Journal of the Marine Biological Association of the United Kingdom, 2008, 88(4), 663–674. ©2008 Marine Biological Association of the United Kingdom
doi:10.1017/S0025315408001318 Printed in the United Kingdom

Trophic organization of the macro-zoobenthic assemblages within coastal areas subjected to anthropogenic activities

AHMED AFLI[1], RAKIA AYARI[1] AND MOULDI BRAHIM[2]

[1]Laboratoire de Biodiversité et Biotechnologies Marines, [2]Laboratoire du Milieu Marin, Institut National des Sciences et Technologies de la Mer 28, Rue de 2 Mars 1934–2025 Salammbô, Tunisia

Coastal areas, in general, are affected more and more by anthropogenic activities. Benthic macrofauna assemblages react to this disturbance and constitute, then, an effective biological tool to study the degree of contamination of the biotope. For this study three coastal sites, more or less exposed to anthropogenic activities but differing according to their opening to the sea, were studied. Sediments were sampled aboard a research vessel and using a 0.1 m^2 Van Veen grab. Results show that Tunis bay and Dkhila coast, which are more open to the sea, appear more balanced on the trophic plan, and the biodiversity state is more satisfactory. However, Bizerte lagoon is closed, except for a limited communication with the sea via a narrow ship canal. So, the ecosystem presents some eutrophication signs and a great trophic imbalance in which carnivores largely dominate the benthic assemblages. In this situation, the herbivore chain is substituted by a microbial chain and only some opportunistic species can survive in these anoxic sediments related to the strong fluctuations of the environment factors during the year.

Keywords: benthic macrofauna, trophic groups, lagoon of Bizerte, bay of Tunis, coast of Dkhila

Submitted 30 July 2007; accepted 17 December 2007

INTRODUCTION

Anthropogenic activities carried on in the coastal areas are the principal source of disturbance of the marine environment. They are increasingly harmful because of the industrial development and the population growth on the littoral. The complexity and the multitude of the factors governing marine life in general require multidisciplinary studies to understand the response of the ecosystems to these disturbances. Each discipline brings, indeed, a contribution more or less large, but necessary, to appreciate the functioning of the ecosystem in affected areas.

In Tunisia, the studies carried out on benthic macrofauna are generally very few. The benthos of Tunis gulf is relatively more studied, and research started with Azouz (1973), then was recently picked up again by Ayari & Afli (2003) and Zaabi & Afli (2005, 2006). However elsewhere in Tunisia, benthic macrofauna is not yet studied, except for the work undertaken by Afli & Ben Mustapha (2004) in the Dkhila area. Some other works have been conducted in limited areas, such as those of Zghal & Bouaziz-Azzouna (1982), Zaouli (1993) and Ben Souissi (2002). In general, the Mediterranean Sea is of the sub-wet shade climate type. The summer is hot and dry, and the winter is cool and rainy. These general particularities and also some other regional characteristics, such as the fluctuations of floods, temperature and salinity give some specificities to the Mediterranean biocoenoses (Pérès, 1972; Bellan-Santini *et al.*, 1994; Lardicci *et al.*, 1997; Albertelli *et al.*, 1999; Salen-Picard & Arlhac, 2002).

This study aims to compare the trophic organization of the benthic macrofauna assemblages in three coastal sites, more or less exposed to various anthropogenic activities and differing, according to their opening to the sea (Figure 1). The first one (coast of Dkhila) is completely open to the sea. The second (bay of Tunis) is half-closed. Whereas, the third one (lagoon of Bizerte) is practically closed. It communicates with the sea only by a narrow ship canal. Nevertheless, the three sites assemble the threats of disturbance generated by the increasing anthropogenic activities.

Study sites

LAGOON OF BIZERTE

Bizerte lagoon covers an area of approximately 128 km^2. Its maximum depth is around 12 m. It communicates, in the north, with the Mediterranean sea by a 7 km length canal and, in the south, with the Ichkeul lake by the Tinja wadi. The principal wadis which feed Bizerte lagoon with freshwater are the wadis of Tinja, Mrezig, Garek, Ben Hassine and Gueniche (Soussi, 1981). Bizerte lagoon is subject to the influence of several physical factors strongly fluctuating during the year. In winter the freshwater flow coming from the Ichkeul lake and several wadis is more important, and in summer the influence of seawater is more interesting (Sakka Hlaili *et al.*, 2003). So, the seasonal gradient of the water salinity in Bizerte lagoon is relatively high. It varies on average from

Corresponding author:
A. Afli
Email: afli.ahmed@instm.rnrt.tn

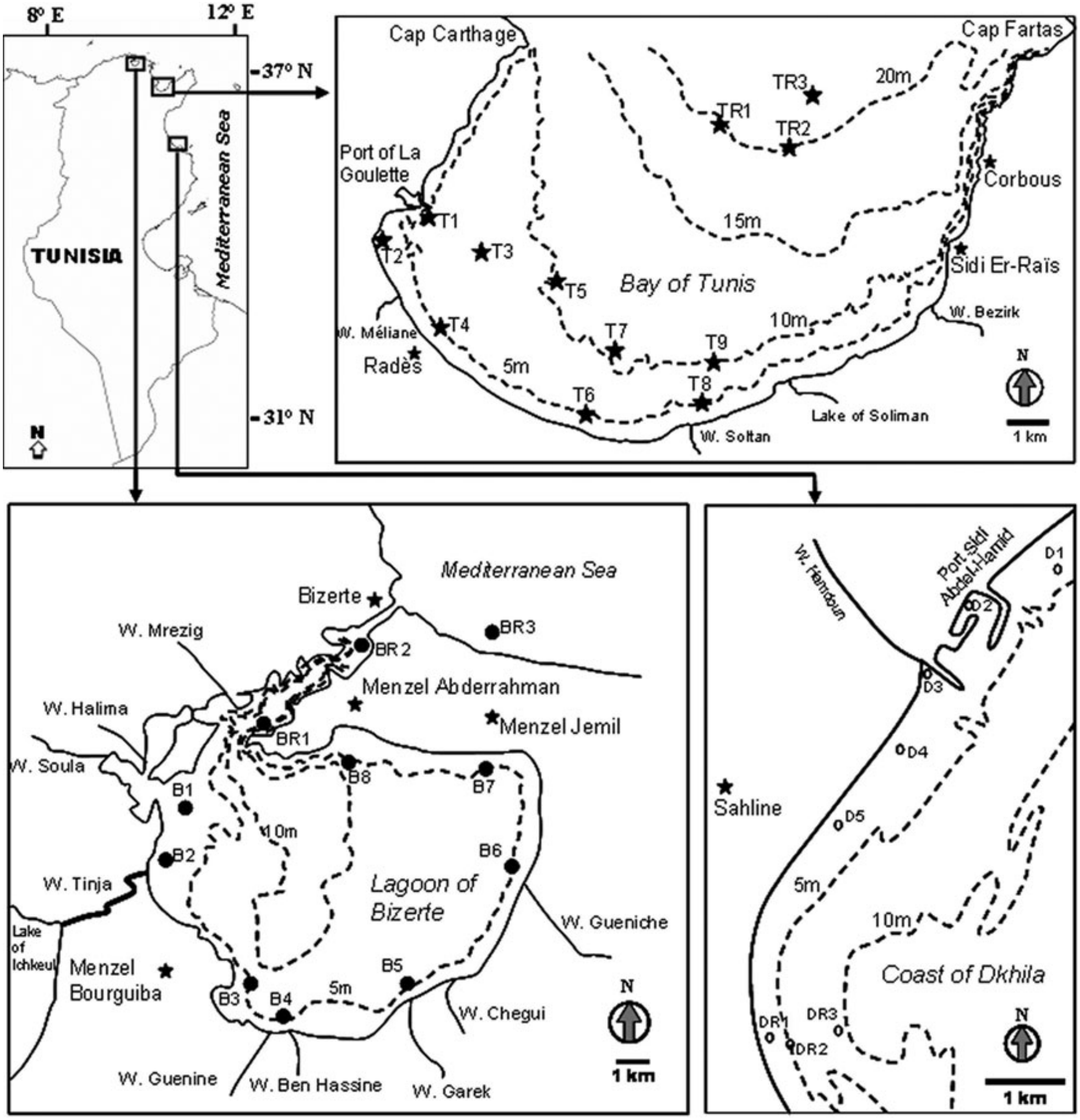

Fig. 1. Maps of the study sites showing the locations of the sampling stations.

20 g/l in winter to 40 g/l in summer (Harzallah, personal communication).

