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# Spatial and temporal variability in distribution, diversity and structure of the polychaete assemblages from Dakhla Bay (Atlantic coast of South Morocco)

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## Abstract

The polychaete assemblages at Dakhla Bay (Atlantic coast of South Morocco) were studied during spring 2013 and winter 2014 to analyse the spatial-temporal variability in diversity and community structure, as well as their relationships with the main environmental variables. 42 stations were sampled all over the bay, yielding a total of 22 species (21 in spring, 22 in winter) belonging to 16 families. The three most abundant species were *Maldane sarsi* (25.1%) *Eunice vittata* (11.1%) and *Nainereis laevigata* (10%) in spring, and *Ophelia rathkei* (43%), *M. sarsi* (21.5%) and *N. laevigata* (5.9%) in winter. The main drivers of the polychaete community structure at Dakhla Bay were the hydrographic characteristics of the bay as well as the type sediment (in spring and winter) and food availability, organic matter and Chl-a content (in spring). Accordingly, the cluster analysis identified three assemblages in spring and winter, named according to the dominant species. The *M. sarsi* assemblage occurred in inner bay fine sediments and were replaced by the *E. vittata* (spring) and *N. laevigata* (winter) assemblages in mid-bay medium grain-sized sediments, and by the *C. tentaculata* one in sandy sediments closer to the outer inlet. This represents a shift from a typical brackish, lacunar assemblage to two different, temporal aspects of a marine assemblage, with a transitional one in between. Our study confirms the singularity of the macrofaunal pool at Dakhla Bay and provides a fundamental baseline for future monitoring of an endangered southern Moroccan wetland that will contribute to facilitate its management and protection.

**Keywords** Polychaete fauna, spatial distribution, biodiversity, Atlantic Ocean, Dakhla Bay, Morocco.

## Introduction

Benthic organisms play a key role in marine ecosystem functioning. Among other relevant processes, they contribute to nutrient cycle regulation, pollutants' burying and dispersal and secondary production (Snelgrove 1998), particularly in semi-enclosed areas such as estuaries (e.g., Kristensen et al. 2014; Magallanes et al. 2011), bays and gulfs (e.g., Belan 2003; Junoy et al. 2013; Girbert et al. 2015; Sardá et al. 2000). The knowledge on the spatial-temporal structure of the benthic assemblages is a key issue allowing environmental health assessments (Borja et al. 2000; Aubry and Elliott 2006; Arbi et al. 2017).

Among benthic marine macroinvertebrates, polychaetes, crustaceans, molluscs and echinoderms are usually the dominant and most diverse taxa (Snelgrove 1998; Byers and Grabowski 2014). Particularly, the polychaetes are a basal group in any study on marine benthic communities. They dominate the macrofaunal assemblages in terms of abundance, biomass and diversity at practically all depths and benthic habitats (Jumars et al. 2015). Since classical studies on responses of benthic organisms to environmental gradients (e.g. Perason and Rosenberg 1978), the polychaetes are well known by their adaptability to a wide variety of environmental conditions, thus playing a key role in ecosystem functioning. Furthermore, they have been used successfully as surrogates to estimate the diversity, spatial-temporal dynamics and functional roles of benthic communities (Olsford et al. 2003; Papageorgiou et al. 2006; Dixon-Bridges et al. 2014). In fact, analysing the polychaete assemblage structure proved to be an efficient tool in environmental health assessment. Thus, it is commonly used as a biological criterion for water quality in biomonitoring studies (Pocklington and Wells 1992; Olsford et al. 2003; Samuelson 2001; Giangrande et al. 2005) and as a relevant component in ecological indexes (see Dauvin et al. 2016, and references herein).

Dakhla Bay, located in the Atlantic coasts of southern Morocco, is one of the most productive natural systems of the country, whose remarkable ecological, biological and socio-economic services have been recently recognized (Zidane et al. 2008). The bay harbours a significant amount of exploitable native populations of bivalves, such as the grooved carpet shell (*Ruditapes decussatus* (Linnaeus 1758)), the edible cockle (*Cerastoderma edule* (Linnaeus 1758)), the grooved razor shell (*Solen marginatus* Pulteney, 1799) and the mussel (*Perna perna* (Linnaeus 1758)) (Zidane et al. 2008). The bay is also well known for its ornithological importance, constituting a stopover migratory and a winter refuge appreciated for numerous species of birds (Qninba et al. 2003). Thus, it has been classified as a site of biological and ecological interest (SIBE), through the Protected Areas Master Plan of Morocco, and as a RAMSAR site since 2005. Overall, Morocco is a very rich country in terms of wetlands, including bays, estuaries, lagoons, lakes and rivers, among others. However, many of them need to be well managed and better exploited, thus requiring baseline descriptive studies to assess faunal patterns and trends. Dakhla Bay is not an exception. In fact, the studies conducted to date in the bay mainly focused on its oceanographic features and aquaculture capacities (Guelerget et al. 1996; Dafir et al. 1997; Saad et al. 2013; Zidane et al. 2008, 2017), while there is no information on the characteristics of its benthic macroinvertebrate assemblages.

In this context, our study represents the first baseline study focusing on the patterns and trends of the benthic organisms from Dakhla Bay, using the polychaete assemblages as surrogates. We analyse the spatial-temporal variability of both diversity and community structure descriptors, as well as their relationships with the main environmental variables. As a result, we described for the first time the polychaete assemblages inhabiting Dakhla Bay. We also intended to reveal its singularity, which acquires a particular relevancy taking into account the worsening anthropogenic-driven conditions in the bay.

