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Macrobenthic community structure of soft-bottom sediments in the Khnifiss lagoon, South of Morocco

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Abstract
Located in the coastal Sahara, South of Morocco, and constituting the only lagoon of the whole Saharian bioclimatic stage, the National Park of Khnifiss plays an essential role for many benthic species. In the course of this study, a prospection of the lagoon was carried out, with the principal aim of conducting the cartography of the benthic fauna. Fifty seven taxa were identified, mainly of Molluscs, Crustaceans, and Polychaetes. The abundance and the specific richness found in the lagoon prove that this ecosystem is still in good health. However, projects for aquaculture and tourism probably will disturb this fragile and original ecosystem. An integrated management of the National Park of Khnifiss must be established to reconcile all these projects, and so improve the living conditions of the local populations while preserving the biodiversity. This work was conducted under the auspices of the Hubert Curien Program "*Volubilis*" with the financial support of the French and Moroccan Ministries.

Keywords: Khnifiss lagoon, benthic community, National Park of Khnifiss, Coastal Sahara.

1. Introduction

Benthic macrofauna of the lagoon is a natural resource of primary importance, since it includes both species of great economic value and a large number of species that serve as food for the ichthyofauna and avifauna. Benthic macrofauna is a good indicator of the variability of environmental conditions. Indeed, temporal variations in benthic communities associated with the environmental characteristics of lagoons, have been studied [1, 2, 3]. Benthic macrofauna is closely correlated with the ecological conditions prevailing at the sediment-water interface where a multiple effect of organic enrichment and pollutant occurs [4]. Thus, benthic macrofauna is one of the best biological tools for reflecting environmental change [5].
This study concerns the Khnifiss lagoon, located in the coastal Sahara in the south of Morocco (20 km long and 65 km^2 surface area). The lagoon was a : Natural Reserve in 1962, Site protected by the RAMSAR Convention on the conservation of wetlands of international importance in 1980, Biological Reserve in 1983, and National Park with a 606,000 ha surface area since 2006.
Many studies in the past concerned the avifauna of Khnifiss lagoon [6, 7]. The lagoon is a stop-over site for the many European species as the Oystercatcher, *Haematopus oestralegus* (Linnaeus, 1758), the Red Knot, *Calidris canutus* (Linnaeus, 1758) and the Bar-tailed Godwit, *Limosa lapponica* (Linnaeus, 1758) [8]. The most important species of the Khnifiss lagoon are the four endemic species: the Moroccan Cormorant, *Phalacrocorax carbo maroccanus* (Hartert, 1906), the Audouin's Gull *Ichthyaetus audouinii* (Payraudeau 1826), the Moussier's Redstart, *Phoenicurus moussieri* (Olphe-Galliard, 1852) and the Tristam's Warbler, *Sylvia deserticola* (Tristam, 1859), and the Slender-billed Gull, *Larus genei* (Brème, 1839), a threatened species [9]. Recently, the wintering of the Brant Goose, *Branta bernicla* (Linnaeus, 1758) was studied [10], and the reproduction of Anatidae in the National Park of Khnifiss [11].
Hydrology and hydrodynamics conditions were studied [3, 12 13], and a first list of benthic species was given [14]. In this paper, we aim to study the macrobenthic community structure in relation to physicochemical factors

throughout the lagoon. Recent studies of our team concern the polychaete species *Marphysa sanguinea*, and the heavy metal concentrations in *Nereis diversicolor* [15].

2. Materials and methods

2.1. Sampling and laboratory procedures

Study area is situated in the south of Tan Tan 28°03' N and 12°15' W in the Laâyoune province along the Atlantic coast of South Morocco (Fig. 1). The Khnifiss lagoon is located in Sahara between the dunes of Lassi Fleiga, Foum Agwitir, and the Sebkha Tazra [16]. The Khnifiss lagoon area has an arid climate with very low precipitation and a maximal annual rainfall of 50 mm. The air temperature in the Khnifiss lagoon varies between 13°C and 24°C.