Bizerte lagoon is known, these last decades, by the aquaculture of the mussel *Mytilus galloprovincialis* Lamarck, 1819 which reproduces in the lagoon naturally. It is also a natural environment, favourable to the growth of oysters, especially the European flat oyster *Ostrea edulis* Linnaeus, 1758 with high growth rate in spring, and the Japanese oyster *Crassostrea gigas* (Thunberg, 1793) which grows throughout the year. The Japanese clam *Tapes* (*Ruditapes*) *decussatus* (Linnaeus, 1758) is also relatively abundant in the site and is subjected to commercial collection. The total production of fishing in Bizerte lagoon is around 90 tons a year (Bejaoui, 1998).

The Bizerte lagoon ecosystem is currently destabilized. The worn water rejections coming from the bordering towns increase with demographic growth (Dellali *et al.*, 2001). The human population around the lagoon is estimated in 2004 at 163,000 inhabitants (census of 2004) of which approximately 70% are concentrated in Bizerte town. Industries (iron and steel plant, cement factory and refinery) are established on its circumference (Essid & Aissa, 2002). The construction of dams in the Ichkeul lake upstream has strongly affected its natural equilibrium (Riera *et al.*, 1999, 2002). The supply of fresh water in the lagoon fell, therefore, from 165 to only 20 million m^3 a year after the construction of these dams (Harzallah, 2003).

BAY OF TUNIS

Tunis bay is a depression in the south of Tunis gulf of approximately 350 km^2. Few wadis feed Tunis bay with freshwater, but the most important is Méliane wadi (Ben Charrada, 1997).

The dominant winds come from the north-western sector and cause swells during the cold season carrying alluvia to the south and the south-east (Ben Charrada, 1997). The average depth of Tunis bay is low and does not exceed 31 m, and water movements are controlled by currents generated by winds (Zarrad, 2001; Ayari & Afli, 2003).

For a few years, the littoral of Tunis gulf has been subjected to industrial, urban and tourist development. Significant commercial and fishing activities in the harbour of La Goulette, Radès and Tunis have been noted, as well as the thermal discharges of the Radès power station. The population of Tunis City, of its northern and southern suburbs, was estimated in 2004 approximately at 2,250,000 inhabitants. On the other hand Méliane wadi discharges directly and permanently into the bay and also by the effluents of the water-treatment plant of 'Sud Méliane', with some uncontrolled industrial wastes (Azouz, 1973; Oueslati, 1993; Ben Charrada, 1997). Further east, the area receives the effluents of three other water-treatment plants as well as waste water discharges of other coastal agglomerations, such as the town of Korbous (4000 inhabitants). Also, the presence of the food-processing industry and of the sources of thermal water (Korbous) constitute potential sources of pollution in the long term.

COAST OF DKHILA

The coastal zone of Dkhila is completely open to the sea. The depth of the sampled area does not exceed 10 m. The only wadi feeding Dkhila coast with freshwater is Hamdoun wadi (Afli & Ben Mustapha, 2004). The harmful effects which could occur in the zone would be the urban rejections of the neighbouring cities and the development of balneal tourism in the zone. The town of Sousse, bordered in the south by the Sidi Abdel-Hamid port, is considered the most important agglomeration of the zone with approximately 173,000 inhabitants, while the small town of Sahline counts only approximately 15,000 inhabitants. In summer, the population increases with the reception of visitors and holidaymakers.

In addition, a power station located between the Sidi Abdel-Hamid port and the Hamdoun wadi uses seawater to cool the engines. It pumps the water from the port, near the D2 station, and rejects it hotter into the Hamdoun wadi, near the D3 station. Afli & Ben Mustapha (2004) conducted a study on the benthic assemblages of the site. They showed the existence of first signs of pollution in the port and in the wadi mouth.

MATERIALS AND METHODS

Sampling and laboratory procedures

In total, 31 stations were sampled, 11 in Bizerte lagoon, 12 in Tunis bay and 8 in Dkhila coast (Figure 1). In each site, 3 stations further away from the potential sources of disturbance were considered as stations of reference. The marine surveys were carried out in beginning of winter (November–December) aboard a research vessel, and samples were collected by a 0.1 m^2 Van Veen grab which penetrated approximately 10 cm into the sediment (Borja *et al.*, 2000; Rosenberg *et al.*, 2004). Based on a variety of criteria, calculations of the minimum required sampling surface were estimated to three samples to determine the number of species present in the community as well as their abundance and diversity (Cain & Castro, 1959; Boudouresque & Belsher, 1979; Martín *et al.*, 1993; Gómez Gesteira & Dauvin, 2005). Thus, four samples were collected at each station, three intended for fauna study and another one for the particle size composition of the sediment.

At the laboratory, samples for fauna study were also sorted out with fresh water, on a square mesh of 1 mm a side (Borja *et al.*, 2000; Grall & Glémarec, 2003; Gómez Gesteira & Dauvin, 2005; Dauvin *et al.*, 2007). The animals collected were preserved with diluted alcohol (70%) before being identified, for most of them, up to species level. The particle size composition of the sediment was determined by drying for 48 hours at 60°C, then washed through a 63 μm sieve in order to eliminate the thin fraction (silt and clay) (Afli & Chenier, 2002). The refuse was dried again at 60°C, after that all samples were sieved on AFNOR succession meshes. Consequently, the quantity of sediment recovered in each sieve represents the sedimentary fraction of size ranging between its meshes and those of the top sieve.

Data analysis

The classification of the sediments was carried out according to Shepard's diagram (Shepard, 1954) by placing each station in the triangular diagram according to the three principal fractions (mud, sand and gravel). Then, the determination of the sediment type was realized by using Chassé & Glémarec principles (Chassé & Glémarec, 1976).

The identified species were classified into the trophic groups by using the feeding guides established by Fauchald & Jumars (1979) and used then by Grall & Glémarec (1997), Afli (1999a) and Afli & Glémarec (2000):

- Herbivores (H): algae-feeding organisms (e.g. some echinids).
- Scavengers (N): feed on carrions deposited on the bottom (essentially gastropods and decapods).
- Detritus feeders (Dt): feed on particulate organic matter, essentially vegetable detritus (mainly amphipods and tanaids).
- Carnivores (C): predatory animals (mobile polychaetes, sea-anenomes).
- Micrograzers (μG): feed on benthic microalgae, bacteria and detritus (essentially polyplacophores and gastropods).
- Suspension feeders (S): feed on suspended food in the water column (e.g. most bivalves).
- Selective deposit feeders (SDF): feed on organic particles which settle on the sediment (most sedentary polychaetes).
- Non-selective deposit feeders (NSDF): burrowers which ingest the sediment from which they take their food.

Also, the principal biodiversity parameters were determined at each station. The abundance (A) is the average number of individuals per surface unit, generally carried forward to one m^2. The specific richness (S) is the cumulated number of species in a station or in a site. The Shannon–Wiener index (H′) (Shannon & Weaver, 1963) permits to describe the distribution of the individuals into the various species. It is calculated at each station by the following formula:

$$H' = -\sum_{i=1}^{S} \frac{n_i}{N} \log_2\left(\frac{n_i}{N}\right)$$

where n_i is the number of individuals of the species i, N is the total number of individuals and S is the number of species at the station.

The equitability E(H′) (Pielou, 1966a, b) is calculated at each station by the following formula:

$$E(H') = \frac{H'}{\log_2 S}$$

The H′ and E(H′) indices are used together to compare the biodiversity in the sampled stations.

The percentage of occurrence (P) is also calculated for each species and at each site by using the formula $P = m/M$ where m is the number of stations where the species is present and M is the total number of stations in the site.

To assemble the similar stations on the trophic level and characterize them by the principal trophic groups, a correspondence factor analysis (CFA) was carried out on data organized in rectangular matrices where the 31 stations occupy the columns and the trophic groups occupy the lines (Hill, 1974; Lebart *et al.*, 1982).

For the assessment of the environmental quality, Pearson & Rosenberg (1978) were the pioneers using synthetic parameters relating to benthic macrofauna to evaluate the ecological state of the communities. Their model SAB used the variability of the Specific richness (S), the Abundance (A) and the Biomass (B) in an organic gradient. Then several other methods and biotic indices were established (Dauvin *et al.*, 2007). In this study, the AZTI Marine Biotic Index (AMBI) (Borja *et al.*, 2000) was used. It defines the benthic coefficient (BC), calculated on the basis of the 5 ecological groups (EG_I, sensitive species; EG_{II}, indifferent species; EG_{III}, tolerant species; EG_{IV}, second-order opportunistic species; and EG_V, first-order opportunistic species) as following:

$$BC = \frac{\begin{pmatrix} 0 \times \%EG_I + 1.5 \times \%EG_{II} + 3 \times \%EG_{III} \\ + 4.5 \times \%EG_{IV} + 6 \times \%EG_V \end{pmatrix}}{100}$$

This BC allows to define 5 stages of degradation relating to the calculated values. AMBI is considered among the more efficient biotic indices based on benthic macrofauna, especially if it is used jointly with specific richness and abundance (Simboura, 2004; Muniz *et al.*, 2005). Species were assigned to the 5 ecological groups according to the classification of Afli (1999a, b), Borja *et al.* (2000), Afli & Chenier (2002), Simboura & Zenetos (2002), Grall & Glémarec (2003), Afli & Ben Mustapha (2004) and Reiss & Kröncke (2005).