## Materials and methods

### *Study area*

Dakhla Bay is located at 23°35'N and 16°W, along the Atlantic coast of south Morocco (Fig. 1). This region shows a typically desert climate and receives an oceanic influence, particularly as a result of the interaction between the cold Canary current and the subtropical ridge currents (Orbi et al. 1999). Dakhla Bay is 37 km long and ranges from 10 to 12 km wide. It has a NE-SW orientation and is separated from the Atlantic Ocean by the peninsula of Oued Ed-Dahab. The bay is divided into two different areas according to its bathymetry and distance to the opening: (1) the inner, southern zone (West Zone), which has a series of channels oriented in the same direction as the bay; and (2) the outer northern zone (Northeast Zone), which has a more regular morphology. Bathymetry increases from both shores toward the middle of the bay, where it reaches a maximum depth of 20 m (Orbi et al. 1995).

### *Sampling and data analysis*

Forty-two stations (Fig. 1) were sampled both in spring (May 2013) and in winter (February 2014). All samples (two replicates) were collected using a Van Veen grab (0.0625 m<sup>2</sup> in surface area). Despite samples were collected at approximately the same location in each station, the surface area at each selected site were large enough, compared to sample surface, to prevent interferences between the successive seasonal sampling. The samples were sieved in situ through a 1 mm pore size mesh. The material retained on the mesh was transferred to containers and fixed in a 10% formalin/seawater solution.

At each station, water salinity (‰) and temperature (°C) and distance from the bay opening (i.e., distance) were recorded. An additional sediment sample was collected to analyse grain size, organic matter and chlorophyll-a contents. Grain size was measured with a laser granulometer (Malvern, Mastersizer) at the LETG (Littoral, Environnement, Geomatique, Teledetection) (UMR 6554, University of Nantes) and expressed as mean grain size, in  $\mu\text{m}$ . Organic matter contents (OM, %) were obtained as weight losses of dried samples (24 h, 60°C) after ignition (4h, 450°C). The chlorophyll-a content (Chl-a, mg/m<sup>2</sup>) was determined according to the Lorenzen method (Holm-Hansen et al. 1965).

All macroinvertebrates were sorted under a binocular microscope. The polychaetes were identified at the lowest taxonomic level possible and counted. Selected specimens of the most relevant species have been deposited in the collections of the Centre d'Estudis Avançats de Blanes (CEAB) (Table 1). To analyse the assemblage structure, the following indices were calculated: (1) species richness (as number of species per sample); (2) density (as ind./m<sup>2</sup>); (3) Shannon diversity (log<sub>2</sub> basis) (Shannon 1948); and evenness (Pielou 1966).

A hierarchical ascending classification analysis (HACA), based on Euclidean distance, the Wards method and log<sub>10</sub> (x+1) transformed data to limit the influence of the most dominant taxa (Vakharia and Wemmerlöv 1995; Cao et al. 1997), was used to analyse the spatial structure of the populations, both in summer and in winter. The most representative species of each community were identified by the IndVal index (Dufrêne and Legendre 1997). Wilcoxon tests were used to determine the significance ( $P < 0.05$ ) of the difference between seasons. Canonical correspondence analyses (CCA) based on log<sub>10</sub> (x+1) transformed data were performed to analyse the relationships between environmental variables and the polychaete assemblages, both in summer and in winter. One-way Permutational multivariate analysis of variance (PERMANOVA) based on Euclidean distances and 9999 permutations (Anderson 2001), was used to test for differences between the assemblages identified in the

HACAs in both seasons. All analyses were carried out using the PAST software package (Hammer et al. 2001), Statistical Version 2.17 for Windows software.

## Results

### *Environmental variables*

Salinity in Dakhla Bay ranged from 36.2 to 39.9 ‰ and progressively increased downstream–upstream both in winter and summer (Fig. 2a). The temperature ranged from 15.8–19.5°C in spring and from 16.3–19.5°C in winter, following also the same increasing gradient as in the case of salinity (Fig. 2b). Chl-a showed a very heterogeneous distribution and ranged from 0.4 to 24.9 mg.m<sup>-2</sup> in spring and from 0.2 to 34.6 mg.m<sup>-2</sup> in winter (Fig. 2c). Organic matter contents ranged from 0.3–9.6% in spring and from 0.2–7.5% in winter, showing maxima in the centre and in the north of the bay at both seasons (Fig. 2d). The granulometry varied from sandy (upstream) to sandy-silt or silt (downstream) (Fig. 2e). No significant seasonal variations were detected for the analysed environmental variables.

### *Polychaete assemblage descriptors*

4,324 polychaete individuals belonging to 22 species and 16 genera were collected during this study (Table 1). Among them, 2,144 individuals from 21 species occurred in spring and 2,160 from 22 species in winter.

The most abundant species in spring were *Maldane sarsi* (25.1%), *Eunice vittata* (11.1%), *Naineris laevigata* (10%), *Platynereis dumerilii* (7.4%) and *Arabella iricolor* (6.3%), while in winter these were *Ophelia rathkei* (43%), *M. sarsi* (21.5%), *N. laevigata* (5.9%) and *Cirriformia tentaculata* (5.2%).

Polychaete densities did not differ significantly between winter and spring, although they tended to be higher in the former (0 to 856 ind./m<sup>2</sup>) than in the latter (0 to 176 ind./m<sup>2</sup>). The number of species and the Shannon diversity also did not differ significantly between winter and spring, being overall similar at both seasons (ranging from 0 to 7 species and from 0 to 1.9 bits, respectively). Evenness was significantly lower ( $p < 0.05$ ) in winter than in spring (Fig.3).