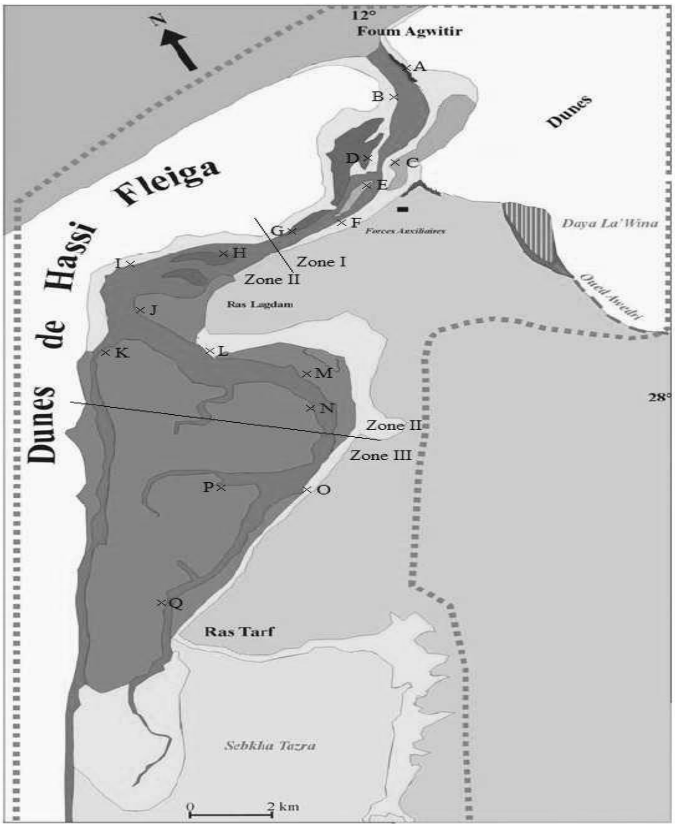

Figure 1: Location of study area and sampling sites along the Khnifiss lagoon

Benthic fauna was sampled at 17 stations (site A to Q) (Fig. 1) during spring 2008, between the 4^{th} and the 10^{th} of April. Samples were collected using a grab at low tide [17]. For the purpose of identification, samples were washed through a 1-mm mesh sieve and fixed in 7% sea water formaldehyde. In the laboratory, samples were rinsed in fresh water and preserved in 70% ethanol.

Additional sediment samples (100 g) were taken at each site to measure particle grain size. These samples were dried for 48 hours at 60°C, and then washed through a 63-µm mesh sieve in order to separate the small fraction (silt + clay). The remaining sediment was dried again at a temperature of 60°C, and all samples were then sieved through an AFNOR series of meshes (2000, 1400, 630, 500, 315, 250, 125, and 63µm). The following fractions were observed: gravel (GR, >2 mm), very coarse sand (VCS, 2–1 mm), coarse sand (CS, 1–0.5 mm) medium sand (MS, 0.5–0.25 mm), fine sand (FS, 0.25–0.125), and silt and clay (>0.063 mm). Median grain size (Q_{50}) was determined for each sample and sediment types were classified according to Chassé & Glémarec [18]. The sediments were exclusively sandy, ranging from coarse to fine sand.

2.2. Data analyses

Diversity index was calculated for each sample of benthic fauna using the number of individuals (N), the species richness (S), the Shannon-Weaver diversity index H´ and the Pielou's evenness J´ [19]. Rank-Frequency Diagrams [20] were used to study the community structure, based on two criteria: (1) the abundance of species and (2) the rank of species. RFD was applied to show temporal succession in benthic communities [21]. The faunal composition of shallow-water and deep-water sites in different stations was compared using the Jaccard Index and cluster analysis based on the similarity between stations using the software PAST. A cluster diagram was produced using Bray-Curtis similarity and following the algorithm recommended by Lance & Williams (1967) [22]:

$$dh\ ij = 0.625\ dh\ I + 0.625\ dh\ j - \beta\ dij \text{ (with } \alpha = 0.625 \text{ and } \beta = 0).$$

