Community structure and spatial patterns of soft-bottom macrozoobenthos in Oualidia lagoon, Moroccan Atlantic

EL ASRI Fatima*[1, 5], ERRHIF Ahmed[1], MARTIN Daniel[2], TAMSOURI Mohamed-Naoufal[3], MAANAN Mohamed[4] and ZIDANE Hakima[5]

[1] Health and Environment Laboratory, Faculty of Sciences Ain Chock, University Hassan II, B.P. 5366 Maârif, 20100 Casablanca, Morocco

[2] Centre for Advanced Studies of Blanes (CEAB-CSIC), Accés a la Cala St. Francesc, 14 Blanes 17300, Girona, Spain

[3] Fishing Laboratory, National Institute for Fisheries Research (INRH). – Tanger, Morocco

[4] UMR 6554 LETG-Nantes, University of Nantes, BP 81227, 44312 Nantes, France

[5] Prospection of Littoral Resources Laboratory, National Institute for Fisheries Research (INRH). Road Sidi Abderrahmane Club Equestre Ould Jmel – Casablanca, Morocco

* Corresponding author (e-mail: fatimaelasri25@gmail.com)

Abstract

The paper analyse the composition, structure and spatial organization of the soft-bottom macrozoobenthos inhabiting Oualidia lagoon (Moroccan Atlantic coasts), as well as their relationships with the main environmental variables. Material for the study was collected from 43 stations in winter 2013. A total of 56 species belonging to 6 phyla were recorded and identified. Species diversity was highest in molluscs, crustaceans and polychaetes. We used a Hierarchical Ascending Classification and a non-Metric Multidimensional Scaling to characterize the macrozoobenthos of the lagoon. We identified three groups of stations arranged from the outer -most to inner-most areas of the lagoon, harbouring a *Cerastoderma edule*, a *Tritia pfeifferi* and a *Tanais dulongii* assemblage, respectively. The trophic structure of the macrozoobenthos was dominated in density by deposit-feeders (88.1%)and species richness by carnivores (20%) and detritivorous (20%). The BIO-ENV analysis showed that the combination of granulometry, salinity and temperature were the major factors controlling the spatial distribution of the macrozoobenthos in the Oualidia Lagoon.

Keywords: Macroinvertebrates, Biodiversity, Environmental factors, spatial patterns, Oualidia lagoon, Morocco.

Introduction

In marine ecosystems, soft-bottom macrofauna represents a main basal component of the food web. Most macrobenthic species represent an important nutritional resource for many higher-level consumer, such as epibenthic crustaceans, fish and especially shorebirds (Jędruc et al, 2019). Shorebirds in particular are typically benthivorous and the most important consumers of intertidal benthic communities (Herman et al. 1999; Goss-Custard et al. 2006, Platell et al. 2006).

Benthic communities are also widely used to monitor the effects of environmental change. Being relatively long-living, compared to meio- and micro-benthos, they integrate water and sediment quality conditions with time and thereby, indicate temporary and chronic disturbances (Gray et al. 1990; Borja et al. 2000; Blanchet et al., 2008). The composition and structure of macrobenthic fauna are strongly correlated with the ecological conditions prevailing in the water-sediment interface, where multiple effects of organic enrichment and pollution occur (Borja et al. 2000; Dauvin et al. 2016). Thus, having a detailed knowledge of the macrobenthos appears essential to understand the functioning of coastal ecosystems including lagoons, and is a mandatory step to implement effective management and conservation measures.

Costal lagoons occupy around a 13% of the world coastline (Kjerfve 1994), playing a key ecological role (Velasco et al. 2017). They are among the marine habitats with the highest biological productivity (Kennish & Paerl, 2010), while being subjected to intense anthropogenic activities as they provide many goods and services. Among them, there are valuable social and economic activities such as traditional fisheries of fish and molluscs. Oualidia lagoon is not an exception and their natural resources supports many aspects of local people lives, including economic, cultural, and community relationships (Maanan et al. 2014). In addition, its biological, ecological and landscape potential favoured the a growing development of recreational and tourist activities. Altogether, these various human activities contribute to generate pressures that may impact biodiversity and cause ecosystem malfunctioning (Dauer et al. 2000; Borja and Dauer, 2008).

Moroccan coasts include a rich network of lagoons, one of them being Oualidia, which is located in its Atlantic coast. This lagoon provides a valuable environment for a rich variety of plants, birds, fish, and other wildlife (El Hamoumi et al. 2003). It is currently considered a Natural Park and, being the most important wintering area for migratory birds in Morocco (El Hamoumi et al. 2003), it is also considered a Wetland of International Importance (under the RAMSAR Convention).

Despite its intrinsic interest, the studies on Oualidia lagoon mainly focused on oceanography (Bennouna et al. 2000; Hilmi et al. 2005; Damsiri et al. 2014; Maanan et al. 2015) and wholesomeness (Bellucci et al. 2002; Zourarah et al. 2007; Hassou et al. 2014). Only three approached the analysis of the biodiversity of benthic species (Chbicheb 1996; El Asri et al. 2015, 2017). The aim of the present paper is, thus, to provide an overview of the biodiversity of the whole soft bottom macroinvertebrate assemblages inhabiting Oualidia lagoon, with particular emphasis on their distribution patterns and community structure, as well as their relationships with the main environmental variables explaining their spatial distribution.

