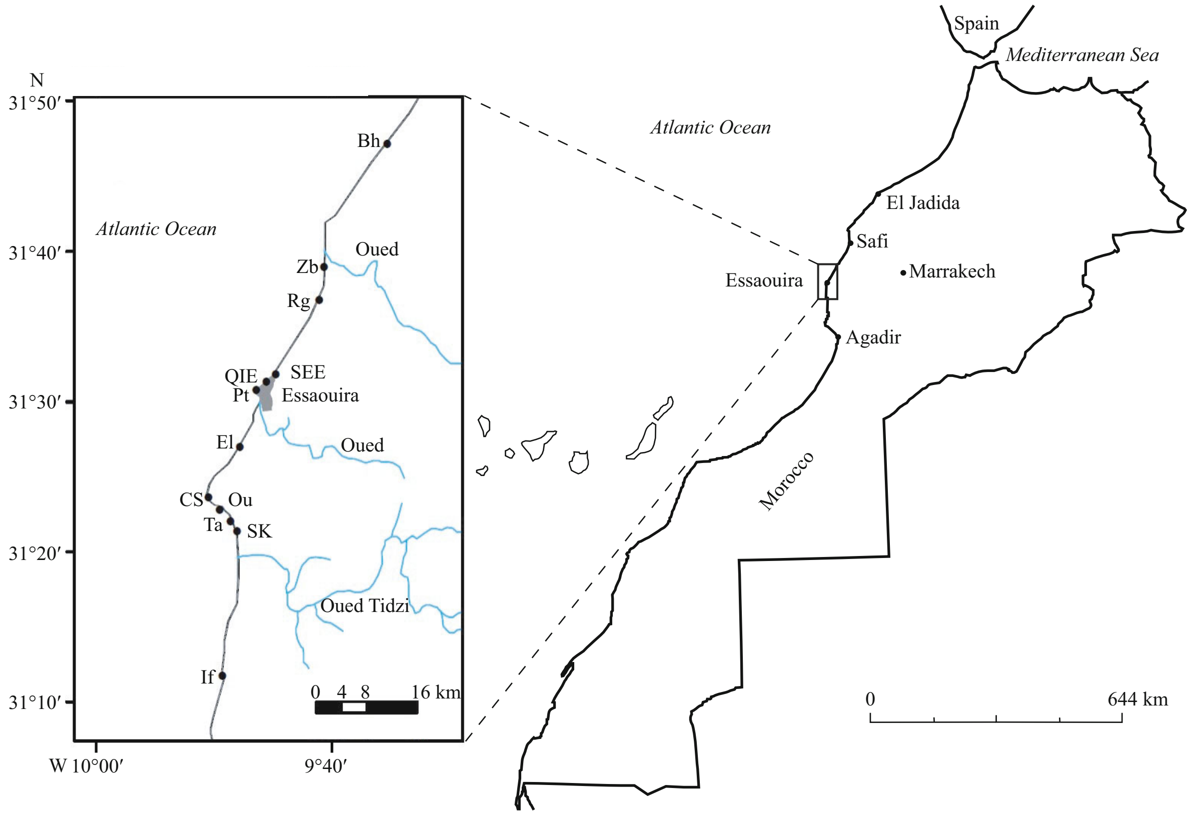

Fig.1 Map showing the location of sampling sites along the coast of Essaouira (Atlantic coast of Morocco)

The annual precipitation is between 285 mm and 344 mm (Molua Mwambo et al., 2007), unevenly distributed throughout the months of the year. The months of July and August are driest, typically (0 mm rainfall). The pluviometric regime in Essaouira is "HPAE" type (where H: Winter; P: Spring; A: Autumn; E: Summer), with a rainier winter, followed by spring, then autumn and finally summer (Bal, 1993). This pattern of rainy winters and dry summers is characteristic of the Mediterranean climate type. The study area is also subjected to the action of the east wind ("Chergui") and north / northwest wind. The first is hot, dry and occasionally violent which increases temperatures and decreases the humidity, the second has a contrary effect decreasing temperatures and increasing humidity (Benzayane, 1989). Strong winds are a constant feature of the study area, dominated by North-Easterlies (36%) and Northerlies (26%) (Bal, 1993). The Atlantic coast of Essaouira is also characterised by upwelling that tends to be persistent because of the exceptionally wide continental plate. Upwelling is particularly active from June to October, the period corresponding to the maximum power of the trade winds. In addition, upwelling generates atmospheric stability, and creates a semi-arid zone along the coast with a consistent average air temperature of about 16.7°C during the year (Belvèze, 1983; Gentile, 1997; Simone, 2000; Bazaïiri et al., 2010; Benazzouz, 2014). The seawater transparency at the intertidal rocky shores of Essaouira could be characterized as satisfactory, since the bottom is clearly visible at each biotope. It should be noted though that when north and northeast winds blow in the area, the water transparency is limited due to water turbulence and the incoming material from the northern coast by littoral drift (Bal, 1993; Flor-Blanco et al., 2013).