3. Results and discussion

3.1. Spatial variation of physicochemical factors

3.1.1. Results

The spatial variation of temperature and salinity during the sampling period in 17 sites in the Khnifiss lagoon is illustrated in Figure 2. A similar spatial pattern was observed for water temperature (Figure 2. A) and salinity (Figure 2. B). It showed a tendency to increase when moving from downstream to upstream of the lagoon. The values are close to ocean values in the downstream part of the lagoon, and they increases when moved upstream. Temperature values increased slightly from site "A" to site "O" reaching a maximum value (25°C), and values were comprised between 17°C and 25°C. The similar pattern was observed for salinity evolution from site "A" to site "Q" and values were comprised between 36 psu and 45 psu.
The study of sediment grain size is illustrated in Figure 3. It indicates a great diversity of sedimentary types between the various sites. The portion most represented is between 0.250 and 0.125 mm, fine sand. Sites E and K are those with the most of coarse sediment. They are located respectively on an island that appears at low tide at the mouth of an inlet of the upstream part of the lagoon (see Fig. 1), and are subject to significant hydrodynamic constraints. On the other hand, stations D, N, P, O and J are have a greater proportion of sandy clay sediments that reflect more sheltered areas. The calculation of the rate of organic matter has also confirmed the results of particle size. Indeed, the stations with the highest rate of organic matter are those that had significant fractions of sediment below 63 m (D, J, N, O and P). It is also not surprising to find a high rate of organic matter for station D (Fig. 4). In respect of this parameter, all other stations are homogeneous with a rate that is around 2%.

3.1.2. Discussion

The physicochemical parameters measured in our study are consistent with those of the previous study [3]. The water parameters, temperature and salinity, are closely linked with oceanic influence (Fig. 2). Thus, further away upstream from the lagoon, these settings fluctuate significantly and may take extreme values. In fact, the ocean has a buffering capacity for the downstream part of the lagoon and the living conditions observed become more and more difficult with the increasing distance upstream. Measurements of dissolved oxygen had also made [3], which values were highly variable from one station to another, with a steep gradient of oxygen from downstream to upstream according to the tides. They also noted that during the floods, the water renewal improved levels of dissolved oxygen in the lagoon. They demonstrated that the lagoon is governed by the dynamics of tidal cycles.
The sediment types may vary significantly from one station to another, either in terms of size or organic matter (Fig. 3 and 4). A sediment study conducted in the lagoon in September 1998 [23] had shown the existence of three sediment types: sandy, muddy sand and sandy mud [3]. It was shown that most of the sediment consists of sandy mud. Indeed, the areas along the left bank of the downstream zone and salt marshes of the upstream area are relatively calm. They have a high level of fine sediment and organic matter (Fig. 3 and 4). Instead, the areas along the left bank of the first part of the channel are sandy and have a low rate of organic matter because of heavy turbulence.
Other parameters such as phosphates, nitrates and chlorophyll pigments, have been studied and reported by other authors. They have concentrations that vary according to the tide and are characterized by daily and seasonal variations [13, 3]. Nitrate concentrations tend to decrease when heading upstream, while in contrast, those of phosphate and chlorophyll tend to increase the further they are from the ocean. Lagoon zero state have been determined by studying chemical and microbiological conditions [24]. It shows that lagoon water has a good quality for aquaculture, but the authors have founded eutrophisation in a part of the lagoon with a microbiological contamination of animal origin.

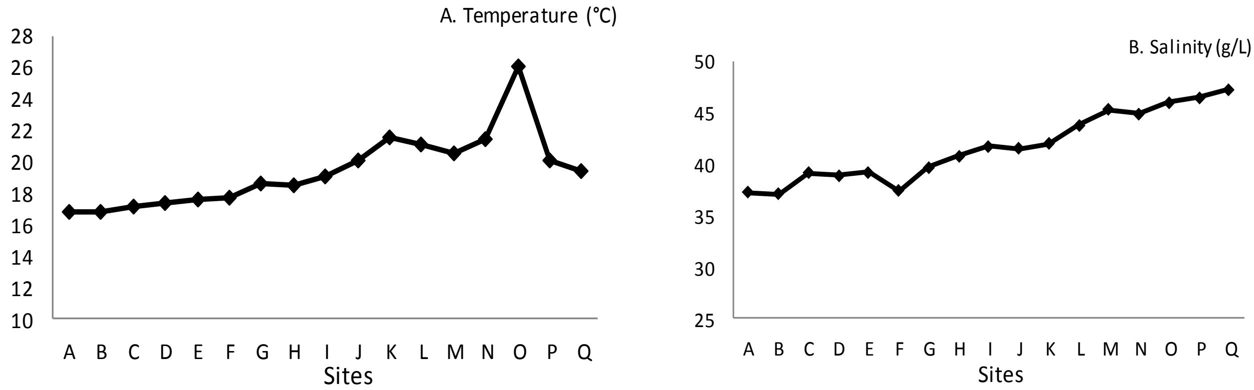

Figure 2: Spatial variation of temperature (A) and salinity (B) in 17 sampling sites in Khnifiss lagoon during the sampling period.