Three station clusters were obtained both during spring and winter, which differed significantly (PERMANOVA, Table 3). In spring (Fig. 4a), cluster 1 included 12 stations located mainly in the inner region of the bay. They were characterized by sediments mostly composed by different proportions of silt and clay, with a  $4.3 \pm 3.8$  % OM,  $7 \pm 6.6$  of Chl-a, on average. The polychaete assemblages showed relatively low average density ( $60 \pm 35.9$  ind./m<sup>2</sup>), species richness ( $2.7 \pm 1.4$ ) and diversity ( $0.8 \pm 0.4$ ), while the average evenness (c.a. 0.8) was similar in the three clusters. The dominant species were *Maldane sarsi* and *Paraprionospio pinnata* (Table 2). Cluster 2, consisted of 7 stations occupying mostly the inner-central region of the bay. They had mainly silty and clayed sands, as well as high Chl-a ( $11.6 \pm 4.2$  mg/m<sup>2</sup>) and moderately high OM ( $2 \pm 1.3$ %). They show high average density ( $94.9 \pm 28.3$  ind./m<sup>2</sup>), species richness ( $5.1 \pm 1.6$ ) and diversity ( $1.4 \pm 0.4$  bits). The dominant species was *Eunice vittata* (Table 2). Cluster 3, consisted of 12 stations mainly located close to the bay opening. Accordingly, they had predominantly sandy sediments, low OM ( $1.4 \pm 1.2$ %) and moderate Chl-a ( $8.6 \pm 4.9$  mg/m<sup>2</sup>). Polychaete assemblages showed relatively low average density ( $63.3 \pm 50.3$  ind./m<sup>2</sup>), species richness ( $3.7 \pm 1.9$ ) and diversity ( $1.0 \pm 0.5$  bits), The dominant species was *Cirriformia tentaculata* (Table 2).

During winter (Fig. 4b), Cluster 1 included 10 stations, mainly located in the inner central region of the bay, which were characterized by having relatively high OM ( $3.2\pm 2.7\%$ ), low Chl-a ( $4.9\pm 4.4\text{ mg/m}^2$ ), clay and silty clay, together with a moderate average density ( $56\pm 38.1\text{ ind./m}^2$ ) and low species richness ( $2.5\pm 1.9$ ). Diversity ( $0.5\pm 0.7\text{ bits}$ ) and evenness ( $0.4\pm 0.4$ ). The dominant species was *Maldane sarsi* (Table 2). Cluster 2 included 13 stations located all along the bay, but mostly in the central part. They were characterized by having high Chl-a ( $12.2\pm 9.2$ ), moderately high OM ( $2.8\pm 2.5\%$ ) and silty and clayed sands, while there was low average density ( $14.2\pm 12.3\text{ ind./m}^2$ ), species richness ( $1.2\pm 0.4$ ), diversity ( $0.1\pm 0.3\text{ bits}$ ) and evenness ( $0.2\pm 0.4$ ). The dominant polychaete was *Naineris laevigata* (Table 2). Cluster 3 included 11 stations located mostly near the bay opening. They were characterized by having low OM ( $1.3\pm 0.7\%$ ), moderately high Chl-a ( $11.3\pm 5.9\text{ mg/m}^2$ ), and a high percentage of sand. Moreover, this cluster showed the highest recorded average density ( $136\pm 239.5\text{ ind./m}^2$ ), species richness ( $4.8\pm 1.5$ ), diversity ( $1.4\pm 0.5\text{ bits}$ ) and evenness ( $0.9\pm 0.3$ ), while the dominant species were *Cirriformia tentaculata* and *Ophelia rathkei* (Table 2).

### *Relationships between polychaete assemblage descriptors and environmental variables*

In spring, the first two CCA axes accounted for 61.88% of the observed variance. The species composition was mainly related to granulometry and distance (Fig. 5a). In winter, the first two CCA axes accounted for 59.28% of the relationships, with the most influencing environmental variables being Chl-a, granulometry and OM (Fig. 5b).

In spring, the projections of the species on the environmental parameter vectors (Fig. 5a), showed positive correlations of *Panousea Africana*, *Cirriformia tentaculata*, *Platynereis dumerilii*, *Schistomeringos neglecta*, *Maldane sarsi*, *Glycera alba*, *Glycera cf. tridactyla*, *Paraprionospio pinnata* and *Pistella lornensis* with distance, OM, salinity and temperature. In turn, *Eunice vittata*, *Eumida sanguinea*, *Axiothella constricta* and *Glycinde nordmanni* were positively correlated with granulometry and Chl-a. As for the stations, they are left-right oriented for axis 1, which corresponds to a downstream-upstream gradient. Accordingly, downstream stations (e.g., 31, 33, 34, 35, 36, 38, 39) were characterized by larger grain sizes and high chl-a, whereas the upstream stations (e.g., 1, 2, 3, 4, 5, 8, 9, 10, 11, 19) were characterized by high distance, OM, salinity and temperature.

In winter, the projections of the species on the environmental parameters vectors (Fig. 5b), showed the positive correlations of *Pistella lornensis*, *Schistomeringos neglecta*, *Naineris laevigata*, *Eunice vittata*, *Glycinde nordmanni*, *Phyllodoce* sp., *Cirriformia tentaculata* and *Ophelia rathkei* with granulometry, chl-a and temperature, while *Maldane sarsi*, *Panousea africana*, *Sthenelais boa*, *Platynereis dumerilii* and *Glycera alba* were positively correlated with distance, OM and salinity. As for the stations, they are oriented towards the right of axis 1, which also corresponds to a downstream-upstream gradient, with the downstream stations (e.g., 28, 32, 33, 34, 35, 37, 38, 39) being characterized by larger grain sizes and high Chl-a, whereas the upstream stations (e.g., 1, 4, 3, 6, 8, 10, 11, 12, 15) were characterized by having high distance, salinity and OM.

## **Discussion**

Dakhla Bay is one of the most important wetlands along the Moroccan Atlantic coastline. Situated in a Saharan area, this ecosystem is highly diverse both in terms of fauna and flora. Curiously enough, it has not been extensively studied, and the present work contributes to this knowledge by providing the first report describing the temporal and spatial patterns of the

diversity and structure of the polychaete assemblages and their relationships with the main environmental parameters. The novelty of this study for the southern Atlantic coast of Morocco, lead us to consider it as a good baseline for future ecological research.