RESULTS

Sediment

Shepard's diagram (Shepard, 1954) shows that the sediment at the sampling stations is fine (Figure 2). It is constituted principally of mud and sand. According to Chassé & Glémarec principles (Chassé & Glémarec, 1976), it belongs to 5 types (muddy heterogeneous sands, fine sands, muddy sands, sandy muds and muds). In Bizerte lagoon, all these sediment types are represented (Table 1). In Tunis bay, only muddy heterogeneous sands are not observed. However the Dkhila stations are classified only in fine sands and muddy sands.

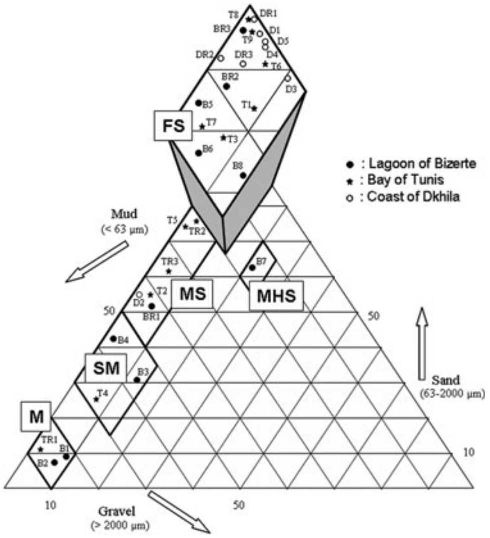

Fig. 2. Particle size composition of the sediment determined at the sampling stations according to Shepard's diagram. MHS, muddy heterogeneous sands; FS, fine sands; MS, muddy sands; SM, sandy muds; M, muds.

Fauna

In Tunis bay (Figure 3), abundance varies from 90 (T3) to 620 ind/m^2 (T1), specific richness from 9 (T2) to 33 species (T8) and equitability from 0.27 (T1) to 0.63 (T3). Regarding the site of Dkhila, abundance varies from 50 (D3) to 1520 ind/m^2 (D2), specific richness from 3 (D3) to 25 species (DR2) and equitability from 0.43 (D2) to 0.98 (DR3). Whereas Bizerte lagoon appears more impoverished, abundance varies from 10 (BR2) to 470 ind/m^2 (B3), specific richness from 2 (BR2) to 17 species (B6) and equitability from 0.15 (B1) to 0.52 (B8).

The predominance of the trophic groups (Figure 4) shows great differences between the three sites, but also between the stations of each site:

- In Bizerte lagoon, 6 stations (B3, B2, BR3, B6, B8 and B7) are dominated at 77% on average by the carnivores. Four others (B4, B5, B1 and BR2) are co-dominated by the deposit feeders (44%) and suspension feeders (47%). In this site, only BR1 seems heterogeneous at the trophic plan with about equivalent proportions.
- In Tunis bay, carnivores are clearly dominant only at T7 with about 44%, deposit feeders dominate with approximately 69% on average in half of the stations (T1, T2, T5, TR1, TR2 and TR3) and suspension feeders dominate at T8 and T4 with nearly 60%. Whereas, the other stations

Table 1. Sediment types determined by using Shepard's diagram and the Chassé & Glémarec principles.

Sites	Types of sediment	Sampled stations	Stations of reference
Lagoon of Bizerte	Muddy heterogeneous sands (MHS)	B7	
	Fine sands (FS)	B5, B6, B8	BR2, BR3
	Muddy sands (MS)		BR1
	Sandy muds (SM)	B3, B4	
	Muds (M)	B1, B2	
Bay of Tunis	Fine sands (FS)	T1, T3, T6, T7, T8, T9	
	Muddy sands (MS)	T2, T5	TR2, TR3
	Sandy muds (SM)	T4	
	Muds (M)		TR1
Coast of Dkhila	Fine sands (FS)	D1, D3, D4, D5	DR1, DR2, DR3
	Muddy sands (MS)	D2	

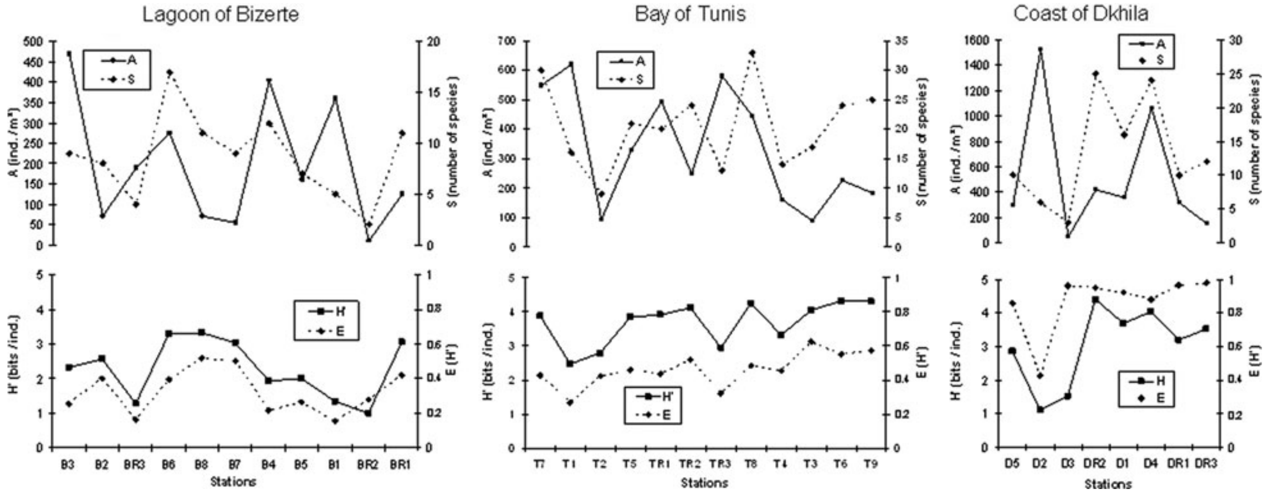

Fig. 3. Spatial variability of the principal biodiversity parameters: abundance (A), specific richness (S), Shannon–Wiener index (H′) and equitability (E).

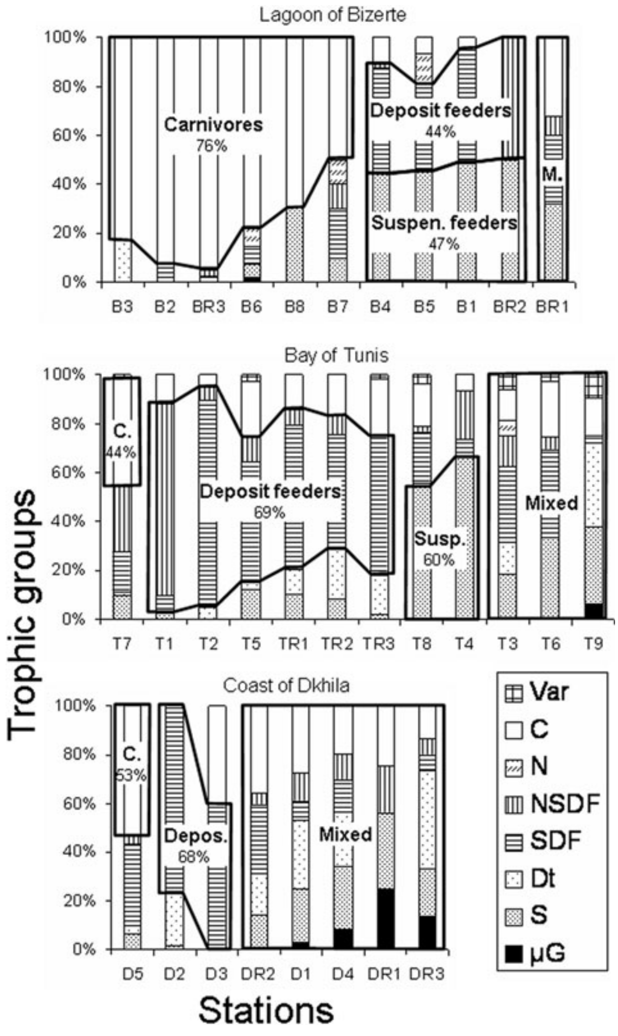

Fig. 4. Predominance of the trophic groups at sampling stations in the study sites. Var, various; C, carnivores; N, scavengers; NSDF, non-selective deposit feeders; SDF, selective deposit feeders; Dt, detritus feeders; S, suspension feeders; µG, micrograzers.

of this site (T3, T6 and T9) are represented by several trophic groups and with, more or less, equivalent proportions.