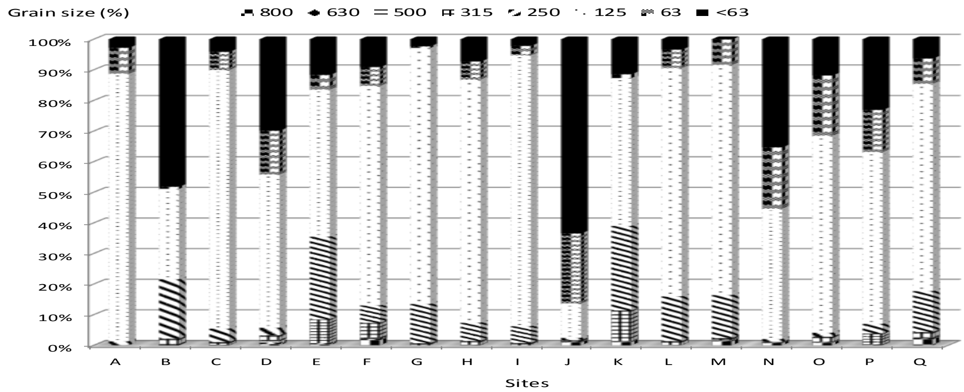

Figure 3: Sediment grain size and types along sampling sites in Khnifiss lagoon.

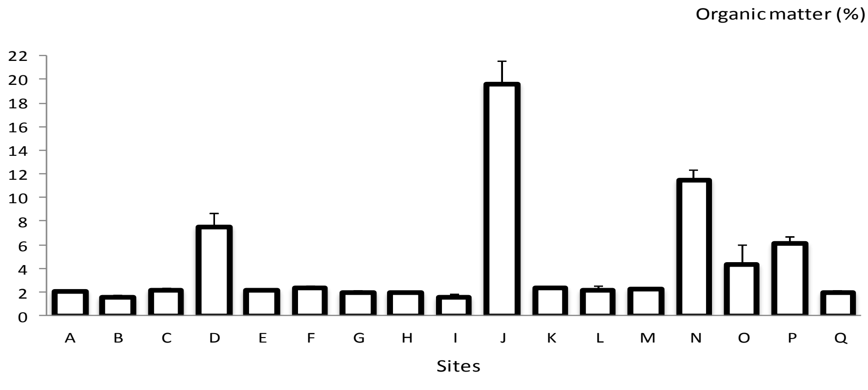

Figure 4: Rate of organic matter in sites sediment sampling at Khnifiss lagoon.

3.2. Spatial variation of macrobenthic communities

3.2.1. Results

In this study, 36,983 individuals of 57 taxa have been identified in the 17 stations sampled. Molluscs are dominant with 96.1% of total benthic fauna. Molluscs have also the highest number of species with 34 taxa representing 60% of the specific richness. Two species are largely dominant: *Hydrobia ulvae* and *Turritella communis*. Polychaetes have 17 taxa, representing 30% of specific richness. Three species are abundant: *Diopatra neapolitana*, *Terebella lapidaria* and *Nicomache lumbricalis*. As far as the spatial distribution of the species is concerned, 18 species are present on 50% of the stations. Only one species, *Hydrobia ulvae,* is present on all 17 stations of the Khnifiss lagoon.

Diversity Index (H') and Evenness (J) show that the stations located in the mouth of the lagoon (A, B and C) have a very low specific richness but high evenness. On the contrary, the stations located upstream (from J to Q) have a large number of species (Fig. 5).
Rank Frequency Diagrams (RFD) show the spatial differences between the communities structure of the three different zones and their evolution toward the stages (Fig. 6), defined by Rhoads & Germano [25]. The diagrams for the marine sites show a progressive straightening of the curves with a shift towards stage 3 corresponding to a state of equilibrium [26].