2.2 Sampling and laboratory techniques

Twelve sampling sites (Fig.1; Table 1) were studied in summer 2016. The samples were collected using a quadrat method (Misra, 1968) with four quadrats (each 25 cm×25 cm, surface area 0.062 5 m^2) in the intertidal zone of each site. Sampling was done by scraping off the surface layer (sediments, algae) and digging 2 cm in the hard substratum using a hammer. The material retained was fixed in formaldehyde (8%). Major water variables such as pH, conductivity and temperature were recorded in situ for each site, and the salinity was calculated from the conductivity and temperature of sea water (Aminot and Kérouel, 2004). At the same time, the intertidal range (m) of each rocky shore was

Table 1 Detailed description of the sampling sites

Sampling site	Description
Bhibeh (Bh)	Located about 47 km to the north of Essaouira, rocky shore relatively wide with marked roughness, bounded in its upper part by a cliff of 2 to 3 m. Many tide pools developed on the rocky shore
Zaouiet Bouzarktoune (ZB)	Located 18 km to the north of Essaouira, a small sandy beach with a large flat rocky substratum and very hard with many basins, bounded in its upper part by a cliff of 7 to 9 m. Tourist site with relatively important activity
Rguigua (Rg)	Located 13 km to the north of Essaouira, platform with developed tide pools. Flat rocky shore bounded in its upper part by a strip of sand and dunes
Wastewater treatment plant of Essaouira (SEE)	Situated to the north of Essaouira city (approximately 1.5 km), wide sandy beach with a flat rocky substratum small sized depressions interspersed with pools
Industrial district of Essaouira (QIE)	Located in Essaouira city near the industrial area. Wide flat rocky substratum with zone of decompression of the basins relatively developed and covered with a layer of fine sediment in its upper part. Solid discharge installed on site plus pollution from discharges from neighborhoods of the city
Port (Pt)	Located in Essaouira city in the vicinity of the fishing port. Narrow rocky flat with small islands minimizing the action of waves on the coast. The intertidal zone is subhorizontale and dewatered at low tides containing relatively numerous tide pools. Pollution from port activities and discharges from neighborhoods in the city
Elkarkoura (El)	Located 9 km south of Essaouira, a large rocky flat with extensive basins and numerous rock pools, bounded in its upper part by a wide beach of coarse sand and dunes
Cap Sim (CS)	Located 16 km south of Essaouira, large rocky flat very hard having roughness marked with developed tide pools exposed directly to the action of the waves. This rocky flat is delimited in its upper part by a cord of unstable pebbles and a band of sand and dunes of some meters in height
Ouassen (Ou)	Located 18 km south of Essaouira, a small rocky bay with well-developed and numerous tide pools, bounded in its upper part by a strip of sand and an unstable gravel beach at the base of a high tide cliff of 8 to 9 m
Tagnza (Ta)	Located 20 km south of Essaouira, near the Ouassen site. The substratum consists of a horizontal rocky plateau covered with a layer of fine sediment with small tide pools. The upper part is bounded by a sandy beach and dunes. Site with relatively low fishing activity with fish market recently built on site
Sidi Kaouki (SK)	Located 23 km south of Essaouira, large and horizontal rocky flat with tide pools. The bedrock of this rocky shore is covered with a crust of about 3 cm of clayey material highly perforated by burrowing organisms. This rocky flat is delimited in its upper part by a narrow strip of sand and a cord of unstable pebbles. Sidi Kaouki is a tourist place with moderately important human activities
Iftane (If)	Located 43 km south of Essaouira, rocky flat relatively wide, very marked roughness with ditches perpendicular to the coast, platform with developed tide pools. This flat is bounded in its southern part by a bay of sandy beach and in its upper part by a narrow layer of sand and with the presence of some grouts and cliffs of 3 to 4 meters. This site is relatively protected and is characterized by a very important biological diversity compared to the other sites

measured from low water to high water using a measuring tape, and rock samples (20 cm in length and 15 cm in width) were collected for each sampling site. All these samples were at least triplicated at each site to ensure the representativeness of the samples and measured parameters. In the laboratory, biological samples were rinsed in freshwater and preserved in 70% ethanol and the polychaetes were identified to species level when possible using various guides, e.g., Fauvel (1923, 1927) and Fauchald (1977), and then counted. The rock samples were cut and dozens of thin sections were prepared and grains size from these thin sections was measured using polarizing optical microscope (OLYMPUS BH 2). The void percentage in each thin sections was estimated using "Chart for estimating mineral grain percentage composition of rocks and sediments" (Compton, 1962).