Materials and methods

Study area

Oualidia lagoon, located on the Atlantic coast of Morocco between El Jadida and Safi (32°44’42” N–09°02’50” W) (Figure 1), has a surface area of 3.5 km² and exchanges water with the ocean through a 150 m wide major inlet. During spring, the tidal regime gives rise to a secondary shallower inlet about 50 m wide. The lagoon is characterized by having lateral channels connected to a meandering main channel with an average depth of 2 m and a maximum depth during flood tides not exceeding 5 m (Carruesco 1989). Flood tides cover more than 75% (2.25 km²) of the lagoon surface, bringing salt water up to the upstream reaches of the lagoon and into a saline marsh.

Sampling and processing

The soft bottom macrofauna was sampled at 43 stations (Figure 1) during winter 2013. Sediment samples were collected using a Van Veen grab, with two replicate samples in each station (0.125 m^2 in surface area). Samples were washed in situ through a 1 mm mesh sieve and fixed in a 10 % seawater formaldehyde mixture.

Superficial water salinity and temperature were recorded at each station by a thermo-salinometer. One additional sediment sample was also collected at each station to measure chlorophyll a concentration, grain size, and organic matter content. The chlorophyll 'a' content was determined according to the Lorenzen method (Holm-Hansen et al. 1965). Grain size was measured with a laser granulometer (Malvern, Mastersizer) at the LETG (Littoral, Environnement, Geomatique, Teledetection) (UMR 6554, University of Nantes). The percentage of organic matter was obtained as the weight losses after ignition at 450°C for 4 hours.

Data analysis

Macrobenthic communities were described through the following indicators: species richness, abundance, Shannon diversity (H', as log2) (Shannon 1948) and evenness (J') (Pielou 1966), calculated using the PAST software (Paleontological Statistics v2.14) (Hammer et al. 2001). Hierarchical Ascending Classification (HAC) based on Bray-Curtis distance (Ward's method) and non-metric multidimensional scaling (nMDS) were used to analyse the structure of the sampling stations based on the density matrix, using the SYSTAT 11 program. Densities were transformed log10 (x+1) to limit the influence of the most dominant taxa, and the species with a single occurrence in the lagoon were omitted from the analysis. The IndVal index (Dufrêne and Legendre 1997) was calculated for each species in each assemblage and the species showing the highest value were used to describe the respective assemblages. A multivariate correlation (BIOENV) (Clarke & Ainsworth 1993) was used to test the observed patterns and to define the existing correlations between species abundance and abiotic parameters, which allowed us to quantitatively explore the relationship between the levels of different factors and the biotic patterns. The BIOENV analysis was based on the Euclidean distance for the abiotic dataset and on the Spearman rank correlation, and were carried out in the R computational software 3.4.3. The analysis of the functional structure of the assemblages was based on the trophic groups assigned to the different macrobenthic taxa identified, according to Fauchald & Jumars (1979) and notably modified by Grall and Glémarec (1997), Hily and Bouteille (1999), Afli and Glémarec (2000), Pranovi et al. (2000) and Afli et al. (2008).

Results

Environmental data

Most environmental descriptors of Oualidia lagoon showed a clear gradient from outer to inner parts of the lagoon: temperature increased from 16.9 to 19.9 °C (Figure 2), salinity decreased from 10.1 to 39.5‰ (Figure 2), , organic matter increased from 1.94 to 31.97 %, showing the maximum at station 20 and the minimum at station 39 near the sandpit where the hydrodynamic regime favours sediment instability (Figure 3) And the granulometry was mainly sandy in the outer area and varied from sandy-silt to silty-sand in the inner one (Figure 3). Chlorophyll a showed a heterogeneous distribution and ranged between 1.19 and 23.41 mg/m² (Figure 3).

Species composition and diversity

A total of 56 taxa were recorded, specifically 28 mollusks, 17 crustaceans, seven polychaetes, two echinoderms, one cnidarian and one insect larvae (Table 1). Molluscs were the most abundant taxa (95.3%), followed by polychaetes (2.7%), and crustaceans (1.2%).

The middle part of the lagoon showed the highest number of species. Up to 21 species were recorded at stations 35 and 36 and only 1 at stations 33 and 42 (Figure 4). The highestdensity was also found in the middle part of the lagoon. Up to 5,142 ind.·m-^{2} were recorded at station 23, while only 8 ind.·m-^{2} occurred a station 32 (Figure 4). The diversity varied from 0 to 3.8 bits (Figure 5) and did not show any defined gradient, ranging in most stations between 1 and 2 bits. The evenness varied from 0 to 0.9 (Figure 5), being of less that0.4 in several stations.

Trophic structure

The soft bottom microbenthic fauna of Oualidia lagoon can be grouped in eight feeding groups: carnivores, detritivorous, herbivorous, micrograzers, surface deposit feeders, subsurface deposit feeders, suspension feeders and scavengers,. In terms of the species richness carnivores (19%), detritivorous (19%), herbivorous (18%), suspension feeders (16%) and surface deposit feeders (14%) were dominant, while micrograzers, scavengers and subsurface deposit feeders exhibited the lowest values (Figure 6A). In terms of density, the deposit-feeders were dominant (88.1%), followed by the scavengers (5%) and by a weak representation of all other groups (Figure 6B).

Assemblage structure

Three main groups of stations were identified in Oualidia (HAC, distance = 20%, Figure 7A; stress level = 0.14, nMDS, Figure 7B) showing significant differences (PERMANOVA, Table 2).

The first group included the stations from the outer part of the lagoon. It was characterized by having sandy bottoms with low organic matter, high species richness (37 species), the lowest mean density (99.7±104.5 ind.·m-²), and the highest mean H′ and J′ (2.5±0.8 bit/ind. and 0.8±0.1, respectively). The most dominant species were the crustacean *Tanais dulongii,* the gastropods *Peringia ulvae, Tritia pfeifferi* and *Tritia reticulate,* and the bivalve *Abra alba*.