The lower temperature at the entrance of the bay reflects the influence of the cold ocean waters Dafir (1997). The other stations tended to be easily warmed because of their shallow depth and the loss of momentum. However, in our study, this trend was only evident in spring, as reflected by the positive correlation between temperature and the distance, while it does not occur in winter. Similarly, and for the same reason, downstream salinity tended to be lower, reaching almost the oceanic 35 ‰ (Aminot and Chaussepied, 1983). This finding has also been reported by Saad et al. (2013) and coincided with our own observations in which there was a positive correlation between salinity and the distance both in spring and in winter. On the other hand, the overall distribution of the granulometry and organic matter follows the hydrodynamic state (Dafir 1997; Zidane 2009; Zidane et al. 2017), with the upstream area tending to be relatively calm and to have more fine sediments and organic matter, although the relationships of both parameters and the distance were non-significant.

The presence of 12 families and 22 species of polychaetes in Dakhla Bay (Table 1) represents a moderately high diversity. It was certainly higher than in Camamu Bay, Brazil (17 species) (Paixão et al. 2010) and Chabahar Bay, Iran (16 species) (Taheri et al. 2010), but was lower than in Veys Bay, France (27 species) (Timsit et al. 2004), Tijucas Bay, Brazil (47 species) (de Almeida and Vivan 2011), Admiralty Bay, New Zealand (76 species) (Pabis and Siciński, 2012), Blanes Bay, Spain (ca. 80 species) (Pinedo et al. 1996) and Els Alfacs Bay, Spain (101 species) (Martin et al. 2000). Among other reasons, differences in sampling devices, sampling effort and area covered may contribute to explain the variability in species diversity, but also intrinsic environmental factors such as the depth range, sedimentary heterogeneity and hydrodynamic regimes have been argued to explain the local diversity patterns. Despite the temporal environmental differences found in Dakhla Bay, and, to some extent, the differences in composition, the structure of the polychaete assemblages was almost the same during the two study periods (Fig. 4a and 4b). The environmental descriptors, including the granulometry and, particularly, the salinity and temperature (the latter only in spring) conformed a regular gradient, which was mirrored by the polychaete assemblages. In fact, the *Maldane sarsi* assemblage found in the fine sediments of the inner bay were replaced by the *E. vittata* (spring) *N. laevigata* (winter) ones in the medium grain-sized sediment of the mid-bay, and by the *C. tentaculata* one in the sandy sediments closer to the outer inlet. The shift was, in fact, from a classical, brackish, lacunar assemblage to two different, temporal aspects of a marine assemblage (close to the outer inlet), with a transition assemblage in between.

The diversity, distribution and structure of the polychaete assemblages are closely driven by environmental parameters (Carrasco and Carbajal 1998; Simboura et al. 2000; Labruno et al. 2007; El Asri et al. 2017), with a special relevance in the case of sediment characteristics and organic matter (Glémarec 1973; Martin et al. 2000; Barbosa et al. 2010; Martins et al. 2013). In Dakhla Bay, sediments on one hand (in spring and winter) and the parameters related with the food availability, organic matter and Chl-a content (in spring) highly influenced the polychaete density distribution (Fig. 5a and 5b), while they show a range of different degrees of influence at the species level (in most cases resulting in positive relationships).

The environmental factors most often reported as being responsible for the observed patterns of benthic assemblages in marine bays tend to be rather similar. Among them, gradients in sediment composition, organic matter content, hydrodynamics and, occasionally, salinity are suggested as the main driving factors. However, the dominant species are clearly different, suggesting that other factors may be more strongly influent. Among them, the

assemblages inhabiting a given bay may be dependent on but also on biogeographic and, to some extent, historical reasons, but also on the regional organisms' pool, which led different species to respond to equivalent sets of environmental conditions in bays with markedly different biogeographical locations. Accordingly, the local environmental stressors (i.e., mainly particle size, chl.-a, salinity, OM, and temperature) combined with regional species pool lead the following species to be dominant in Dakhla Bay: *M. sarsi* (25.1%), *E. vittata* (11.1%) and *N. laevigata* (10%) in spring and *O. rathkei* (43%), *M. sarsi* (21.5%) and *N. laevigata* (5.9%) in winter. This pattern of dominant species seems to be highly characteristic for a given bay, and may vary depending on the local environmental conditions, and the regional species pool. For instance, in Bou Ismail Bay the dominant species were *Aponuphis bilineata* (Baird 1870) and *Hialinoecia brementi* Fauvel, 1916 (Bakalem 2008). Algiers Bay was dominated by *Owenia fusiformis* Delle Chiaje, 1844 (Bakalem 2008). Admiralty Bay was dominated by *Capitella* sp. (as *C. capitata*) and *Leodamas marginatus* (Ehlers 1897) (Sicinski and Janowska 1993). The most abundant species in Terra Nova Bay were *Tharyx cincinnatus* (Ehlers 1908) and *Spiophanes tcherniai* Fauvel 1950 (Gambi et al. 1997). In Chile Bay, *M. sarsi* and *T. cincinnatus* were the dominant species (Gallardo et al. 1988), while in Todos os Santos Bay (Brazil), the most abundant species was *Armandia polyophthalma* Kükenthal, 1887 (Pires-Vanin et al. 2011).

Moreover, all the above-mentioned bays differ considerably from one another in size, morphology, water depth, salinity, etc. This may certainly contribute to explain the differences in composition and dominance of the respective polychaete assemblages. The strong dominance in abundance by a few number of species can be explained by the existence of large fluctuations in the environmental conditions, which ensure that only species tolerant to changes in the driving abiotic factors (e.g., salinity, temperature, oxygen availability, and type of substrate) turned to be adapted to survive and proliferate in this kind of coastal ecosystem (Guelorget and Michel 1979; Martin et al. 2000; El Asri et al. 2015). Moreover, drastic alterations in species composition through time may also occur, particularly if there are associated changes in anthropogenic pressure (Hernández-Guevara et al. 2008). Finally, inter-specific interactions among polychaetes, but also with other benthic invertebrates, including predation, competition etc., may also contribute to explain the changes in species dominance, but also in the structure of the whole polychaete assemblage (Gambi et al. 1995; Artemis et al. 2006; Schücker et al. 2014).