- In Dkhila coast, carnivores dominate only at D5 (53%), deposit feeders at D2 and D3 (68%) and the other stations (DR2, D1, D4, DR1 and DR3) are balanced on the trophic level.

Only the first two factors of the CFA, carried out on the respective proportions of the trophic groups at the 31 sampled stations, were considered. The first represents 28.4% and the second 25.3% of contributions (Figure 5). The trophic groups having high contributions (Table 2) are the carnivores (67% on the first 2 factors), the NSDF (55%), the SDF (48%) and the suspension feeders (16%). For the stations, those of Bizerte lagoon contribute more in this analysis (23% for BR2, 16% for BR3, 18% for B3, 14% for B2 and 10% for B6). Nevertheless, the station which contributes more in this CFA is T1 (28%) which is located in

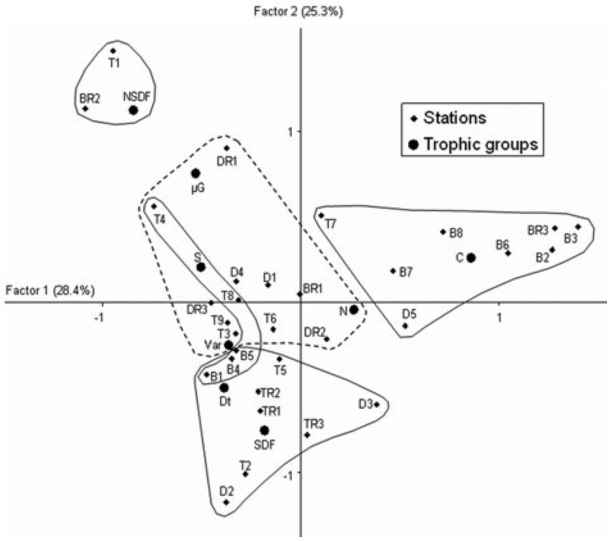

Fig. 5. Results of the correspondence factor analysis carried out on the percentages of trophic groups at the sampling stations.

Table 2. Contributions of stations and trophic groups at the 2 first factors in the correspondence factor analysis.

	Factors							
	F1	**F2**		**F1**	**F2**		**F1**	**F2**
Stations			**Stations**			**Stations**		
B1	1.93	1.76	T4	4.69	3.03	DR1	1.19	7.89
B2	13.83	0.90	T5	0.10	1.10	DR2	0.15	0.46
B3	16.81	1.86	T6	0.16	0.25	DR3	1.74	0.00
B4	1.04	1.08	T7	0.09	2.47			
B5	0.90	0.79	T8	0.85	0.00	**Trophic groups**		
B6	9.37	0.79	T9	0.58	0.07	µG	1.30	2.99
B7	1.88	0.31	TR1	0.35	3.97	S	13.35	2.43
B8	4.44	1.63	TR2	0.39	2.71	Dt	2.81	5.46
BR1	0.00	0.02	TR3	0.01	5.90	SDF	2.32	46.05
BR2	10.15	12.53	D1	0.23	0.10	NSDF	18.36	36.85
BR3	14.11	1.81	D2	1.19	13.47	N	0.23	0.01
T1	7.70	21.03	D3	1.27	3.51	C	61.36	6.05
T2	0.66	9.93	D4	0.90	0.13	Var	0.26	0.15
T3	0.92	0.33	D5	2.40	0.19			

Tunis bay, whereas the Dkhila stations do not have high contributions, except D2 (15%).

In this CFA, the regrouping of the stations according to the predominance of the trophic groups distinguishes, all in all, 4 groups. The first one is located in the positive values of the first two factors. It is mainly made up of Bizerte lagoon stations and characterized by the carnivores. The second group is located in the negative values of the factor 2 and is characterized by the presence mainly of Tunis bay and Dkhila stations. In the negative values of factor 1 and the positive values of factor 2, BR1 and T1 are consolidated with the NSDF and form the third group. Finally, in the centre of the graph, a large group assembles the other 'heterogeneous' stations with the other trophic groups. It should be noted that the stations with predominance of suspension feeders (B4, B5, B1, BR2, T8 and T4) are not well consolidated in this CFA. They form, so, a rather diffuse group.

Calculated values of the AMBI define 3 environmental statuses in the studied sites (Table 3). 'Heavily polluted' only at D2, 'slightly polluted' at BR3, T1, T2, T4, T5, T7, TR1, TR2, TR3, D3, D4 and D5 and 'unpolluted' at the other sampled stations.

Table 4 assembles the major species collected in the three study sites. It shows that there are very few common species in the study sites, and Tunis bay and Dkhila coast appear richer in species compared to Bizerte lagoon. The polychaetes are the main important species in the two sites and the higher specific abundance is registered by *Scolelepis fuliginosa* (1133 ind/m^2) at the D2 Dkhila port station. Other species, such as the polychaetes *Nereis diversicolor* (300 ind/m^2 at D2), *Capitella capitata* (100 ind/m^2 at D4), the genus *Sabella* (130 ind/m^2 at D4) and the amphipoda *Gammarella fucicola* (150 ind./m^2 at D4) are well represented in the Dkhila site. In Tunis bay, *Notomastus latericeus* (253 ind/m^2 at T1), *Melinna palmata* (210 ind/m^2 at TR3), *Euclymene oerstedii* (203 ind/m^2 at T1) and *Lumbrineris fragilis* (133 ind/m^2 at T7) represent the major species. However, in Bizerte lagoon other taxonomic groups are present, such as the Anthozoa genus *Actinia* (203 ind/m^2 at B3) and the bivalves *Dosinia lupinus* (180 ind/m^2 at B4) and *Tellina tenuis* (170 ind/m^2 at B1) and the isopod *Cymodoce truncata* (103 ind/m^2 at B3).

DISCUSSION

Ecological studies on the benthic fauna note the importance of sedimentary texture for the communities' distribution. Certain species colonize the very fine sediments in which they build tubes or other protecting biogenic constructions of mud, such as the polychaete *Melinna palmata*. Others prefer the sand or the coarse sediment which has important porosities (Desroy & Retière, 2001). Thus, sedimentary texture is a paramount factor for the benthic communities' study which should not be neglected (Glémarec & Hily, 1981; Hily, 1984; Le Bris, 1988; Dauvin *et al.*, 2004). In order to minimize the role of sedimentary texture in the spatial variability of benthic communities in this work, selected study sites are constituted exclusively of fine sediment, mainly mud and sand. The only station constituted of coarse sediment is B7, but the proportion of the gravel does not exceed 21%.

The description of the studied sites shows clearly that Tunis bay is more exposed to anthropogenic activities induced by the industry and the urban rejections. However, Bizerte lagoon appears more remarkable because it is currently in front of many environmental variables related to its very particular position into the lagoonal complex. It is influenced, at the same time, by seawaters coming from the ship canal and also by freshwaters coming from Ichkeul lake and a large catchment area. Consequently, several additional factors can influence the benthic macrofauna biodiversity (Desroy *et al.*, 2003), mainly the extreme conditions of salinity and temperature, the fluctuation of nutrient supply of continental origins and the slowness of the water renewal.

The stations of reference, yet selected far from the supposed disturbance sources, do not show, significant differences compared to the other stations, except perhaps Dkhila coast. For Bizerte lagoon, they are biologically poor; two among the three reference stations (BR2 and BR3) count respectively only 2 and 4 species. These areas seem affected by the urban inputs of the Bizerte town which extends on both sides from the ship canal connecting the lagoon to the sea.

Overall, in Tunis bay H′ and E(H′) show less fluctuation compared to the two other sites, but the abundance and the specific richness appear higher on average than those of Bizerte lagoon, and not significantly different from those of Dkhila coast. The analysis of these parameters, station by station, shows already the first signs of degradation, it is the case for example of the marine area under influence of the lagoon and the town of Bizerte (BR3), of the harbour areas of La Goulette (T1) and Sidi Abdel-Hamid (D2) and of the mouth of Hamdoun wadi (D3) where the Shannon–Wiener index and equitability are relatively low. This situation becomes very critical in Sidi Abdel-Hamid port where abundance is very high and specific richness is low, which shows that only some opportunistic species, such as the polychaete *Scolelepis fuliginosa*, benefit from the situation and develop more to reach high densities (Margalef, 1968; Odum, 1969).