The second group included the stations from the middle part of the lagoon. It was characterised by showing the highest mean density (1726.8±1485.7 ind. m-²), a moderate species richness (31) and the lowest mean H′ and J′ (1.1±0.5 bit/ind. and 0.3±0.2, respectively). The most dominant species were the gastropods *Tritia pfeifferi, Peringia ulvae* and the bivalve *Abra alba*.

The third group included stations from the inner part of the lagoon. It was characterized by a low species richness (17 species), a density intermediate between the two previous groups (209.9±188.3 ind.m-²) and moderate H′ and J′ (1.1±0.7 bit/ind. and 0.4±0.2, respectively). The sediments were characterized by a fine-grained texture and high organic matter, while the temperature was the highest.. The dominant species were the bivalve *Cerastoderma edule,* the gastropods *Peringia ulvae*, *Haminoea cf. japonica* and the polychaetes *Hediste diversicolor*, *Capitella* sp.

Relationships between biotic and environmental patterns

The highest rank correlation (Bio-Env, rho = 0.541) in Oualidia lagoon showed granulometry, salinity and temperature forming the "best combination" of abiotic parameters playing a relevant role in structuring the macrobenthic assemblages (Table 4).

Discussion

The present study aimed to analyse the spatial variability of the soft bottom macrozoobenthic assemblages in Oualidia lagoon, assessing the relationships between their spatial distribution patterns and the environmental factors driving them. Taking into account that Oualidia lagoon is affected by numerous impacts from different anthropogenic sources of disturbance, and that there is an evident lack of previous studies analyzing its macrozoobentic assemblages as a whole, our study certainly provides a good baseline and will be a useful reference for future ecological research and monitoring of environmental impacts in this lagoon, as well as in similar coastal ecosystems.

Our results proves the existence of a very pronounced decreasing gradient of salinity from the outer to the inner parts of the lagoon, where there were massive inland freshwater inflows (Hilmi et al. 2005), which agrees with our finding of marked lower salinities in the inner part. However, inland freshwater also affected the outer station 43, as previously reported (Hennani et al. 2012; Hassou et al. 2014; El Asri et al. 2015, 2017). The lower temperature at the entrance of the lagoon reflects the influence of the cold ocean waters. Being far from this influence, the mid and inner stations tended to be easily warmed due to their shallower depth and the loss of momentum (Rharbi et al. 2001; Hilmi et al. 2005; Hennani et al. 2012; Damsiri et al. 2014). The overall distribution of both granulometry and organic matter follows the dominat hydrodynamic characteristics of the lagoon, with the relatively calm inner area tending to have more fine sediments and organic matter (Maanan 2013; Zourarah 2002; El Asri et al. 2015; 2017).

The soft bottom macrofauna of Oualidia lagoon was mainly characterized by the presence of mollusks (especially gastropods and bivalves), followed by crustaceans (especially amphipods and isopods) and polychaetes (especially errant taxa). Despite the occasional presence of tunicates and cnidarians, the resulting taxonomic composition was typical of lagoon environments (Bazaïri et al. 2003; Mistri 2002). Our report of 56 taxa more than doubled the number of species (24) previously reported in the lagoon (Chbicheb 1996). We suggest that this increase can be explained by the progressively increasing organic matter contents in the sediments of the lagoon, as well as by the changes in its hydrodynamic characteristics caused by the construction of a pit upstream, but we cannot discard the fact that we have sampled four times more stations (43 vs. 10 in 1996). Compared to other lagoons (Mergaoui et al. 2003; Marchini et al. 2004; Chaouti and Bayed 2005; Touhami et al. 2019), Oualidia appears to be richer in terms of species, probably because the combined influence of a wide connection with the ocean with the progressive arrival of inland freshwaters. Accordingly, the partuclar environmental characteristics seemed to provide favorable habitats allowing the combined presence of marine, brackish and freshwater benthic organisms.

The presence of as much as eight trophic functional groups in the macrozoobenthos is an indicator of the availability of a wide panoply of trophic resources in the lagoon (Touhami et al.2017). However, the observed trophic structure is certainly comparable with that commonly observed worldwide in other coastal lagoons, as well as in estuaries (McLusky and Elliott 2004), particularly in what concerts to the dominance of deposit-feeders in density (Bachelet et al. 2000; Gaudêncio and Cabral 2007; Marchini et al. 2000; Ysebaert et al. 2003).

The particular combination of geological, hydrographical and environmental characteristics of Oaulidia lagoon generates a macrofaunal structure characterized by three assemblages that can be clearly distinguished in the HAC and nMDS plots (Figure 7A-B) and proved to be organized along a inner-to-outer lagoon gradient (Figure 8), in a similar was as previously reported for other lagoons (e.g. Bazaïri et al. 2003; Lefrere et al. 2015): 1) the inner-lagoon, which was characterised by having highest fine sediment contents and harboured a *Cerastoderma edule* assemblage; 2) the mid-lagoon, which had medium grain-sized sediments and harboured a *Tritia pfeifferi* assemblage; and 3) the outer-lagoon, which was closer to the lagoon inlets, showed sandy sediments, and harboured a *Tanais dulongii* assemblage.