Despite the unavoidable usefulness of baseline studies like the present one at Dakhla Bay to assess future changes in benthic environments and the associated assemblages, more specific studies are required to fully understand the particular functioning of the bay. Nonetheless, it is necessary to emphasize that the benthic communities in the bay are severely threatened by the worsening conditions mainly in relation with the spread of human activities. The growing relevance of the commercial exploitation of benthic species and the touristic developments certainly increases their influence on the bay that, as a semi-enclosed, transition ecosystem, is particularly vulnerable to threats derived from human activities (Newton et al. 2014).

The polychaetes are well known as relevant contributors to the biodiversity of marine sediments since the earliest reviews by Snelgrove (1998, 1999). Despite their relevance, however, they are the single taxa being described from Dakhla Bay. Therefore, there is a high risk that many other not yet studied taxa would disappear, even before their presence in the Bay will be registered. We are aware that the present characterization of the polychaete assemblages from Dakhla Bay may be considered as incomplete (particularly in terms of seasonal and inter-annual variability). However, the information generated by the present biotic inventory, including spatial and, in part, seasonal variability, arose as a key dataset to allow future monitoring of the functioning of these communities and their responses to the



treats to which they are submitted. Hopefully, it may also stimulate further studies of the endangered wetland environments in southern Moroccan coast, which would be a major contribution to facilitate the management and protection of these natural resources.

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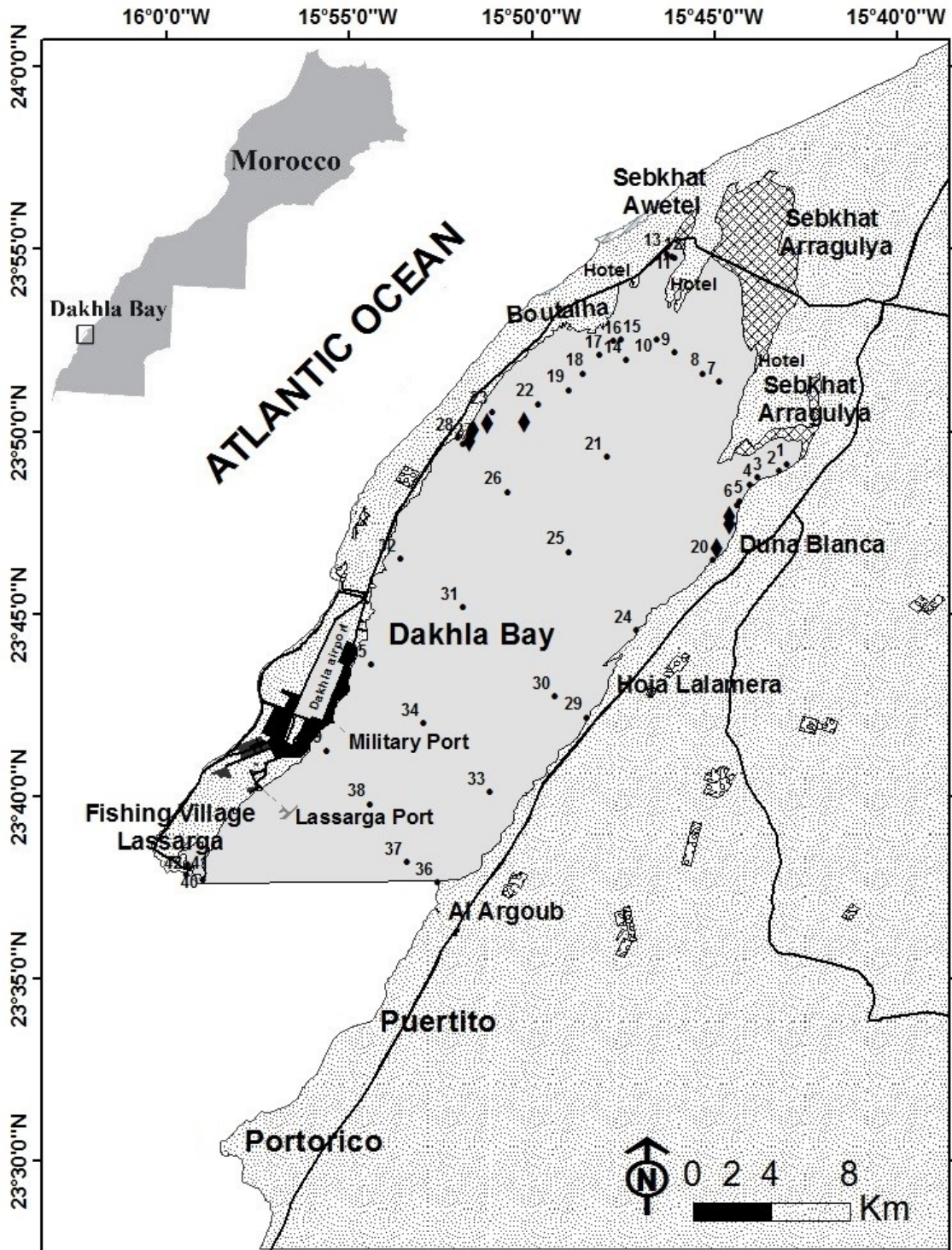
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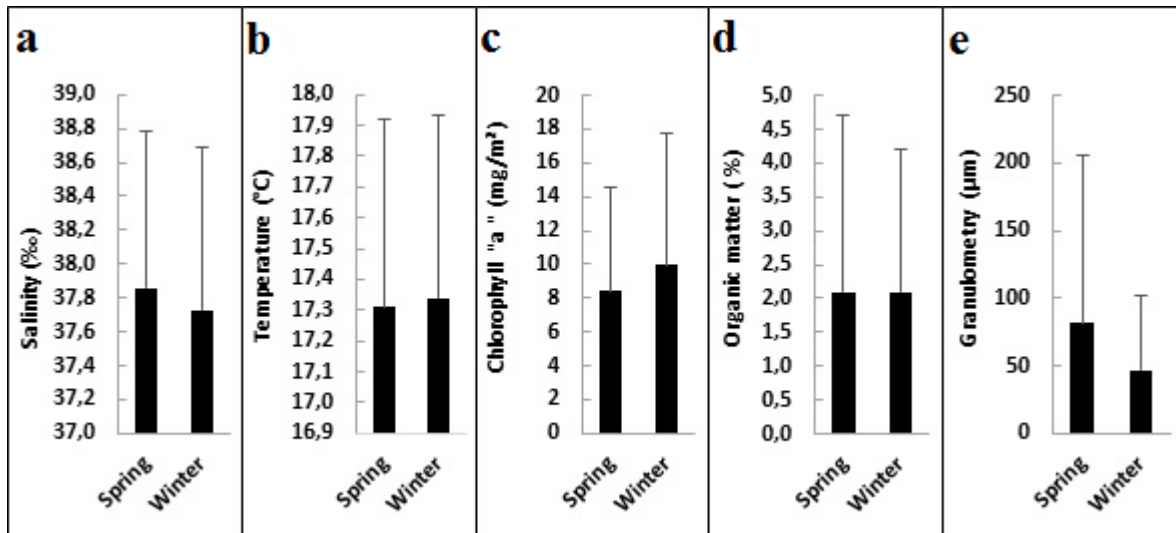
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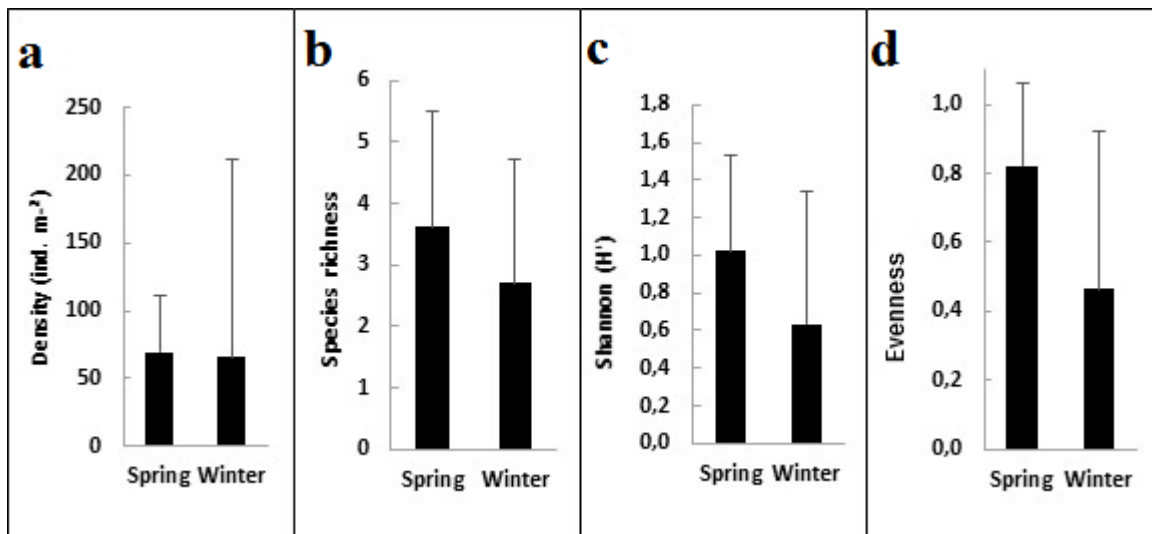
**Legend**