On the other hand, the analysis of the trophic structure in the study sites shows remarkable differences:

In Tunis bay, the mud deposit feeder polychaetes are present in the vicinities of the La Goulette port (T1 and T2) and also in open sea (T5, TR1, TR2 and TR3). They are represented essentially by SDF such as *Melinna palmata*, *Cirratulis cirratus* and *Chaetozone setosa*, except for T1 which is dominated at more than 80% by NSDF, mainly *Notomastus latericeus* and *Euclymene oerstedii*. It is also the case of Dkhila, at the harbour level (D2) where *Scolelepis fuliginosa* reaches a specific abundance record (1133 ind/m^2) and in the Hamdoun wadi (D3) where the polychaete genus *Polydora* and the bivalve *Abra ovata* represent the major species. In wadis' mouths where freshwater coming from the continent is charged with organic matter pulled by the currents, the suspension feeders are predominant (Riera *et al.*, 2002; Riera, 2007), like at T4 in front of the Méliane wadi, and T8 in front of Soltan wadi where the Ophiuroid *Amphiura chiajei* is notably present. It is also the case in Bizerte lagoon, but this time the suspension feeders co-dominate with the deposit feeders, *a priori*, because of the current weakness which allows organic matter of continental origin to decant on the bottom and constitute a food resource for the deposit feeders (Kiørboe & Mohlenberg, 1981; Solis-Weiss *et al.*, 2004). This situation concerns mainly the stations located in front of the Guenine and Ben Hassine wadis (B4), of Garek and Chegui (B5) and also of Halima and Soula (B1) where the bivalves *Dosinia lupinus* and *Tellina tenuis* are predominant. However, at BR2 ship canal station, the very low values of the abundance and also of the specific richness do not allow to discuss the obtained results.

In general Dkhila coast appears, on the trophic structure, the most balanced area, and then Tunis bay presents some trophic imbalance signs. But the most remarkable observation is the very strong domination of the carnivores in the majority of the Bizerte lagoon stations. Even if the community is dominated in these stations by the carnivores, it remains even so more diversified at the taxonomic level since several groups, such as the anthozoa genus *Actinia*, the isopod *Cymodoce truncata* and the polychaetes *Nephtys hombergii* and *Eunice pennata*, share the resources. *Actinia* develops well in Bizerte lagoon because it tolerates the extreme fluctuations of temperature and salinity. However, *Cymodoce truncata* is normally characteristic of *Posidonia* beds, especially on routs in the deep infralittoral (Dumay, 1971). According to Castelló & Carballo (2001), it can develop also in fine

Table 3. Values of the AZTI Marine Biotic Index (AMBI) calculated at the sampled stations and their corresponding environmental status.

Lagoon of Bizerte	**B3**	**B2**	**BR3**	**B6**	**B8**	**B7**	**B4**	**B5**	**B1**	**BR2**	**BR1**	
Values of AMBI	0.9	0.8	1.6	0.7	0.7	1.1	0.2	0.3	0.0	0.0	0.4	
Evironmental status	Unpolluted	Unpolluted	Slightly polluted	Unpolluted	Unpolluted	Unpolluted	Unpolluted	Unpolluted	Unpolluted	Unpolluted	Unpolluted	
Bay of Tunis	**T7**	**T1**	**T2**	**T5**	**TR1**	**TR2**	**TR3**	**T8**	**T4**	**T3**	**T6**	**T9**
Values of AMBI	2.0	2.8	2.3	2.4	2.1	1.4	2.7	0.8	1.5	1.1	0.9	0.5
Evironmental status	Slightly polluted	Slightly polluted	Slightly polluted	Slightly polluted	Slightly polluted	Slightly polluted	Slightly polluted	Unpolluted	Slightly polluted	Unpolluted	Unpolluted	Unpolluted
Coast of Dkhila	**D5**	**D2**	**D3**	**DR2**	**D1**	**D4**	**DR1**	**DR3**				
Values of AMBI	2.0	5.2	2.4	0.7	1.0	1.6	1.1	0.6				
Evironmental status	Slightly polluted	Heavily polluted	Slightly polluted	Unpolluted	Unpolluted	Slightly polluted	Unpolluted	Unpolluted				

Table 4. Major species with their percentages of occurrence by site (P) and the high abundances (HA, ind/m^2) registered at the three study sites.

Major species	**Lagoon of Bizerte**			**Bay of Tunis**			**Coast of Dkhila**		
	P	**HA**	**Stations**	**P**	**HA**	**Stations**	**P**	**HA**	**Stations**
Actinia sp.	36.36	203	B3						
Dosinia lupinus (Linnaeus, 1758)	45.45	180	B4						
Tellina tenuis da Costa, 1778	36.36	170	B1						
Cymodoce truncata Leach, 1814	36.36	103	B3				25.00	37	DR2
Nephtys hombergii Savigny, 1818	18.18	103	BR3	33.33	30	TR1			
Eunice pennata (O.F. Müller, 1776)	63.64	37	B6						
Nassarius nitidus (Jeffreys, 1867)	18.18	17	B6						
Harmothoë sp.	18.18	17	B3, B6						
Nematonereis unicornis (Grube, 1840)	18.18	13	B5						
Pagurus sp.	54.55	17	B3	16.67	20	T8	12.50	20	D1
Notomastus latericeus M. Sars, 1851				16.67	253	T1	37.50	20	DR1, DR2
Melinna palmata Grube, 1870				50.00	210	TR3	12.50	7	DR2
Euclymene oerstedii (Claparede, 1863)				8.33	203	T1	25.00	3	D5, DR3
Lumbrineris fragilis (O.F. Müller, 1766)				50.00	133	T7			
Amphiura chiajei Forbes, 1843				25.00	97	T8			
Apseudes talpa (Montagu, 1808)				33.33	90	TR3	12.50	30	D4
Cirratulus cirratus (O.F. Müller, 1776)				16.67	70	TR3			
Aonides oxycephala (Sars, 1862)	18.18	10	B6	50.00	60	T8			
Chaetozone setosa Malmgren, 1867				33.33	50	T5			
Angulus tenuis (da Costa, 1778)				8.33	47	T8			
Glycera convoluta Keferstein, 1862	45.45	7	B3, B4	50.00	43	T7			
Scolaricia typica Eisig, 1914				16.67	43	T5			
Paraonis fulgens (Levinsen, 1884)	9.09	7	B7	50.00	40	TR1			
Tanais sp.				8.33	40	TR2			
Diopatra neapolitana Delle Chiaje, 1841				25.00	37	T2			
Chamelea gallina (Linnaeus, 1758)				8.33	37	T4			
Gammarus aequicauda (Martyinov, 1931)				8.33	33	T9			
Pharus legumen (Linnaeus, 1758)				33.33	30	T4			
Ampelisca rubella A. Costa, 1864				16.67	30	T6			
Phyllodoce sp.				33.33	27	T1			
Magelona rosea Moore, 1907				25.00	27	T5			
Tellina pulchella Lamarck, 1818				16.67	23	T7			
Lumbrineris impatiens (Claparède, 1868)				16.67	20	T7			
Tellina (Moerella) donacina Linnaeus, 1758				16.67	20	TR1			
Iphinoe trispinosa (Goodsir, 1843)	9.09	3	B6	33.33	17	TR1			
Ampelisca diadema (Costa, 1853)				25.00	10	TR1			
Nereis (Hediste) diversicolor (O.F. Müller, 1776)	27.27	70	B3				25.00	300	D2
Nephtys sp.	9.09	73	BR3	25.00	50	TR3	62.50	103	D5
Scolelepis fuliginosa (de Claparède, 1868)							12.50	1133	D2
Gammarella fucicola (Leach, 1814)							12.50	150	D4
Sabella sp.							37.50	130	D4
Capitella capitata (Fabricius, 1780)							50.00	100	D4
Venerupis aurea Gmelin, 1791							62.00	90	D4
Onuphis eremita Audouin & Milne-Edwards, 1833							37.50	80	D4
Microdeutopus anomalus (Rathke, 1843)							25.00	65	D1
Melita sp.							25.00	50	DR2
Ensis sp.							12.50	37	DR1
Loripes lucinalis (Lamarck, 1818)							25.00	33	DR1
Terebellides stroemi Sars, 1835							12.50	33	DR2
Abra alba (Wood W., 1802)							12.50	33	D5
Prionospio malmgreni Claparède, 1870							25.00	30	D5
Cirriformia tentaculata (Montagu, 1808)							25.00	30	D4
Maera grossimana (Montagu, 1808)							12.50	27	D1
Scalibregma inflatum Rathke, 1843							12.50	27	D1
Panoploea minuta Stebbing, 1906, Chev & Fage, 1925							12.50	27	DR2
Lumbrineris latreilli Audouin & Milne-Edwards, 1834							50.00	23	DR2
Eurydice pulchra Leach, 1815							25.00	23	DR3
Pontophilus sp.							12.50	23	DR3
Abra ovata Philippi, 1836							12.50	23	D5
Platynereis dumerilii (Audouin & Milne-Edwards, 1833)							37.50	23	D4
Polydora sp.							25.00	20	D3
Calliostoma zizyphinum (Linné, 1758)							25.00	20	DR1

sediments and at 0–20 m depth provided that it finds favourable conditions. Normally, the presence of carnivores in an ecosystem in a balanced state should not exceed a certain share, and their role is to control the community and prevent the monopolization of the resources (food and space) by some populations (Afli & Glémarec, 2000). In Bizerte lagoon, the very strong domination of the carnivores raises a great question about the food resource origins ensuring the functioning of the benthic community and also about the trophic balance of the area.