The spatial organisation of the lagoon and its associated benthic assemblages, as defined based on our data, agrees with the previous consideration of the lagoon as 'an estuary without a river' based on a physical oceanography approach (Hilmi et al. 2005). This also corresponded with the spatial arrangement typically characterising paralic environments, whose main descriptors responded to a gradient of confinement (Guelorget and Perthuisot 1983). Despite the absence of a river, the taxonomic organization of the macrozoobenthic assemblages of Oualidia lagoon closely resembled that of an estuarine system, where the tidal regime plays a key structuring role (Cherkaoui et al. 2003). In Oualidia lagoon, however, the main driving factor appear to be the combined influence of granulometry, temperature and salinity, which seems also to be a common trend in lagoon systems (Uwadiae 2013). However, the environmental factors controlling the species distribution may change from one paralic environment to another being, for example, vegetation and grain size in the Smir lagoon (Mediterranean coast of Morocco) (Chaouti and Bayed 2008), dissolved oxygen, temperature and salinity in the Sacca di Goro (Adriatic coast of Italy) (Mistri et al. 2001), or temperature and depth in Monolimni lagoon (Mediterranean lagoon, Northern Aegean) (Kevrekidis 2004).

Conclusions

The present study proves the high diversity and abundance of the benthic macrofauna of Oualidia lagoon, and determines the main factor(s) controlling the species distribution to be a combined influence of granulometry, temperature and salinity. We also prove that the lagoon provides a high diversity of trophic resources to the macrozoobenthic organisms, as shown by the high number (up to eight) of trophic-functional groups identified. The assemblages of the lagoon were characteristically dominated by a few species, which appears to be a common trend in lagoon macrozoobenthos and reflects its very high vulnerability and fragility. Our study helps to compensate the lack of fundamental knowledge on the structure of the benthic macroinvertebrate assemblages of the lagoon, while providing a useful tool for further ecological assessment and environmental impact monitoring of these coastal ecosystems of Moroccan Atlantic. The Additional studies of the relationships between macrobenthic communities and abiotic parameters are needed to discuss spatial and seasonal variations.

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Data availability

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

Conflict of interest

The authors declare that they have no conflict of interest.

Ethical approval

This article does not contain any studies with animals performed by any of the authors.

Sampling and field studies

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Competing interests

The authors declare that they have no competing interests.

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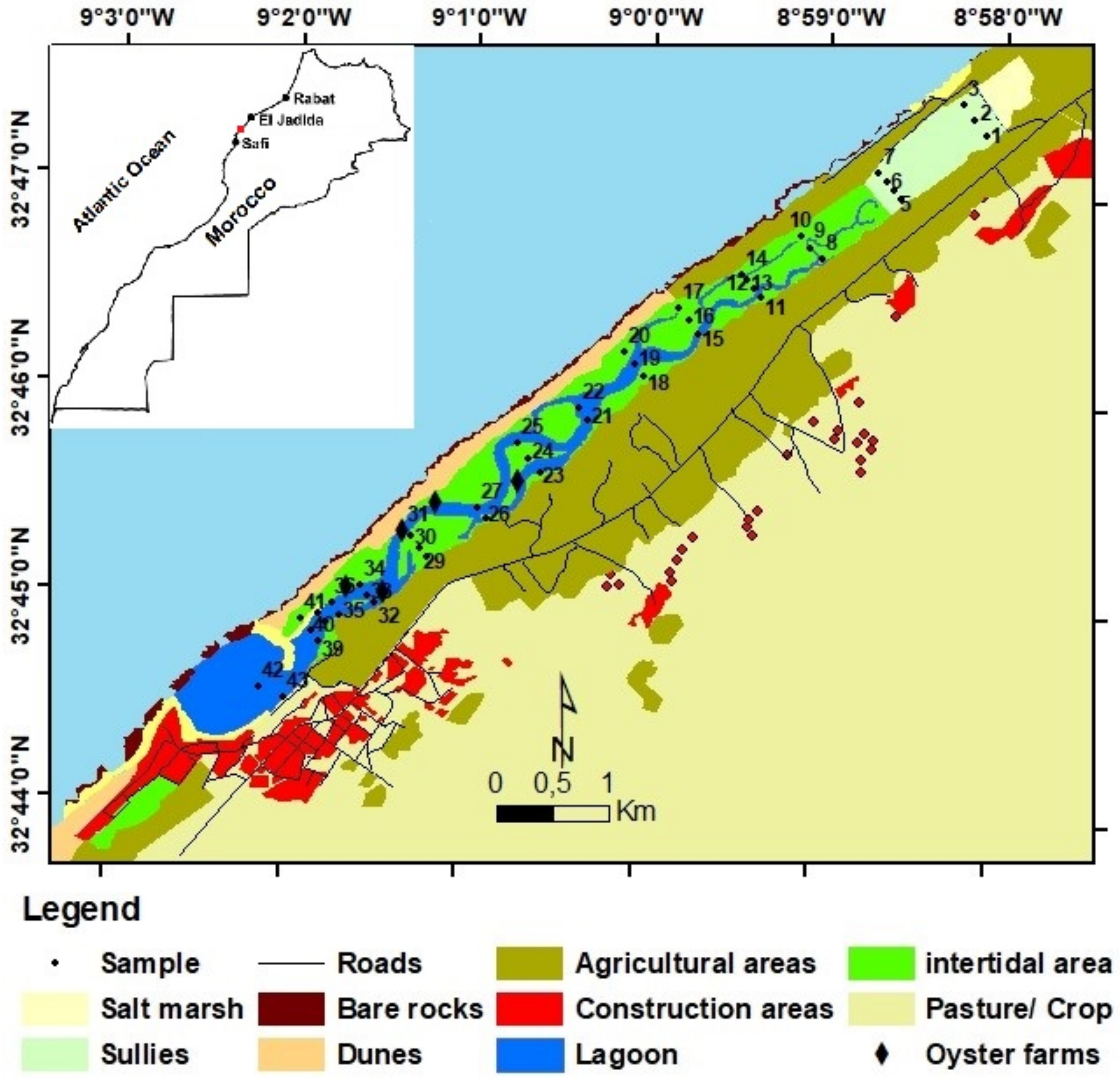

Figure 1. Geographical location of the Oualidia lagoon, showing the position of the sampling stations.