3.2.2. Discussion

Our results for the composition of the benthic fauna of the lagoon confirm the absence of pollution in the Khnifiss lagoon. Macrobenthos is indeed a good indicator of the health of the ecosystem of the lagoon [27]. Polluted environments often present low species richness. In some sites still contaminated with a large number of taxa, there is a strong dominance of one group [17].

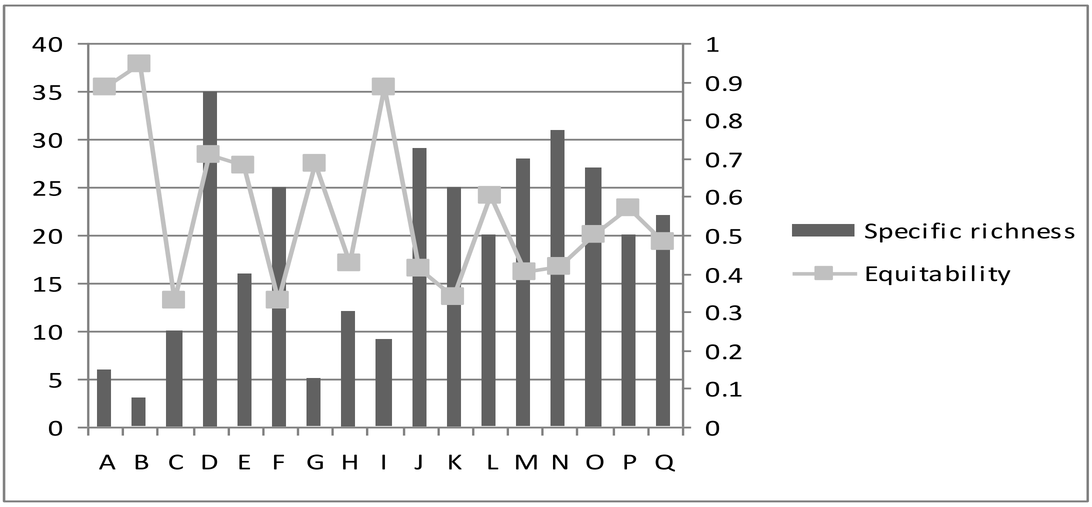

Figure 5: Specific richness and equitability in 17 sampling sites in Khnifiss lagoon.

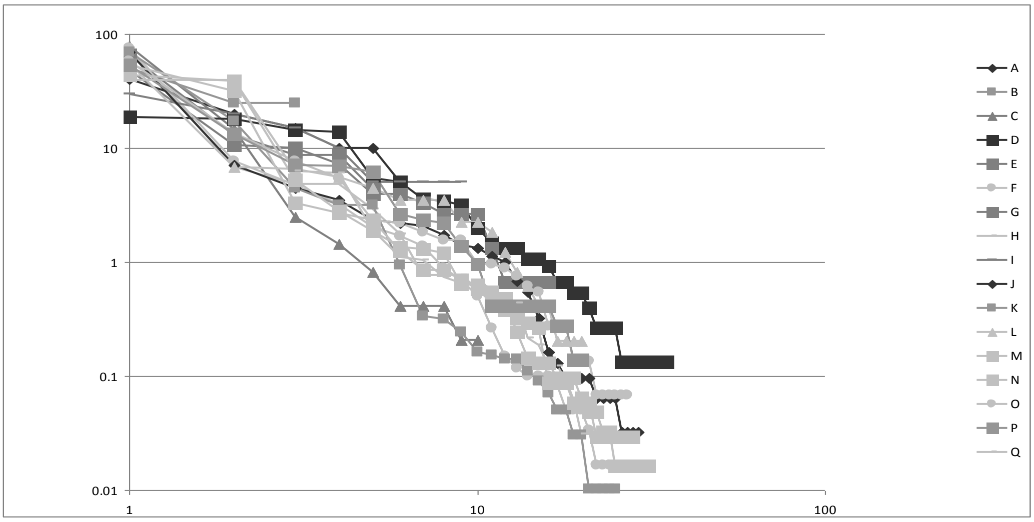

Figure 6: Rank Frequency Diagrams (RFD) established for the 17 sampling sites in Khnifiss lagoon.