Essid & Aïssa (2002) analysed the principal physicochemical parameters in Bizerte lagoon. The recorded values showed a certain homogeneity level, except the low of the oxygen rate in water column, and the strong rate of the total organic carbon in the sediments, in some places of the lagoon. This strong carbon concentration could explain the noted deficit of oxygen which is necessary for the microbial degradation of the organic matter (Brandes & Devol, 1997; Heilskov & Holmer, 2003). Consequently, the mineral particles associated to organic compounds favour the formation of organo-mineral complexes (Aloisi & Monaco, 1975) resulting from electrochemical and organo-mineral flocculation. While trapping metal particles, the organo-mineral aggregates thus formed make them less available for epibenthic fauna, such as the majority of the polychaetes (Cauwet, 1985). This phenomenon is well known in the Mediterranean lagoonal areas (Aloisi *et al.*, 1975). Several studies carried out in some Mediterranean areas show the particularities of the organization of the macrobenthic communities, especially concerning their trophic structure (Pérès, 1972; Lardicci *et al.*, 1997; Albertelli *et al.*, 1999; Salen-Picard & Arlhac, 2002).

In addition, for the total organic carbon rate in the sediments, Dellali (1996) recorded rates from 1.8 to 9.1% in Bizerte lagoon. Beyrem (1999) recorded rates between 0.8 and 2.1% in the Ichkeul lake, whereas in the Ghar El Melh lagoon, adjacent on the east side to Bizerte lagoon, Mansouri (1979) recorded rates from 0.64 to 5.42% and Hamouda (1996) between 0.79 and 5.12%. Consequently, Bizerte lagoon presents a relatively high organic matter rate; it seems to suffer from a generalized eutrophication because, in particular, of the rejections of the Bizerte refinery and the oil port (Grall & Glémarec, 1997; Afli, 1999b; Glémarec & Grall, 2000). According to Beyrem *et al.* (2002), the trophic structure of benthic assemblages in the eutrophized areas bordering the Bizerte lagoon, depends mainly on the water contents of salts and dissolved oxygen, and also of the sedimentary rates of fine fraction, organic matter and hydrocarbons.

According to Sakka Hlaili *et al.* (2003), the ultraphytoplancton in Bizerte lagoon is mainly constituted of small flagellates and cyano-bacterium. These small autotrophic cells can be grazed only by microplanctonic protozoa, ciliates and large flagellates (Sanders & Wickham, 1993; Sakka *et al.*, 2000). Then, these grazers will convey the carbon produced by the small phototrophic organisms towards the large metazoan. So the trophic chain in Bizerte lagoon, in the water column and also into the sediment, is apparently of microbial type where the major participants are micro-organisms. This chain is completely different from the herbivore trophic structure in which the large cells (diatoms) which dominate the ecosystem are consumed by the mesozoobenthos. In a general context, the two types of trophic chains, microbial and herbivore, play different roles in the carbon cycle since they differently transfer biogenic carbon towards the higher trophic levels (Legendre & Rassoulzadegen, 1996). In Bizerte lagoon, this process is supported by the strong concentrations of the microplancton (Sakka Hlaili *et al.*, 2003).

On another plan, urban and industrial inputs in Bizerte lagoon need, on average, 10 days to arrive at the ship canal. But to leave definitively the lagoon, they need approximately 7 months because the canal connecting the lagoon to the sea is very narrow and very long (7 km) (Harzallah, 2003). Consequently, the Bizerte lagoon concentrates, permanently and on average, the rejections of approximately 7 months. On the other hand, in the other study sites the water renewal is much faster since they are open to the sea and the water dynamic is more interesting (Desroy *et al.*, 2003).

If the AMBI classifies the main exposed areas to pollution conditions in Tunis bay and Dkhila coast as in a slightly polluted state, Bizerte lagoon appears, despite the large recorded trophic imbalance, in an unpolluted state, except for the marine station facing Bizerte town. The question raised here does not concern the presence of sensitive species in such hard conditions, because their abundance is relatively low. But the real question is why the opportunistic species do not develop in the areas which seem favourable to their presence. In fact, this lagoon is quite particular and the response of the benthic communities to environmental conditions seems notable. It is enough that certain climatic factors are strongly fluctuating at any moment of the year, so that the whole system can destabilize completely, and the trophic chain can break down in some places of the site (Albertelli, 1999).

The correspondence factor analysis shows that the centre of the graph assembles the heterogeneous stations on the trophic level, whereas the stations with predominance of one trophic group are placed in the extremities of the graph. Thus and while being focused essentially on trophic groups and stations having a strong contribution in this analysis, the graph can be simplified (Figure 6). Two sets can, thus, be separated according to the degree of eutrophication. The

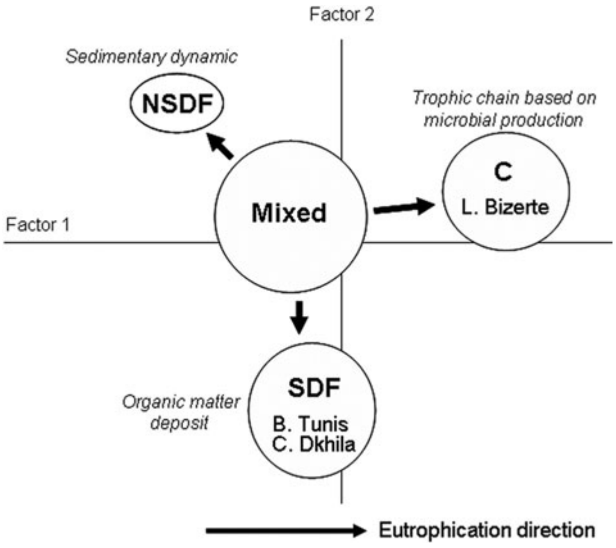

Fig. 6. General schema of the correspondence factor analysis.

first one is composed mainly of Bizerte lagoon stations dominated by carnivores. This set corresponds to the eutrophized stations and the microbial trophic chain. The second set is composed of the other groups. The centre of the graph is occupied by the most diversified stations in trophic groups, mainly Dkhila and Tunis bay stations. In the bottom of the graph, the SDF form a small and well consolidated group composed essentially of Tunis bay stations and some Dkhila ones. This group seems to benefit from the deposits on the organic matter funds because of the deceleration of the marine currents. Some other stations, completely separated, form a small group because of the supremacy of NSDF. It seems that the sediment in these zones is continuously moved, which allows organic matter to be inserted in-depth where the trophic group feeds.

CONCLUSION

Tunis bay and Dkhila coast appear, today, more balanced on the trophic level, while Bizerte lagoon presents some eutrophication signs and a great trophic imbalance due to industrial and urban activities exerted around the area. The relatively very slow renewal of the Bizerte lagoon waters worsens the problem still more. In this case, the analysis of the current situation should not dissociate this lagoon from the Ichkeul lake with which it communicates permanently via the Tindja wadi. Indeed, the Ichkeul lake more confined, therefore more productive, seems the essential feeder of this lagoon, little confined, of trophic sources and allows some aquaculture activities. But in spite of this provisioning of freshwater, nutritive salts and primary production coming from the Ichkeul lake, and also from the bordering wadis, the Bizerte lagoon ecosystem cannot, now, function normally, and currently presents a phenomenon of eutrophication, more or less generalized, and an anoxia state into the sediment. This state induces deep changes in the macrofauna trophic organization by substitution of the herbivore chain by the microbial chain. Under these conditions, the ecosystem becomes very selective and only some species endowed with great capacities to resist anoxia conditions can survive. This situation is certainly not stable and the general state of the lagoon could worsen more and threaten the aquacultural activities which are exerted there. It would be, so, very interesting to study seasonal variability of the benthic assemblages in Bizerte lagoon linked to the physico-chemical parameters, as the heavy metals and biomarkers, in the environment and also in organisms surviving under such hard conditions. This will allow the understanding, in detail, of the seasonal variability of the trophic structure and its resistance level to the environmental and anthropogenic fluctuations.