2.3 Data analysis

The polychaete community structure was characterized taking into account the abundance (N), species richness (S), Shannon-Wiener's diversity index (H') (Shannon and Weaver, 1963) and Pielou's evenness index (J') (Pielou, 1966). The taxonomic similarity between sampling sites was elucidated by a cluster analysis (Bray-Curtis similarity, Complete Link), and the differences in faunistic composition between cluster groups were tested using the 1-way ANOSIM test. The percentage of similarity procedure (SIMPER) was used to indicate the species that are mainly responsible for the differences identified in the results of the ANOSIM test (Clarke, 1993; Clarke and Warwick, 1994). These analyses were done after applying square-root transformation to the polychaete abundance matrix. Pearson's correlation was used to determine the possible correlations between the mean values of environmental parameters and benthic polychaete parameters (abundance, species richness, equitability index (J') and Shannon index (H')). Canonical correspondence analyses (CCA), based on the mean values of environmental parameters and polychaete abundance matrix, were performed to

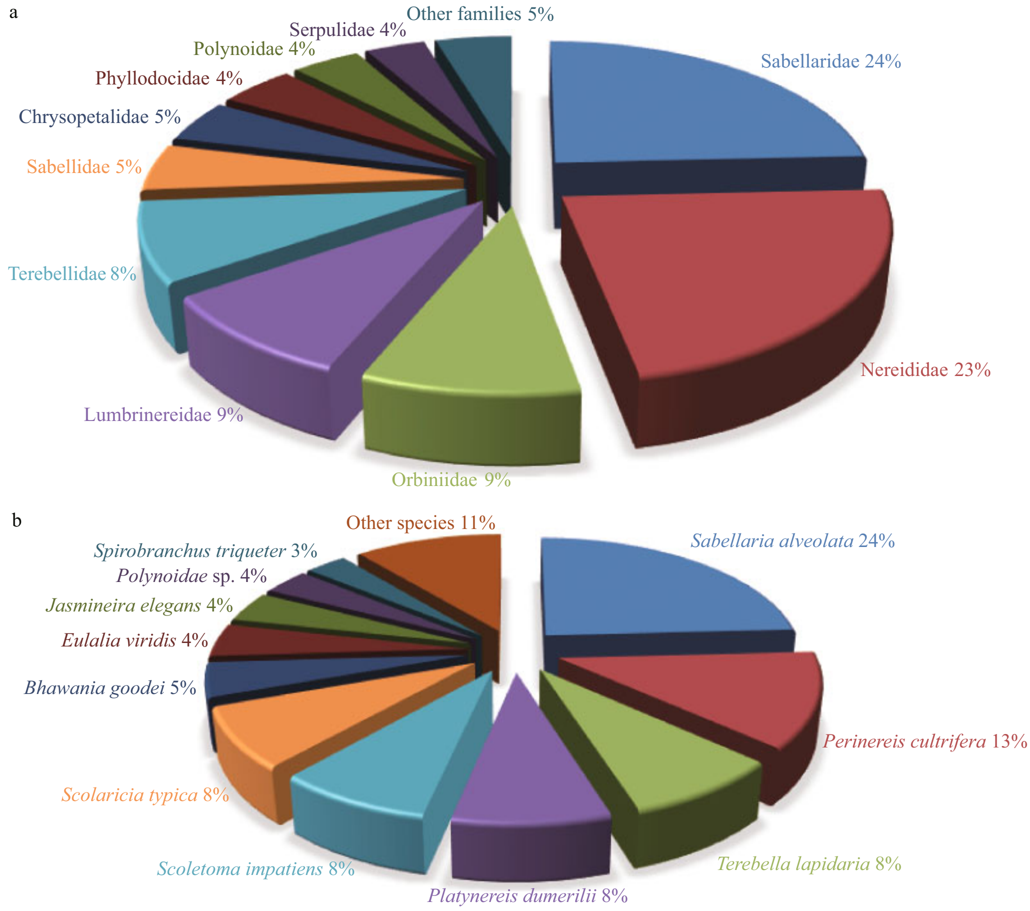

Fig.2 Relative abundance (%) of the polychaete families (a) and species (b) sampled in the study area

determine the relationships between benthic polychaete distribution and measured environmental parameters. All these analyses were performed, using the BioDiversity Pro statistical program (Version 2.0) and PAST software package (Version 3.15 for Windows, Hammer et al., 2001).