Table 1. Comparative list the macrofauna collected in 2013 (our study) and 1996 (Chbicheb 1996) in Oualidia.

Family	Species	This study	Chbicheb (1996)
Mollusca			
Solenidae	*Solen marginatus* Pulteney, 1799	*	
Cardiidae	*Cerastoderma edule* (Linnaeus, 1758)	*	*
	Cerastoderma glaucum (Poiret, 1789)		*
Semelidae	*Abra alba* (W. Wood, 1802)	*	
	Scrobicularia plana (da Costa, 1778)	*	*
Lucinidae	*Loripes orbiculatus* Poli, 1791	*	*
Mactridae	*Spisula subtruncata* Da Costa, 1778	*	
Veneridae	*Ruditapes decussatus* (Linnaeus, 1758)	*	*
	Venerupis Pullastra (Linné, 1758)		*
Mytilidae	*Mytilus galloprovincialis* Lamarck, 1819	*	
Haminoeidae	*Haminoea cf. japonica* Pilsbry, 1895	*	
Aplysiidae	*Aplysia punctata* (Cuvier, 1803)	*	
Runcinidae	*Runcina coronata* (Quatrefages, 1844)	*	
Onchidiidae	*Onchidella celtica* (Cuvier, 1817)	*	
Ellobiidae	*Myosotella myosotis* (Draparnaud, 1801)	*	
Discodorididae	*Jorunna tomentosa* (Cuvier, 1804)	*	
Dendrodorididae	*Dendrodoris* sp.	*	
Epitoniidae	*Epitonium clathrus* (Linnaeus, 1758)	*	
Hydrobiidae	*Peringia ulvae* (Pennant, 1777)	*	
Muricidae	*Hexaplex trunculus* (Linnaeus, 1758)	*	
Nassariidae	*Tritia pfeifferi* (Philippi, 1844)	*	
	Tritia reticulata (Linnaeus, 1758)	*	*
	Tritia mutabilis (Linnaeus, 1758)		*
Trochidae	*Phorcus sauciatus* (Koch, 1845)	*	
	Phorcus lineatus (da Costa, 1778)	*	*
	Gibbula umbilicalis (da Costa, 1778)	*	*
	Gibbula divaricata (Linnaeus, 1758)		*
Phasianellidae	*Tricolia* sp.	*	
Patellidae	*Patella rustica* Linnaeus, 1758	*	
	Cymbula safiana (Lamarck, 1819)	*	
	Patella depressa Pennant, 1777	*	
Cerithiidae	*Cerithium vulgatum* (Bruguière, 1792)		*
Lepidochitonidae	*Lepidochitona cinerea* (Linnaeus, 1767)	*	
Octopodidae	*Octopus vulgaris* Cuvier, 1797	*	
Polychaeta			
Nereididae	*Hediste diversicolor* (O.F. Müller, 1776)	*	*
Phyllodocidae	Phyllodoce sp.	*	
Glyceridae	*Glycera alba* (O.F. Müller, 1776)	*	
Nepthyidae	*Nephtys hombergii* Savigny in Lamarck, 1818	*	*
	Nephtys caeca (Fabricius, 1780)		*
Onuphidae	*Diopatra* cf. *marocensis* Paxton et al, 1995	*	
Ampharetidae	*Alkmaria romijni* Horst, 1919	*	
Oweniidae	*Owenia fusiformis* Delle Chiaje, 1844		*
Capitellidae	*Capitella* sp.	*	
	Capitella capitata (Fabricius, 1780)		*
Crustacea			
Gammaridea		*	
Melitidae	*Melita palmata* (Montagu, 1804)	*	
Corophiidae	*Corophium* sp.	*	
	Corophium volutator (Pallas, 1766)		*
Cirolanidae	*Eurydice pulchra* Leach, 1815	*	
Anthuridae	*Cyathura carinata* (Krøyer, 1847)	*	
Sphaeromatidae	*Sphaeroma serratum* (Fabricius, 1787)	*	
Idoteidae	*Idotea balthica* (Pallas, 1772)	*	

Tanaididae	*Tanais dulongii* (Audouin, 1826)	*	
Apseudidae	*Apseudes* sp.	*	
Cumacea	spp.	*	
Copepoda	spp.	*	
Ostracoda	spp.	*	
Paguridae	*Pagurus bernhardus* (Linnaeus, 1758)	*	*
	Portunus elegans Portunus sp.		*
Portunidae	*Carcinus maenas* (Linnaeus, 1758)	*	*
Palaemonidae	*Palaemon elegans* Rathke, 1837	*	*
Balanidae	*Balanus* sp.	*	
Insecta			
Chironomidae		*	
Ehinodermata			
Holothuriidae	*Holothuria poli* Delle Chiaje, 1824	*	*
Ophiuridae	*Ophiura* sp.	*	
Cnidaria			
Hormathiidae	*Calliactis parasitica* (Couch, 1842)	*	*