In our study, 57 taxa were identified. In 1988, Bayed et *al.*, [14] had identified 34. This high level of richness therefore indicates that the lagoon is still free from any pollution. There is no dominance of any particular taxon as we indicated in the index of equitability, between 0.32 and 0.96. The rank-frequency diagrams of all 17 stations have a similar structure (Fig. 6). None is characteristic of polluted environments.

3.3. Species assemblages: community structure and distribution

3.3.1 Results

Three distinct groups of sites are shown by cluster analysis with each having an average similarity higher than 50% (Fig. 7). The first group, including the marine sites (A, B, G and I), is composed of four sites with a sand bottom and a low specific richness. These sites are located in the downstream part of the lagoon, where the values of temperature and salinity are fairly close to oceanic values. Therefore, in these four stations, there are only two species of Polychaetes and five species of molluscs. This group of sites has by far the biggest proportion of the larger crustaceans (45%). In fact these four sites, located on intertidal sand with Zostera seagrass beds for station G, and with low levels of organic matter (less than 2%), do not offer sufficient living conditions for the development of a large group of benthic fauna. The second group includes the sites (D, E, F, J, K, L, M, N, O and P.) and consists of the sites located in the center of the lagoon with a sub-group (D, J, O, N and P) where the specific richness is very high. In this group, sites D, J, O, N and P are characterised by a high specific richness, a high level of organic matter and clay fraction sediment. The sites of the second subgroup (K, L, and M) are spatially close and have similar values of temperature and salinity. The species richness, abundance and equitability differ greatly for each of these sites. However, despite these differences, the fauna observed is substantially similar on all these sites. It should be noted that the majority of Polychaetes were found in these sites. The third group consists of three sites (C, H and Q) which are widely dispersed in terms of space. These sites have intermediate values of richness and equitability, compared to the rest of the lagoon. Site Q with a high density (12,944 ind.m^2 and a high specific richness (22 species) is bigger than the other two sites. However, we observe a complete absence of Polychaetes. Only one individual was collected for all three sites. The water parameters that have been measured and the sediment types do not explain the absence of Polychaetes in these sites. The only similarities that can be observed are a small percentage of organic matter (2%) and the division of sediment fractions. Three distinct groups of species are shown by cluster analysis with each having an average similarity of higher than 50% (Fig. 8). The first group includes the species *Hydrobia ulvae* and *Terebella lapidaria.* The second group includes a large number of species and the third group includes *Diopatra morocensis*, *Loripes lucinalis* and *Nicomache lumbricalis*.

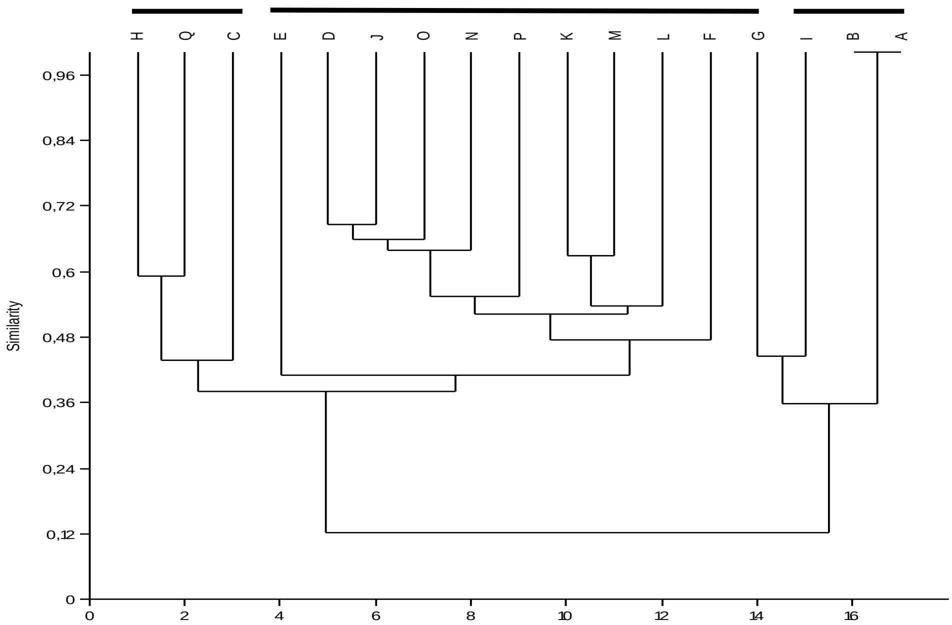

Figure 7: Distinct groups of sites established by cluster analysis for all the 17 sampling sites considered in Khnifiss lagoon.