3 RESULT

3.1 Faunal analysis

A total of 4 435 specimens belonging to 16 families, 29 genera and 34 species were collected. Sabellaridae was the most dominant family with 24% in terms of abundance, followed by Nereididae (23%), Orbiniidae (9%), Lumbrinereidae (9%) and Terebellidae (8%) (Fig.2a). *Sabellaria* was the most abundant genera with 24% in terms of the individuals, followed by *Perinereis* (15%), *Scoletoma* (9%), *Terebella* (8%), *Platynereis* (8%), and *Scolaricia* (8%). *Sabellaria alveolata* (24%) ranked first among species abundance followed by *Perinereis cultrifera* (13%), *Platynereis dumerilii* (8%), *Terbella lapidaria* (8%), *Scoletoma impatiens* (8%) and *Scolaricia typica* (8%); among the three most abundant species, one belonged to the genus *Sabellaria*, one to *Perinereis* and one to *Terebella* (Fig.2b).

The abundance of polychaetes per site ranged over an order of magnitude with highest density recorded at Iftane (3 288 ind./m^2), medium density at Bhibeh (1 312 ind./m^2) and the lowest density at Elkarkoura (380 ind./m^2). The number of species of polychaetes recorded ranged between 11 and 24 with the highest species richness observed at Iftane and the lowest species richness at SEE that receives effluent from the wastewater treatment plant of Essaouira (Table 2).

The values of diversity (Shannon Wiener Index H') and Evenness (Pielou Index J') of polychaetes of Essaouira's rocky shores are presented in Table 2. Diversity and Evenness indices display marked variation with the maximum of the Shannon H' diversity index recorded at Ouassen (H'=3.95) a bay south of Essaouira, and a minimum at SEE (H'=2.28), located north of the urban area of Essaouira. The highest Pielou index, (J'=0.89) was that at the Ouassen coastal site, while the minimum was recorded at the site Bh (J'=0.62) located at north of Essaouira.

Table 2 Spatial variations in number of species (*S*), number of ind./m² (*A*), Shannon-Wiener's diversity index (*H′*) and Pielou's evenness index (*J′*) at the sampling sites (*n*=4)

Site	*S*	*A*	*H′*	*J′*
Bh	16	1312	2.49	0.62
ZB	14	560	2.76	0.72
Rg	18	1200	3.15	0.76
SEE	11	812	2.28	0.66
QIE	18	1776	2.64	0.63
Pt	18	2120	2.79	0.67
El	14	380	2.51	0.66
CS	15	696	2.91	0.74
Ou	22	1072	3.95	0.89
Ta	19	2040	3.22	0.76
SK	19	2484	3.22	0.76
If	24	3288	3.34	0.73

Table 3 Faunal assemblage characteristics on the Essaouira coastline

Parameter	Group A	Group B	Group C
Site number	5	4	3
Total species richness	24	30	20
Mean abundance (ind.)	355	555	146
Mean diversity (bit/ind.)	2.79	3.43	2.51
Mean evenness	0.68	0.78	0.68
Dominant species	*Sabellaria alveolata*	*Sabellaria alveolata*	*Platynereis dumerilii*

3.2 Faunal assemblages

The results of the cluster analysis, based on square root-transformed abundance data are illustrated in Fig.3. According to this analysis, there are three distinct assemblages (A–C) with a high level of similarity in the study area:

Group A consists of five rocky sites (Bh, Rg, CS, QIE and Pt). This group has a moderate species richness (24 species) and a medium abundance (355 ind.). This assemblage is characterized by a medium diversity (2.79 bits/ind.) and has a moderate Pielou's evenness (*J′*=0.68) like group C. The most abundant species in this assemblage is *Sabellaria alveolata* followed by *Scolaricia typica* (Table 3).

Group B located in the southern region of Essaouira, includes four rocky sites (Ou, Ta, SK, QIE and If), with the highest number of species (30) and the highest mean abundance (Table 3). This assemblage

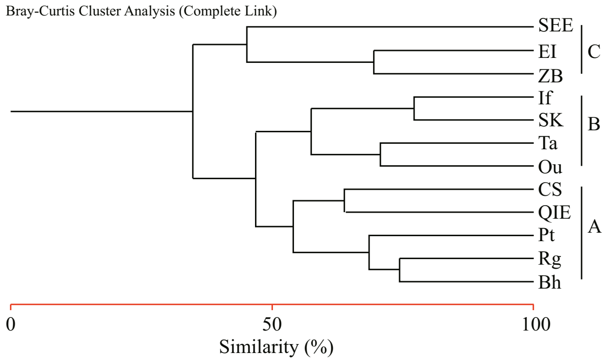

Fig.3 Distinct groups of sites established by cluster analysis for the 12 sampling sites considered on the Essaouira coastline

is characterized by the highest diversity (3.43 bits/ind.) and the highest Pielou's evenness (*J′*=0.78). The most abundant species in this group is *Sabellaria alveolata* followed by *Perinereis cultrifera*.