- Surface samples
- ◆ Oyster farm
- Road
- Urban areas
- Industrial area
- Port area
- Agricultural areas
- Airport
- Sebkhat
- Beach/Coastal dunes
- Sandy dunes

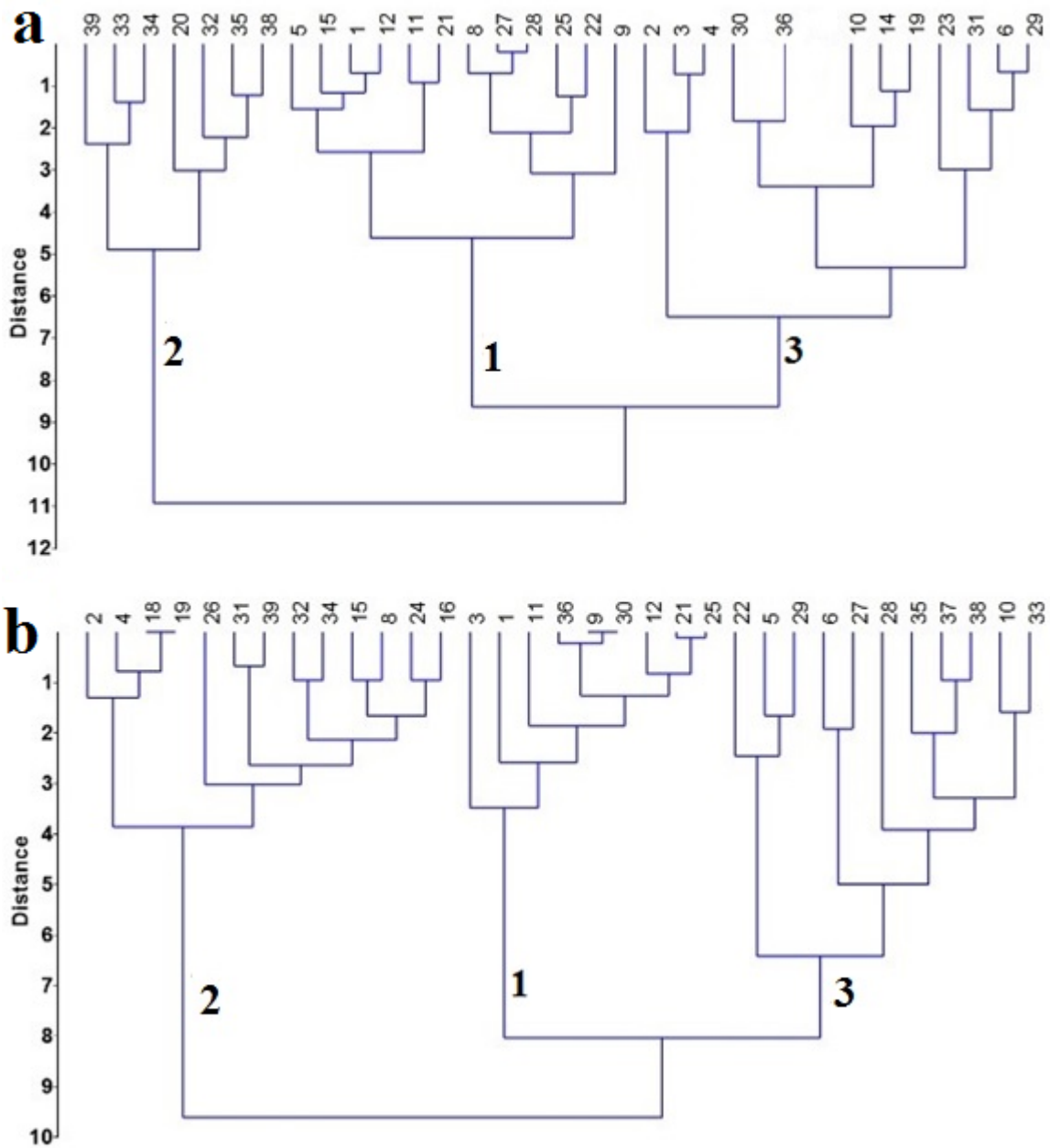
**Fig.1** Study area and sampling sites at Dakhla Bay.



**Fig. 2** Seasonal variations in water salinity, water temperature, chlorophyll-a, organic matter content and granulometry in the sediment of Dakhla Bay. Mean  $\pm$ SD.

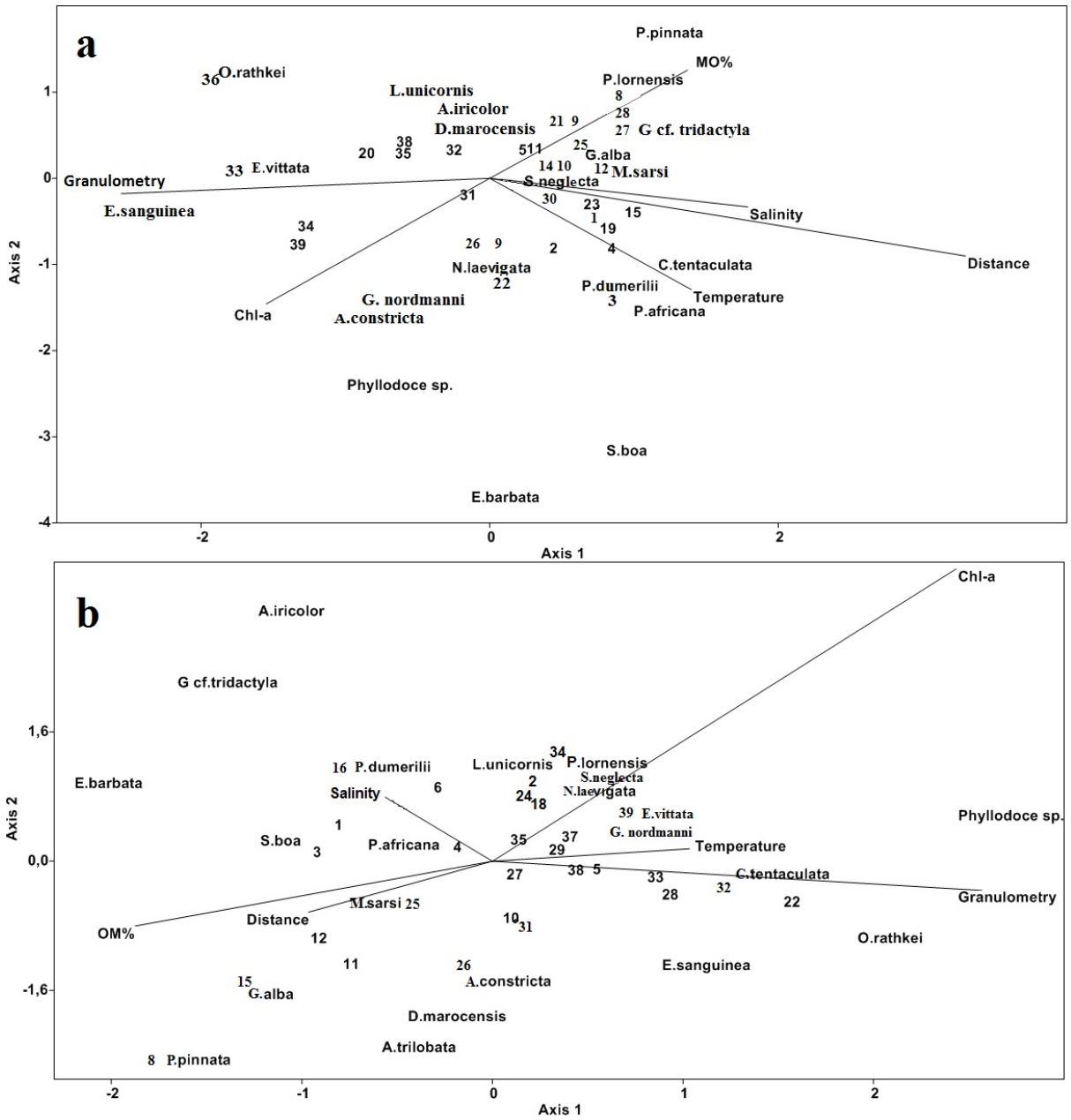


**Fig. 3** Seasonal changes in the main descriptors of the structure of the polychaetes assemblages between winter and summer. a. Density (ind. m<sup>-2</sup>). b. Species richness. c. Shannon diversity. d. Evenness. Mean  $\pm$ SD.