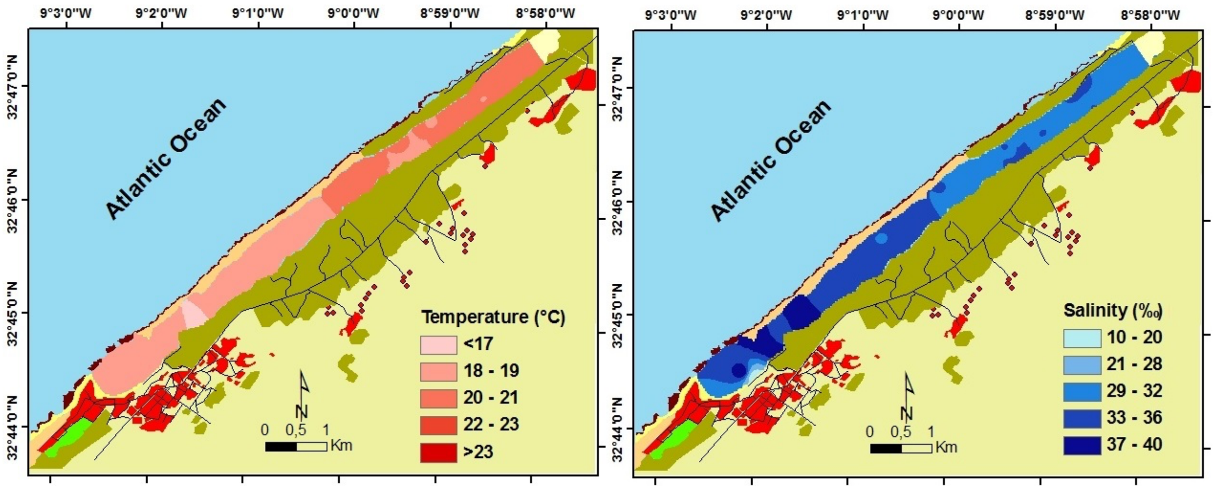

Figure 2. Distribution of temperature and salinity in the Oualidia lagoon.

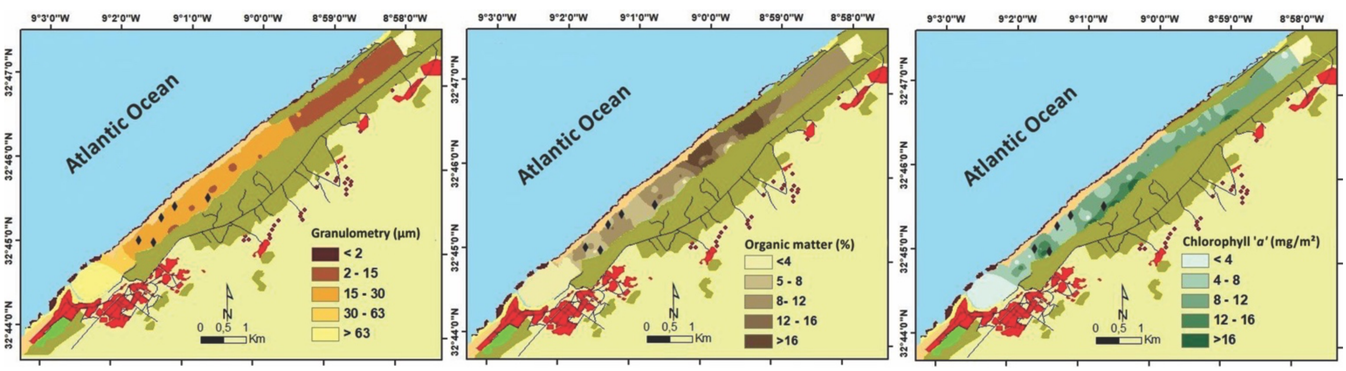

Figure 3. Distribution of organic matter, chlorophyll *a* and granulometry in Oualidia.

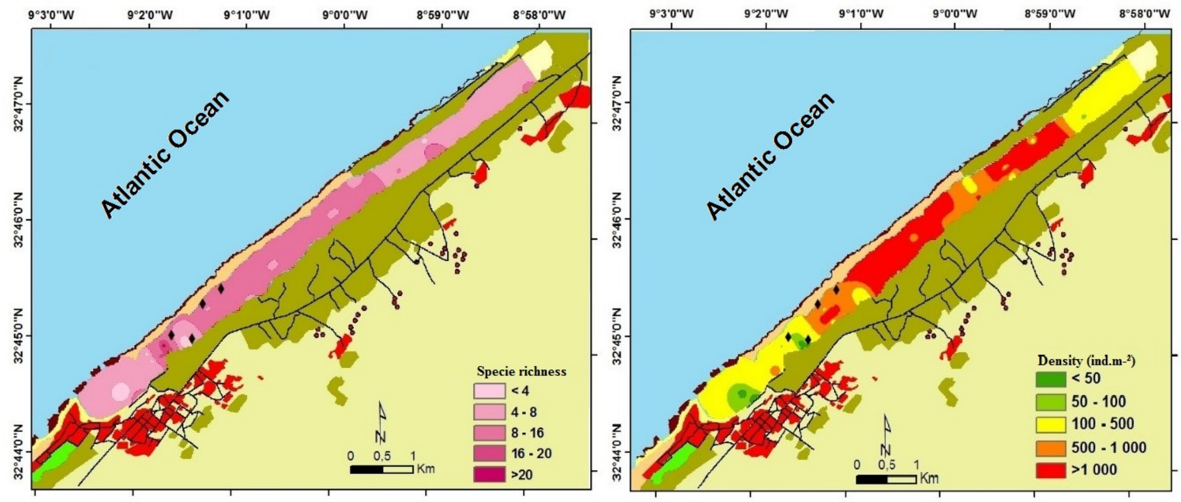

Figure 4. Spatial distribution of density and species richness in Oualidia.