Group C is formed by three rocky sites (ZB, El, and SEE), with the lowest number of species (20) and the lowest mean abundance (Table 3).This assemblage is characterized by the lowest diversity (2.51 bits/ind.) and has moderate Pielou's evenness (*J′*=0.68) like group A. The most abundant species in this assemblage is *Platynereis dumerilii* followed by *Scoletoma impatiens* (Table 3).

The ANOSIM test revealed significant differences in faunistic composition between assemblages (global R=0.633; number of used permutations=999, P<0.001) (Table 4). As indicated by SIMPER analysis (Table 4), the species *Sabellaria alveolata*, *Scolaricia typica*, *Bhawania goodei*, *Polynoidae* sp., *Perinereis marionii*, *Lysidice ninetta*, *Platynereis dumerilii* and *Terebella lapidaria* explain most of dissimilarity between assemblages A and B (average dissimilarity=41.7%). *Sabellaria alveolata*, *Scolaricia typica*, *Terebella lapidaria*, *Platynereis dumerilii* , *Perinereis marionii*, *Scoletoma impatiens*, *Perinereis cultrifera* and *Eulalia viridis* contributed most to dissimilarity between assemblages A and C (average dissimilarity=49.66%). The main sources of dissimilarity between assemblages B and C (average dissimilarity=55.93%), were *Sabellaria alveolata* (5.82%), *Terebella lapidaria* (4.02%), *Bhawania goodei* (3.91%), *Perinereis cultrifera* (3.72%), *Polynoidae* sp. (3.62%), *Platynereis dumerilii* (3.32%), *Jasmineira elegans* (3.04%) and *Spirobranchus triqueter* (2.46%). Generally, the SIMPER analysis which identifies the taxa responsible for spatial grouping did not show great differences along the coast of Essaouira (Table 4).

Table 4 Results of the ANOSIM and SIMPER analyses between assemblages established after cluster analysis

Compared assemblage	ANOSIM		SIMPER dissimilarity (%)	Contributions (%) of major species to dissimilarity
	R	*P*		
A and B	0.487	0.018	41.7	*Sabellaria alveolata* (3.99%), *Scolaricia typica* (3.31%), *Bhawania goodei* (2.89%), *Polynoidae* sp. (2.69%), *Perinereis marionii* (2.28%), *Lysidice ninetta* (2.16%), *Platynereis dumerilii* (2.15%), *Terebella lapidaria* (2.08%)
A and C	0.672	0.013	49.66	*Sabellaria alveolata* (6.78%), *Scolaricia typica* (5.04%), *Terebella lapidaria* (4.36%), *Platynereis dumerilii* (3.88%), *Perinereis marionii* (3.33%), *Scoletoma impatiens* (3.12%), *Perinereis cultrifera* (2.83%), *Eulalia viridis* (2.30%)
B and C	0.852	0.022	55.93	*Sabellaria alveolata* (5.82%), *Terebella lapidaria* (4.02%), *Bhawania goodei* (3.91%), *Perinereis cultrifera* (3.72%), *Polynoidae* sp. (3.62%), *Platynereis dumerilii* (3.32%), *Jasmineira elegans* (3.04%), *Spirobranchus triqueter* (2.46%)

Table 5 Pearson correlation matrix for the benthic polychaete parameters and environmental factors of Essaouira intertidal rocky shores

	Length (m)	Void percentage in the rock (%)	Grain size (mm)	Water temp. (°C)	pH	Conductivity (ms/cm)	Salinity	Species richness	Abundance	Shannon index (H')	Equitability index (J')
Equitability index (J')	0.348	-0.309	0.160	-0.052	-0.033	-0.471	-0.051	0.536	0.067	0.920**	1
Shannon index (H')	0.282	-0.329	0.186	-0.374	0.002	-0.306	0.272	0.821**	0.377	1	
Abundance	-0.132	-0.155	0.252	-0.769**	0.226	0.470	0.794**	0.754**	1		
Species richness	0.080	-0.250	0.165	-0.707*	0.099	0.021	0.640*	1			
Salinity	-0.158	-0.087	0.381	-0.982**	-0.217	0.538	1				
Conductivity (ms/cm)	0.114	-0.008	0.299	-0.368	0.355	1					
pH	0.431	-0.259	-0.189	0.314	1						
Water temp. (°C)	0.193	0.090	-0.349	1							
Grain size (mm)	0.352	-0.273	1								
Void percentage in the rock (%)	-0.489	1									
Length (m)	1										

*: correlation is statistically significant according to 0.05 level (two way); **: correlation is statistically significant according to 0.01 level (two way).