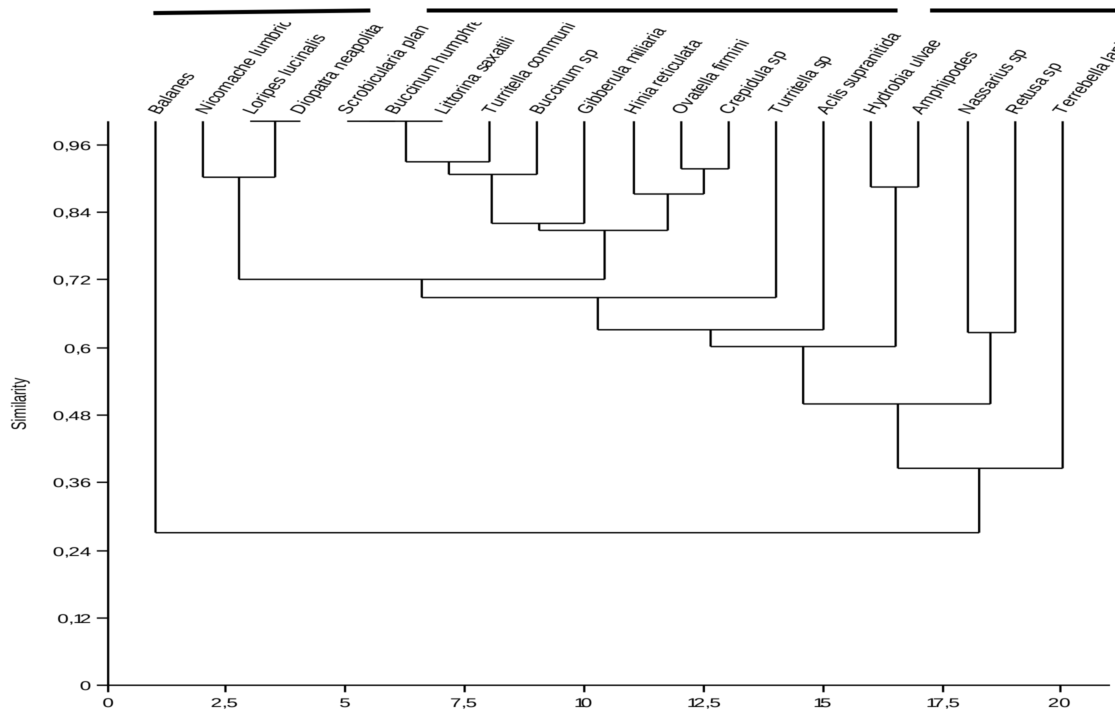

Figure 8: Distinct groups of species established by cluster analysis with each having an average similarity of higher than 50%.

3.3.2. Discussion

Benthos plays an important role in the organization of estuaries and lagoons [28]. It is a preferred food source for many consumers of higher rank (fishes, birds, decapods...). These predators play a role in regulating the dynamics of the benthic fauna by reducing the abundance of some species during part of the year [29]. The Polychaetes themselves take up a large part of the trophic network as predators of other benthic organisms [30].

The most abundant groups are molluscs, whether in terms of numbers of species or abundance, Crustaceans and Polychaetes. The genera *Hydrobia* and *Turritella* overwhelmingly dominate the fauna composition in the Khnifiss lagoon, since they represent nearly 80% of the total abundance of the fauna in the lagoon. Molluscs have the most important frequencies with 15 species (4 Lamellibranches and 11 Gastropods) found in 50% of the sites. These play an important role in the ecosystem. Molluscs are the basic food of many other species. Polychaetes are well represented throughout the lagoon and estuarine ecosystems, both in terms of the number of species or individuals [31]. Many Polychaetes have significant physiological tolerance to extreme environmental changes [32]. It is therefore not surprising to find them in almost all sites of the lagoon. Polychaetes were also an important group in this area, dominating communities within fine sediments [33]. They play a major role in the functioning of the ecosystem through the recycling and reworking of the sediment. Polychaetes may be carnivores, herbivores, may eat mud, eating the suspended particles or sediment surface. Hutchings (1998) [31] says that the tubes of *Diopatra sp*. protect the former from predators such as crabs. This feature is not easily observed from the specific affinity diagram (Fig. 8). Crustaceans are mostly represented by Amphipods. They were found in almost all stations (88.2% of stations). They consist of 15 different species.