ACKNOWLEDGEMENTS

This work was undertaken within the framework of the project ‘EBHaR’ co-financed by the Tunisian Ministry of Higher Education, Scientific Research and Technology, and also by the Islamic Development Bank. Many thanks to those who contributed to the field and laboratory components of this project.

REFERENCES

Afli A. (1999a) *Variabilité temporelle des peuplements macrobenthiques de la partie orientale du golfe du Morbihan (Bretagne).* PhD thesis, University of La Bretagne Occidentale, Brest, France.

Afli A. (1999b) Utilisation des peuplements de la macrofaune benthique pour déceler les signes de perturbation du milieu: exemple du golfe du Morbihan (Bretagne, France). *Bulletin de l’Institut National des Sciences et Technologies de la Mer de Salammbô, Tunisia* 26, 147–163.

Afli A. and Chenier F. (2002) Etat de santé de la macrofaune benthique et rôle des espèces invasives dans la partie orientale du golfe du Morbihan (Bretagne, France). *Life and Environment* 52, 43–57.

Afli A. and Ben Mustapha K. (2004) Réponses des peuplements zoobenthiques aux perturbations. Exemple de la région côtière de la Dkhila (Tunisie) et comparaison avec le golfe du Morbihan (France). *Biologia Marina Mediterranea* 11, 304–311.

Afli A. and Glémarec M. (2000) Fluctuation à long terme des peuplements macrobenthiques dans le golfe du Morbihan (Bretagne, France). *Cahiers de Biologie Marine* 41, 67–89.

Albertelli G., Covazzi-Harriague A., Danovaro R., Fabiano M., Fraschetti S. and Pusceddu A. (1999) Differential responses of bacteria, meiofauna and macrofauna in a shelf area (Ligurian Sea, NW Mediterranean): role of food availability. *Journal of Sea Research* 42, 11–26.

Aloisi J.C. and Monaco A. (1975) La sédimentation infralittorale, les prodeltas méditerranéens. *Comptes Rendus de l’Académie des Sciences de Paris* 280, 2833–2836.

Aloisi J.C., Monaco A. and Pauc H. (1975) Mécanisme de la formation des prodeltas dans le Golfe du lion. Exemple de l’embouchure de l’Aude (Languedoc). *Bulletin de l’Institut de Géologie du Bassin Aquitaine* 18, 3–12.

Ayari R. and Afli A. (2003) Bionomie benthique du petit golfe de Tunis. *Bulletin de l’Institut National des Sciences et Technologies de la Mer de Salammbô, Tunisia* 30, 79–90.

Azouz A. (1973) Les fonds chalutables de la région nord de la Tunisie: 1. Cadre physique et bicoenoses benthiques. *Bulletin de l’Institut National des Sciences Techniques d’Océanographie et de Pêche, Salammbô, Tunisia* 2, 473–565.

Bejaoui N. (1998) *Ecobiologie de la population de moules* Mytilus galloprovincialis *Lamark (1819) du lac de Bizerte.* PhD thesis, University of Tunis, Tunisia.

Bellan-Santini D., Lacaze J.C. and Poizat C. (1994) *Les biocénoses marines et littorales de Méditerranée. Synthèse, menaces et perspectives.* Collection Patrimoines naturels, Secrétariat de la faune et de la flore / Museum National d’Histoire Naturelle publication, Paris, no. 19, 246 pp.

Ben Charrada R. (1997) *Etude hydrodynamique et écologique du complexe petit golfe—Lac de Tunis. Contribution à la modélisation de l’écosystème pélagique des eaux côtières—petit golfe de Tunis.* PhD thesis, Ecole Nationale d’Ingénieurs de Tunis, Tunisia.

Ben Souissi J. (2002) *Impact de la pollution sur les communautés macrobenthiques du lac sud de Tunis avant sa restauration environnementale.* PhD thesis, University of Tunis, Tunisia.

Beyrem H. (1999) *Ecologie des nématodes libres de deux milieux anthropiquement perturbés: la baie de Bizerte et le lac Ichkeul.* PhD thesis, University of Bizerte, Tunisia.

Beyrem H., Mahmoudi E. and Aissa P. (2002) Evolution spatiale de la structure trophique des peuplements de nématodes libres de la lagune de Ghar El Melh pendant l’hiver 2000. *Revue de la Faculté des Sciences de Bizerte, Tunisia* 1, 104–117.

Borja A., Franco J. and Pérez V. (2000) A marine biotic index to establish the ecological quality of soft-bottom benthos within European estuarine coastal environments. *Marine Pollution Bulletin* 40, 1100–1114.

Boudouresque C.F. and Belsher T. (1979) Le peuplement algal du port de Port-Vendres: recherches sur l'aire minimale qualitative. *Cahiers de Biologie Marine* 20, 259–269.

Brandes J.A. and Devol A.H. (1997) Isotopic fractionation of oxygen and nitrogen in coastal marine sediment. *Geochimica et Cosmochimica Acta* 61, 1793–1801.

Cain S.A. and Castro G.M. (1959) *Manual of vegetation analysis*. New York: Harper, 325 pp.

Cauwet G. (1985) *Dynamique de la matière organique dans les milieux marins et polyhalins, son rôle dans les processus géochimiques aux interfaces*. PhD thesis, University of Perpignan, France.

Castelló J. and Carballo J.L. (2001) Isopod fauna, excluding Epicardea, from the strait of Gibraltar and nearby areas (southern Iberian peninsula). *Scientia Marina (Barcelona)* 65, 221–241.

Chassé C. and Glémarec M. (1976) Principes généraux de la classification des fonds pour la cartographie sédimentaire. *Journal de Recherche Océanographique* 1, 1–12.

Dauvin J.C., Ruellet T., Desroy N. and Janson A.L. (2007) The ecological quality status of the Bay of Seine and the Seine estuary: use of biotic indices. *Marine Pollution Bulletin* 55, 241–257.

Dauvin J.C., Thiébaut E., Gomez Gesteira J.L., Ghertsos K., Gentil F., Ropert M. and Sylvand B. (2004) Spatial structure of a subtidal macrobenthic community in the Bay of Veys (western Bay of Seine, English Channel). *Journal of Experimental Marine Biology and Ecology* 307, 217–235.

Dellali M. (1996) *Etat de pollution de la lagune de Bizerte et effet à court terme de certains polluants sur* Sphaeroma serratum *(Fabricius, 1787),* Idotea balthica *(Pallas, 1772) et* Ruditapes decussatus *(Linnaeus, 1758)*. Diplôme d'Etudes Approfondies, University of Tunis, Tunisia.

Dellali M., Elbour M. and Aïssa P. (2001) Evaluation de la pollution bactérienne dans la lagune de Bizerte: résultats préliminaires. *Journal de Recherche Océanographique* 26, 18–28.

Desroy N., Warembourg C., Dewarumez J.M. and Dauvin J.C. (2003) Macrobenthic resources of the shallow soft-bottom sediments in the Eastern English Channel and Southern North Sea. *ICES Journal of Sea Research* 60, 120–131.

Desroy N. and Retière C. (2001) Long-term changes in muddy fine sand community of the Rance Basin: role of recruitment. *Journal of the Marine Biological Association of the United Kingdom* 81, 553–564.

Dumay D. (1971) Ecologie et biologie du genre *Cymodoce* (Isopoda Flabellifera) dans la région de Marseille. *Tethys* 2, 827–858.

Essid N. and Aissa P. (2002) Etude quantitative des nématodes libres des secteurs Nord et Est de la lagune de Bizerte (Tunisie). *Bulletin de l'Institut National des Sciences et Technologies de la Mer de Salammbô, Tunisia* 29, 53–63.

Fauchald K. and Jumars P.A. (1979) The diet of worms: a study of Polychaete feeding guilds. *Oceanography and Marine Biology: an Annual Review* 17, 173–284.

Glémarec M. and Hily C. (1981) Perturbations apportées à la macrofaune benthique de la baie de Concarneau par les effluents urbains et portuaires. *Acta Oecolgica, Oecologica Applicata* 2, 139–150.

Glémarec M. and Grall J. (2000) Les groupes écologiques et zoologiques d'invertébrés marins face aux dégradations de l'environnement côtier. *Bulletin de la Société Zoologique de France* 125, 37–48.