3.3 Relationships between faunistic and abiotic data

Significant positive and negative correlations between the benthic polychaete parameters and major environmental variables are presented in Table 5. The correlation between abiotic factors showed that salinity was negatively correlated with the water temperature (R=-0.982; P=0.001). The species richness was negatively correlated with the water temperature (R=-0.707; P=0.01), whereas it was positively correlated with the salinity (R=0.640; P=0.025). The abundance was also negatively correlated with the water temperature (R=-0.769; P=0.003), but was positively correlated with salinity (R=0.794; P=0.002) and species richness (R=0.754; P=0.005). The Shannon Index (H') was positively correlated with species richness (R=0.821; P=0.001), and Equitability Index (J') (R=0.920; P<0.001).

Whilst it is recognised that such correlations are not necessarily proof of cause and effect, CCA results reinforce the likelihood that abiotic factors contributed significantly in explaining the spatial distribution of benthic polychaetes in the studied rocky shores. The first and second axes accounted for 36.17% and 29.81% of the variance observed in the benthic polychaetes data, respectively. On the CCA plot in Fig.4, the taxonomic composition of If, SK, Pt, Bh, CS, El and ZB sampling sites was mainly related to pH, while salinity and conductivity were the most influential factors at QIE. The Rg and SEE sampling site were linked by void percentage in the rocks. Finally, Ta and Ou sampling sites were linked by grain size and shore length and water temperature, respectively.

4 DISCUSSION

The intertidal rocky shores have received a great deal of attention by marine ecologists and become the topic interest of scientific research. They have been described as natural laboratories and as a field of scientific reflection because a rich array of concepts

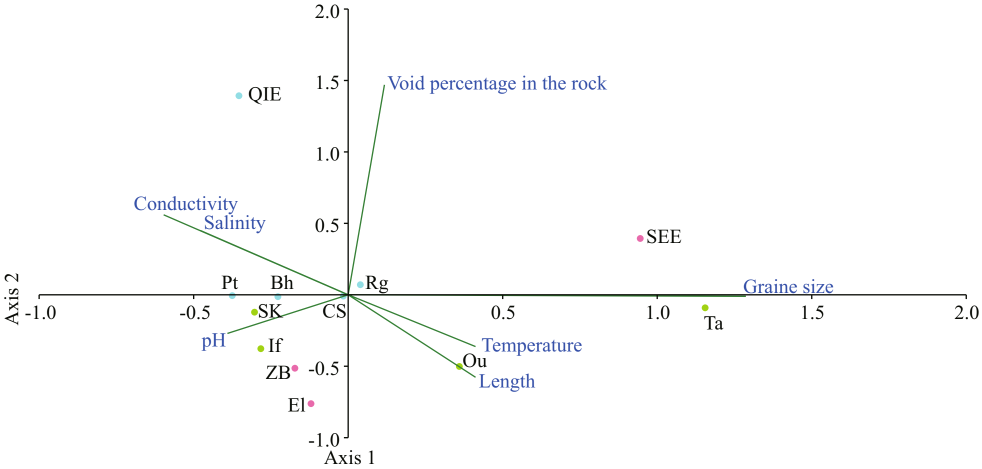

Fig.4 Canonical correspondence analysis (CCA) ordination of the abundance of species and environmental parameters in the study area