The comparison of rank-frequency diagrams of all sites allows us to separate them into three distinct groups. Apart from stations A, B, G and I that have a few species, other sites have a fairly well structured community. The community structures are between stages 1 and 2 according to Frontier. A first group includes sites in which one species predominates (for sites E, F, H, J, L, O and P). The other communities are dominated by two or three species whose frequencies are above 10% with *Hydrobia ulvae* and *Turritella communis* (sites C,

D, K, M, N and Q). All these sites are in a state close to maturity. There may be extremely difficult conditions (large daily fluctuations in salinity, temperature and so on).
The distribution of macro-invertebrates is first conditioned by the physical parameters [34]. Some authors consider that salinity is the main factor affecting the benthic community structure [29, 35, 36], while others believe that the type of sediment and the alternation between immersion and emersion are determining factors [37, 38]. But many factors, more or less related, must be taken into account, such as currents, organic matter, pH and dissolved oxygen. The author [3] have divided the lagoon of Khnifiss into three major areas, according to various abiotic factors, including the currents. They have also shown that the current in the lagoon is stronger downstream than upstream. These three areas have been included in our study of the sites. Following the present work, these sites have been grouped, but this time based on their faunal composition. The results obtained are substantially different from what we might expect. The sites that are close by their affinity are not necessarily so spatially. Some parameters gradually fluctuate and sink into the lagoon, like currents, temperature, salinity, and are no longer sufficient to explain the distribution of the species.
Compared to other studies on the Moroccan lagoons, the Khnifiss lagoon is characterized by a large number of species (57 taxa) spread over three major groups: Molluscs, Crustaceans and Polychaetes. Even if they are the three groups that dominate consistently the benthic Moroccan lagoons, the hierarchy is not similar. The lagoon of Oualidia is the one that is the most similar to Khnifiss, with a large dominance of Molluscs > Crustaceans > Polychaetes. The lagoons of Nador and Sidi Moussa are also close. However, the lagoons of Smir and the Merja Zerga are different with a ranking going from Crustaceans > Polychaetes > Molluscs. Regarding the number of taxa, the lagoons of the Mediterranean Sea, Nador, Smir and Merja Zerga, are richer than the Atlantic lagoons [38]. Although very far from the lagoon of Oualidia and Sidi Moussa, and undergoing tropical influences, the lagoon of Khnifiss is however quite close to the two other Atlantic lagoons regarding the relative dominance of major faunal groups and the number of taxa.
Coastal ecosystems such as lagoons are often thought of as being fragile and highly productive [39]. Due to their hydrological characteristics and environmental conditions, lagoons endure frequent fluctuations on a daily and seasonal basis [40]. This instability causes many changes in the distribution of benthic species and in the structure of communities [40], often aggravated by anthropogenic influences. Because of such ecological characteristics, conflicts will often arise between their exploitation and the protection of natural resources. A sound understanding of their structure and their way of functioning is therefore necessary to implement effective management and conservation measures [38]. Yet information about natural temporal variability in lagoons is also very important. Establishing patterns of community change under relatively undisturbed conditions can provide some understanding of how lagoon communities function and can result in a better assessment of the extent of anthropogenic disturbances.

Conclusion

In the course of this study, a prospection of the lagoon was carried out, with the principal aim of conducting the cartography of the benthic fauna. Due to its geographical position, its very difficult climatic conditions and very low density of human population, the lagoon Khnifiss is now supposed free from any pollution. This study also highlighted the presence of a rich and abundant macrobenthic fauna more diverse than that present in the most other Atlantic Moroccan lagoons. The abundance and the specific richness found in the lagoon prove that this ecosystem is still in good health. However, we must consider few studies that have specifically interested the pollution on this site. The site's designation as a Ramsar site, and more recently as a National Park, strengthens the protection of the site. Indeed, the obligation to anyone outside the park to get permission to visit the site severely limits access.

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