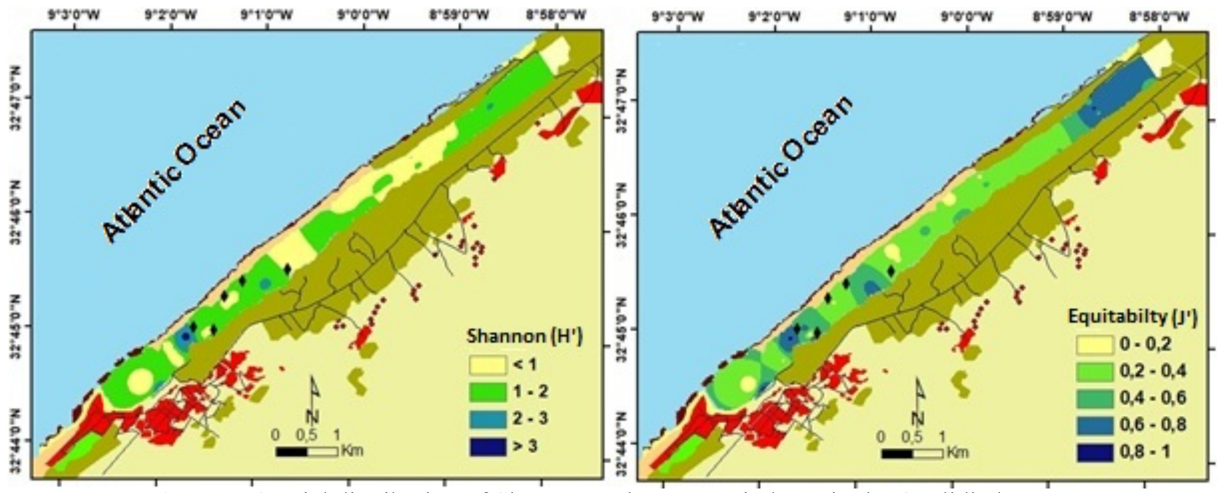

Figure 5. Spatial distribution of Shannon and evenness indexes in the Oualidia lagoon.

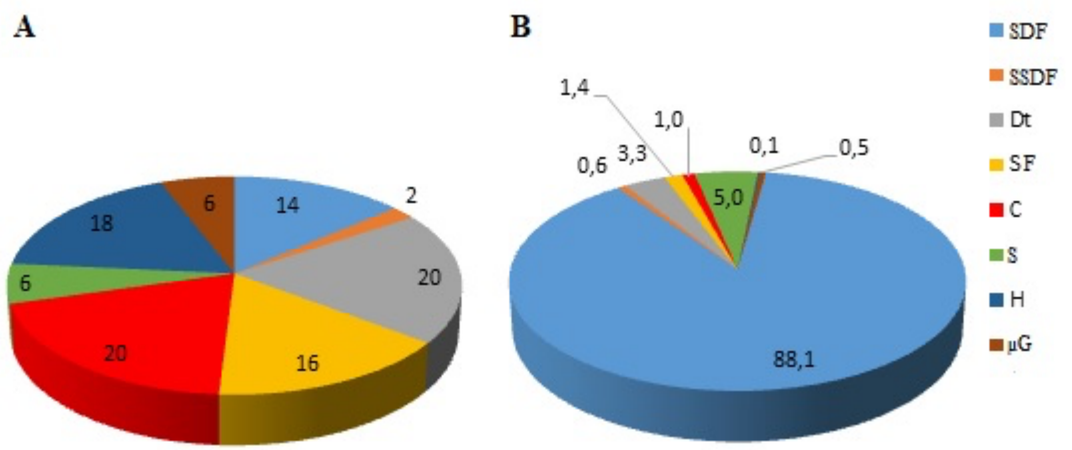

Figure 6. Trophic structure of the macrofauna community in Oualidia, expressed as relative number of individuals (A) and species (B).