has arisen from their study (Branch, 2001). This study provides the first characterization of benthic polychaete communities along the intertidal rocky shores of Essaouira on the Atlantic coast of Morocco in context with major environmental parameters such as topographical complexity (length of rocky shore), substrate characteristics (substrate texture, void in substrate, and substrate heterogeneity), water temperature, pH, conductivity and salinity. According to Chouikh et al. (2019), the longest rocky shore measured was 271.67±12.58 m in the (CS) site, while the shortest was 88.33±7.64 m in the (Pt) site, and the mean grain sizes ranged from 0.19±0.10 mm (CS) to 6.83±6.27 mm (Ta), whereas the void percentage in the rocks varied from (1.00±0.04)% (El) to (43.00±5.77)% (QIE). Topographical complexity and substrate characteristics, resulting from the interaction of several local factors (i.e. hydrodynamics, geology, coastal morphology) have been considered as crucial factors affecting diversity and spatial distribution of intertidal communities (Archambault and Bourget, 1996; Kostylev et al., 1996; Londoño-Cruz, 2007; Londoño-Cruz and Tokeshi, 2007). Kostylev et al. (1996) states that topographical complexity increases the numbers of species and abundance. The greater abundance may be due to larger surface area while the number of species present is influenced by the range of microhabitats available. The tiny pits in the rock may provide refuge for juveniles and small species, while larger cracks and crevices provide shelter for mobile predators (Hill et al., 1998). This habitat diversity provides a favourable environment for a highly specialised fauna of burrowing polychaetes. Temperature can be considered one of the most important abiotic factors affecting coastal ecosystems, given its impacts on the physicochemical characteristics of seawater (Sundaramanickam et al., 2008). The sampling sites studied here are located along the open Atlantic coast, situated a few kilometres from each other and hence large spatial variations were not evident. However spatial variations in seawater temperature showed slight fluctuations with a minimum (17.50±0.50°C) recorded in the (Pt) site and a maximum (21.00±0.15°C) recorded in the (SEE) site (Chouikh et al., 2019). These slight fluctuations can be due to local conditions including hydrodynamics. The pH of seawater also plays an important role in optimum performance and many biological activities can occur only within narrow range of pH (Shephered and Bromage, 1992). As with temperature, pH values did not show large spatial variation at the study sites and were always slightly alkaline ranging from 8.00±0.01 at (Ou) site to 8.51±0.01 at (If) site (Chouikh et al., 2019). The conductivity of seawater depends on tidal influence, rainfall and the intensity of solar radiation. A high conductivity may also reflect strong mineralization. The measured conductivity was typical of seawater, with a minimum (50.00±0.01 ms/cm) and a maximum (51.00±0.62 ms/cm) recorded respectively at (Ou) and (SK) sites (Chouikh et al., 2019). Small variations in the conductivity values in our samples may be due to the varying amounts of suspended solids present in different locations as well as the calcareous nature of this rocky shoreline, though conductivity rarely exceeded the normal range of values reported for sea water (Rodier, 2009). Salinity plays also a crucial role as a limiting factor in the distribution of most marine organisms, and its change due to dilution and evaporation, influences the organisms living on the intertidal zone (Gibson, 1982). Salinity at all surveyed sites was above 'normal' for coastal sea water, probably attributable to faster evaporation during summer. However, slight fluctuations were observed between sampling sites with a lowest value 36.26±0.24 recorded at (SEE) site and a highest value 39.81±0.08 recorded at (Pt) site (Chouikh et al., 2019). These slight spatial fluctuations may be due to the nature of the substrate and the intensity of the prevailing hydrodynamic regime.

In the present study, one of the first in this area, a total of 34 species of benthic polychaetes belonging to 16 families and 29 genera were recorded. The benthic polychaetes of intertidal rocky shores of the Moroccan coast in general are not well studied and the comparison of taxonomic composition at Essaouira with other rocky shores of this Atlantic coastal region is difficult due to lack of data. Sif et al. (2012) identified 39 species of polychaete from the intertidal rocky and sandy shores of El Jadida coastline (to the north of our site, Fig.1). Goumri et al. (2016) reported 21 species of benthic polychaete at Safi rocky shores (to the north of our site, Fig.1) with *Boccardia polybranchia* a new record for the Moroccan Atlantic coast. Elsewhere, on the Atlantic coast of Portugal, Vinagre et al. (2016) investigated the macrozoobenthic diversity on the intertidal rocky shores and reported 61 species of the polychaetes, whilst in the Mediteranean, Cardone et al. (2014) reported 20 species of polychaete from hard substrata of the south-eastern Italian coast. At 14 mid-littoral rocky shore sampling sites in Greece and Italy Keklikoglou et al. (2013) reported 123 polychaete species, five of which were new records for these biogeographic regions. Elsewhere, Surugiu (2011) reported 24 species on rocky and sandy shores of the Black Sea.

The most dominant species during this study was *Sabellaria alveolata* (24% of the individuals), while Sif et al. (2012) and El Asri et al. (2018) indicated that *Hediste diversicolor* was the most dominant species along the intertidal rocky and sandy shores of El Jadida coastline and in the Oualidia lagoon (to the north of our site). In Dakhla Bay (Atlantic coast of South Morocco), the most dominant species were *Maldane sarsi* and *Ophelia rathkei* (El Asri et al., 2019). The analysis of taxonomic structure of polychaetes along a stretch of rocky coast in the Ionian Sea (south Italy), revealed that *Platynereis dumerilii* was the most dominant species (Musco et al., 2009). Baghernezhad et al. (2015) indicated that *Spirobranchus kraussii* was the most dominant species in rocky intertidal area of the Persian Gulf (Bushehr Province). In the intertidal rocky habitats of Tromsø (northern Norway), the most abundant species were *Fabricia stellaris* and *Naineris quadricuspida* (Oug, 2001). In the bay of Mont-Saint-Michel (France), Dubois et al. (2002) and Desroy et al. (2011) indicated that *Sabellaria alveolata* has a preference for exposed rocky shore with high wave action, and the reefs built by this species attract other species and increase the biodiversity.