**Fig. 4** Dendrogram showing the clusters of stations obtained in the Hierarchical Ascending Classification analysis based on polychaete density; 1: cluster 1, 2: cluster 2, cluster: 3. a. Spring. b. Winter





**Fig. 5** Canonical correspondence analysis plots. a. Spring. b. Winter.



**Table 1** List of families and species present at Dakhla Bay in spring and winter. NF: number of families; NS: Number of species; Ref Numb: Reference number at the CEAB collections; \*: present; -: absent.

Family	NF	Species	NS	Spring	Winter	Ref Numb
Cirratulidae	1	<i>Cirriformia tentaculata</i> (Montagu, 1808)	1	*	*	CEAB.AP.875
Dorvilleidae	2	<i>Schistomeringos neglecta</i> (Fauvel, 1923)	2	*	*	CEAB.AP.888
Eunicidae	3	<i>Eunice vittata</i> (Delle Chiaje, 1828)	3	*	*	CEAB.AP.881
		<i>Lysidice unicornis</i> (Grube, 1840)	4	*	*	CEAB.AP.894
Glyceridae	4	<i>Glycera alba</i> (O.F. Müller, 1776)	5	*	*	CEAB.AP.883 A-D
		<i>Glycera</i> cf. <i>tridactyla</i> Schmarda, 1861	6	*	*	CEAB.AP.889
Goniadidae	5	<i>Glycinde nordmanni</i> (Malmgren, 1866)	7	*	*	CEAB.AP.877
Maldanidae	6	<i>Axiothella constricta</i> (Claparède, 1869)	8	*	*	CEAB.AP.892
		<i>Maldane sarsi</i> Malmgren, 1865	9	*	*	CEAB.AP.879
Nereididae	7	<i>Platynereis dumerilii</i> (Audouin & Milne Edwards, 1834)	10	*	*	CEAB.AP.890
Oeononidae	8	<i>Arabella iricolor</i> (Montagu, 1804)	11	*	*	CEAB.AP.887
Onuphidae	9	<i>Diopatra marocensis</i> Paxton, Fadlaoui & Lechapt, 1995	12	*	*	CEAB.AP.878
Opheliidae	10	<i>Ophelia rathkei</i> McIntosh, 1908	13	*	*	CEAB.AP.893
Orbiniidae	11	<i>Naineris laevigata</i> (Grube, 1855)	14	*	*	CEAB.AP.895
Phyllodocidae	12	<i>Eteone barbata</i> Malmgren, 1865	15	*	*	CEAB.AP.880
		<i>Eumida sanguinea</i> (Ørsted, 1843)	16	*	*	CEAB.AP.870 A-C
		<i>Phyllodoce</i> sp.	17	*	*	CEAB.AP.876
Sabellidae	13	<i>Panousea africana</i> Rullier & Amoureux, 1969	18	*	*	CEAB.AP.869
Sigalionidae	14	<i>Sthenelais boa</i> (Johnston, 1833)	19	*	*	CEAB.AP.891
Spionidae	15	<i>Paraprionospio pinnata</i> (Ehlers, 1901)	20	*	*	CEAB.AP.882
Terebellidae	16	<i>Amaeana trilobata</i> (Sars, 1863)	21	-	*	CEAB.AP.874
		<i>Pistella lornensis</i> (Pearson, 1969)	22	*	*	CEAB.AP.896

**Table 2** Main species of each polychaete assemblage according to the IndVal index. Assemblages are termed following the species with the highest IndVal (in bold).

Season	Cluster	Species	IndVal	
Spring	<b>1</b>	<i>Maldane sarsi</i>	186.0	
		<i>Paraprionospio pinnata</i>	160.4	
		<i>Diopatra marocensis</i>	26.2	
	<b>2</b>	<i>Eunice vittata</i>	3314.3	
		<i>Arabella iricolor</i>	522.4	
		<i>Ophelia rathkei</i>	391.8	
		<b>3</b>	<i>Cirriformia tentaculata</i>	108.8
			<i>Glycinde nordmanni</i>	84.2
			<i>Platynereis dumerilii</i>	80.0
Winter	<b>1</b>	<i>Maldane sarsi</i>	1406.1	
		<i>Axiothella constricta</i>	281.2	
		<i>Glycera alba</i>	43.6	
	<b>2</b>	<i>Naineris laevigata</i>	39.1	
		<i>Pistella lornensis</i>	26.0	
		<i>Paraprionospio pinnata</i>	19.5	
	<b>3</b>	<i>Cirriformia tentaculata</i>	151.9	
		<i>Ophelia rathkei</i>	136.4	
		<i>Eunice vittata</i>	111.5	

**Table 3.** PERMANOVA results of polychaete communities among cluster groups.

		<b>Spring</b>			<b>Winter</b>	
		<b>Cluster 1</b>	<b>Cluster 2</b>	<b>Cluster 3</b>	<b>Cluster 1</b>	<b>Cluster 2</b>
<b>Spring</b>	<b>Cluster 2</b>	0.0002				
	<b>Cluster 3</b>	0.0001	0.0001			
<b>Winter</b>	<b>Cluster 1</b>	0.003	0.0002	0.0002		
	<b>Cluster 2</b>	0.0001	0.0003	0.0005	0.0001	
	<b>Cluster 3</b>	0.0001	0.0001	0.0027	0.0005	0.0001