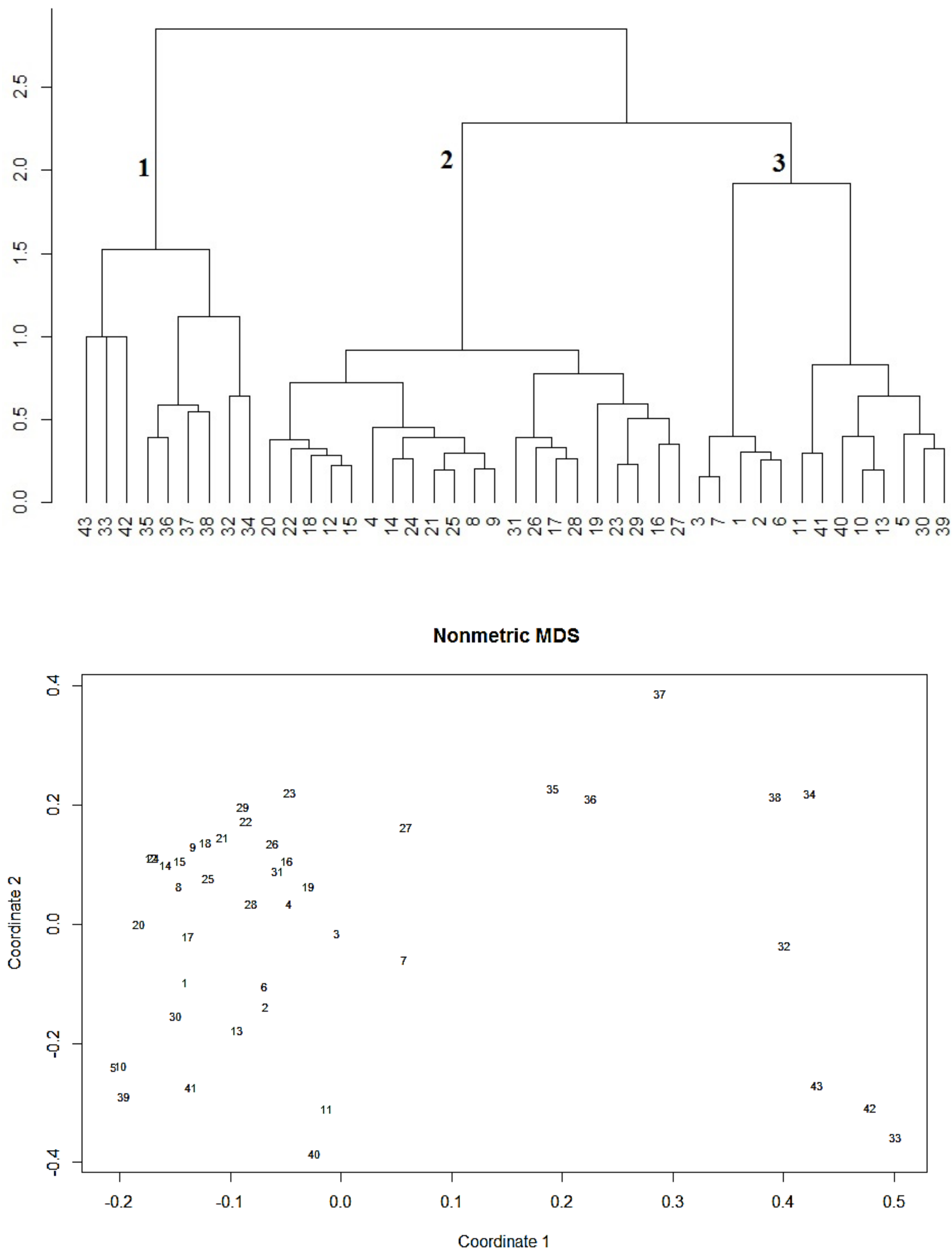

Figure 7. Structure of the macrofaunal assemblages based on abundances. A. Dendogram inferred from HAC. B. MDS plot showing the groups inferred from HAC.

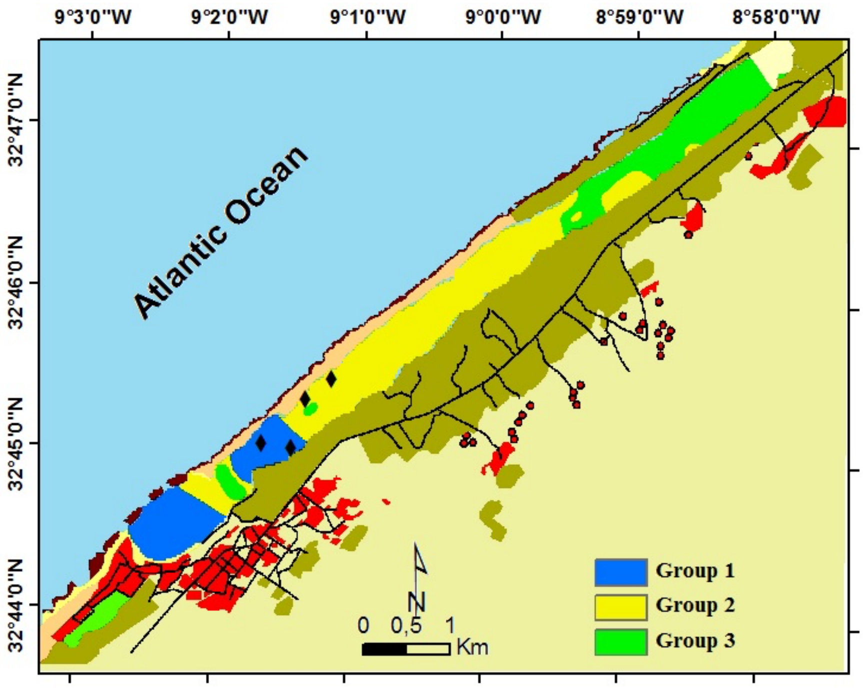

Figure 8. Spatial distribution of the groups obtained in the HAC and nMDS analyses in Oualidia.

Table 2. List of the main species of the macrofaunal assemblages inferred from the HAC and nMDS analyses according to the IndVal index. The species showing the highest IndVal are highlighted in **bold**.

Groups	Species	IndVal
1	***Tanais dulongii***	322.8
	Tritia reticulata	262.5
	Runcina coronata	196.9
	Idotea balthica	187.5
	Ruditapes decussatus	182.8
2	***Tritia pfeifferi***	191.7
	Abra alba	185.4
	Peringia ulvae	184.4
	Hediste diversicolor	116.9
	Calliactis parasitica	111.6
3	***Cerastoderma edule***	102.3
	Haminoea cf. japonica	92
	Chironomus sp.	45.6
	Hediste diversicolor	44.7
	Capitella sp.	26.3

Table 3. Summary of BIOENV results.

Variables	size	correlation
Salinity	1	0.4612
Salinity & granulometry	2	0.5404
Temperature, salinity &granulometry	3	0.5414
Temperature, salinity, chlorophyll “a” &granulometry	4	0.4668
Temperature, salinity, chlorophyll “a”, organic matter &granulometry	5	0.4002