To understand the structure and organization of the benthic polychaetes communities of Essaouira's intertidal rocky shores, we used cluster analysis that allows discrimination between the sampling sites. Spatial changes in the structure of benthic polychaetes were evident using this method, allowing discrimination of three different assemblages. A similar spatial pattern was also reported along the intertidal rocky and sandy shores of El Jadida coastline (Sif et al., 2012). The diversity's indexes (Shannon Wiener Index H', Pielou Index J') were generally high and marked by a variation between these assemblages reflecting a varying diversity of polychaetes over the sites forming each assemblage. This was essentially due to the low dominance of few species, and the existence of a large number of ecological niches at each intertidal rocky shore.

The community structure seen on rocky shores reveals the strong direct or indirect influence of biological interactions, particularly competition and predation, and possible influence of physicochemical factors such as topographical complexity and structure of the substratum, wave action, desiccation, temperature, and salinity, the mix of physical and biological factors and sometimes human impacts (Stephenson and Stephenson, 1949; Lewis, 1964; Kostylev et al., 1996; Hill et al., 1998; Branch, 2001). Wilson (2013) stated that the most critical factors that determine the ecological characteristics of rocky shores are their level (height) within the intertidal zone, their degree of exposure to wave action, the magnitude of tidal range, and the "rugosity" of the surface, i.e., the complexity of the surface in terms of loose stones, ledges, pools, crevices, and gutters. Factors impacting the structure and spatial distribution of benthic polychaetes of Essaouira's rocky shores include biotic and abiotic parameters. The first is likely negligible, as the abundance of species is not sufficiently strong to allow significant biotic interactions (inter and intra-specific competition);

Environmental factors are probably more important. Indeed, water temperature is likely to be the most important factor determining the structure and spatial distribution of benthic polychaetes via its negative influence on species richness and abundance, as was shown by the strength of the correlation. On other hand, the rocky shores of Essaouira are long and rich in microhabitats, providing niches for a larger range of species and reducing the negative effects of species interactions, which favours the increase in biodiversity of polychaetes in this area. Hydrodynamic parameters also influence the distribution of polychaetes along Essaouira's rocky shoreline, probably due to the upwelling of cold waters enriched in nutrients. Thus, upwelling is particularly active from June to October (the time of our sampling), coinciding with the period of strong trade winds (Belvèze, 1983; Gentile, 1997; Simone, 2000; Bazaïiri et al., 2010; Benazzouz, 2014). The influence of water agitation (and secondary factors such as water clarity and levels of suspended matter (Bellan, 1964)), will have influence on suspension feeders and detritivors. It will also have effects on the reproduction of temporarily pelagic benthic species and on gametes and larvae which are carried by currents (Pérès, 1961). It is probably through these mechanisms that hydrodynamics exert their influence on the structuring and distribution of benthic polychaetes at our study sites.

With about 3 500 km of coastline divided between the Mediterranean coast (512 km) and Atlantic coast (2 934 km), the biodiversity of polychaetous annelids of Morocco currently comprises 321 species, 180 genera and 41 families. Comparisons with neighbouring coastlines are difficult due to the lack of data; However, the polychaete fauna in neighbouring Mauritania is represented by only 56 species from 49 genera and 26 families along its 700 km of Atlantic coastline (Gillet, 2017). In contrast, the polychaete fauna of Morocco appears less rich than the Mediterranean shores of Tunisia (375 species; Zaâbi-Sendi, 2013), Spain (661 species), Italy (800 species), and France (934 species) (Dauvin et al., 2006). It will be important to extend taxonomic studies (and accompanying measures of environmental variables) to improve the knowledge of the Moroccan fauna and verify and explain the apparent low diversity of its polychaete communities.

5 CONCLUSION

This study on the taxonomic diversity and structure of benthic polychaete communities of Essaouira's rocky shores has identified 34 taxa representative of the intertidal zone. Salinity, hydrodynamic composition and upwelling phenomena were the most likely water quality parameters affecting the biodiversity of benthic communities. Rocky shores typically show high benthic diversity, as a result of habitat diversity and nutrient availability. Compared to the taxonomic list of other rocky coasts, those of Essaouira appear rich. However, the presence of increasing human activities in the region could negatively impact the benthic fauna, highlighting a need for targeted surveillance and conservation programs for this area.

6 DATA AVAILABILITY STATEMENT

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

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