Grall J. and Glémarec M. (1997) Using biotic indices to estimate macrobenthic community perturbations in the bay of Brest. *Estuarine, Coastal and Shelf Science* 44, 43–53.

Grall J. and Glémarec M. (2003) L'indice d'évaluation de l'endofaune côtière. In: *Bioévaluation de la qualité environnementale des sédiments portuaires et des zones d'immersion*. Alzieu Claude (coordinator). Edition IFREMER 51–85.

Gómez Gesteira J.L. and Dauvin J.C. (2005) Impact of the Aegean Sea oil spill on the subtidal fine sand macrobenthic community of the Ares-Betanzos Ria (Northwest Spain). *Marine Environmental Research* 60, 289–316.

Hamouda R. (1996) *Etude des hydrocarbures des sédiments superficiels de la lagune de Ghar El Melh et de la lagune de Bizerte*. Diplôme d'Etudes Approfondies, University of Tunis, Tunisia.

Harzallah A. (2003) Transport de polluants dans la lagune de Bizerte simulé par un modèle de circulation de l'eau. *Bulletin de l'Institut National des Sciences et Technologies de la Mer de Salammbô, Tunisia* 30, 121–133.

Heilskov A.C. and Holmer M. (2003) Influence of benthic fauna on organic matter decomposition in organic-enriched fish farm sediments. *Life and Environment* 53, 153–161.

Hill M.O. (1974) Correspondence analysis: a neglected multivariate method. *Applied Statistics* 23, 340–354.

Hily C. (1984) *Variabilité de la macrofaune benthique dans les milieux hyper-trophiques de la rade de Brest*, Volume 1. PhD thesis, University of La Bretagne Occidentale, France.

Kiørboe T. and Mohlenberg F. (1981) Particle selection in suspension-feeding bivalves. *Marine Ecology Progress Series* 5, 291–296.

Lardicci C., Rossi F. and Castelli A. (1997) Analysis of macrozoobenthic community structure after severe dystrophic crises in a Mediterranean coastal lagoon. *Marine Pollution Bulletin* 34, 536–547.

Le Bris H. (1988) *Fonctionnement des écosystèmes benthiques au contact des estuaires: la rade de Lorient et la baie de Vilaine*. PhD thesis, University of La Bretagne Occidentale, France.

Lebart L., Morineau A. and Fenelon J.P. (1982) *Traitement des données statistiques, méthodes et programmes*. Paris: Dunod, 518 pp.

Legendre L. and Rassoulzadegen F. (1996) Food-web mediated export of biogenic carbon in oceans: hydrodynamic control. *Marine Ecology Progress Series* 145, 179–193.

Mansouri M.R. (1979) *Contribution à l'étude de la sédimentation littorale historique et actuelle au voisinage du delta de la Medjerda (étude du lac Ghar El Melh et la sebkha de l'Ariana)*. PhD thesis, University of Bordeaux I, France.

Margalef R. (1968) *Perspectives in ecological theory. Chicago Series in Biology*. Chicago: University of Chicago Press, 111 pp.

Martín D., Ballesteros E., Gili J.M. and Palacín C. (1993) Small-scale structure of infaunal polychaete communities in an estuarine environment: methodological approach. *Estuarine, Coastal and Shelf Science* 36, 47–58.

Muniz P., Venturini N., Pires-Vanin A.M.S., Tommasi L.R. and Borja A. (2005) Testing the applicability of a Marine Biotic Index (AMBI) to assessing the ecological quality of soft-bottom benthic communities, in the South America Atlantic region. *Marine Pollution Bulletin* 50, 624–637.

Odum E.P. (1969) The strategy of ecosystem development. *Science* 1964, 262–270.

Oueslati A. (1993) *Les côtes de la Tunisie. Géomorphologie, environnement et aptitudes à l'aménagement*. Publications de la Faculté des Sciences Humaines et Sociales de Tunis, Tunisia, 387 pp.

Pearson T. and Rosenberg R. (1978) Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanography and Marine Biology: an Annual Review* 16, 229–311.

Pérès J.M. (1972) Quantitative investigations of sand-bottom macrofauna along the Mediterranean north-west coast. *Marine Biology* 15, 209–220.

Pielou E.C. (1966a) Shannon's formula as a measure of specific diversity: its use and measure. *American Naturalist* 100, 463–465.

Pielou E.C. (1966b) The measurement of diversity in different types of biological collections. *Journal of Theoretical Biology* 13, 131–144.

Reiss H. and Kröncke I. (2005) Seasonal variability of benthic indices: an approach to test the applicability of different indices for ecosystem quality assessment, *Marine Pollution Bulletin* 50, 1490–1499.

Riera P. (2007) Trophic subsidies of *Crassostrea gigas, Mytilus edulis* and *Crepidula fornicata* in the Bay of Mont Saint Michel (France): a $\delta^{13}C$ and $\delta^{15}N$ investigation. *Estuarine, Coastal and Shelf Science* 72, 33–41.

Riera P., Stal L.J. and Nieuwenhuize J. (2002) $\delta^{13}C$ versus $\delta^{15}N$ of co-occurring molluscs within a community dominated by *Crassostrea gigas* and *Crepidula fornicata* (Oosterschelde, The Netherlands). *Marine Ecology Progress Series* 240, 291–295.

Riera P., Stal L.J., Nieuwenhuize J., Richard P., Blanchard G. and Gentil F. (1999) Determination of food sources for benthic invertebrates in a salt marsh (Aiguillon Bay, France) by carbon and nitrogen stable isotopes: importance of locally produced sources. *Marine Ecology Progress Series* 187, 301–307.

Rosenberg R., Blomqvist M., Nilsson H.C., Cederwall H. and Dimming A. (2004) Marine quality assessment by use of benthic species-abundance distributions: a proposed new protocol within the European Union Water Framework Directive. *Marine Pollution Bulletin* 49, 728–739.

Sakka A., Legendre L., Gosselin M. and Delesalle B. (2000) Structure of the oligotrophic planctonic food web under low grazing of heterotrophic bacteria: Takapoto Atoll, French Polynesia. *Marine Ecology Progress Series* 197, 1–17.

Sakka Hlaili A., Chikhaoui M.A., El Grami B. and Hadj Mabrouk H. (2003) Variation hiverno-estivale de la communauté phytoplanctonique de la lagune de Bizerte en milieux naturel et fertilisé en nutriments. *Revue de la Faculté des Sciences de Bizerte, Tunisia* 2, 37–49.

Salen-Picard C. and Arlhac D. (2002) Long-term changes in a Mediterranean benthic community: relationships between the polychaete assemblages and hydrological variations of the Rhône River. *Estuaries and Coasts* 25, 1121–1130.

Sanders R.W. and Wickham S.A. (1993) Planctonic protozoa and metazoa: predation, food quality and population control. *Marine Microbial Food Webs* 7, 197–223.

Shannon F.P. and Weaver W. (1963) *The mathematical theory of communication*. Urbana: University Illinois Press, 117 pp.

Shepard F.P. (1954) Nomenclature based on sand–silt–clay ratios. *Journal of Sedimentary Petrology, Tulsa, Oklahoma* 24, 151–158.

Simboura N. (2004) Benthic index vs biotic index in monitoring: an answer to Borja *et al.*, 2003. *Marine Pollution Bulletin* 48, 403–404.

Simboura N. and Zenetos A. (2002) Benthic indicators to use in ecological quality classification of Mediterranean soft bottom marine ecosystems, including a new biotic index. *Mediterranean Marine Science* 3, 77–111.

Solis-Weiss V., Aleffi F., Bettoso N., Rossin P., Orel G. and Fonda-Umani S. (2004) Effects of industrial and urban pollution on the benthic macrofauna in the Bay of Muggia (industrial port of Trieste, Italy). *Science of the Total Environment* 328, 247–263.

Soussi N. (1981) *Mécanismes de sédimentation et évolution paléogéographique de la lagune de Bizerte (Tunisie) durant le quartenaire récent.* PhD thesis, University of Toulouse, France.

Zaabi S. and Afli A. (2005) Structure générale des peuplements d'annélides polychètes dans le secteur nord-est du golfe de Tunis. *Bulletin de l'Institut National des Sciences et Technologies de la Mer de Salammbô, Tunisia* 32, 53–58.

Zaabi S. and Afli A. (2006) Significations écologiques de la variabilité des polychètes dans le golfe de Tunis. *Bulletin de l'Institut National des Sciences et Technologies de la Mer de Salammbô, Tunisia* 33, 29–36.

Zaouali J. (1993) Les peuplements benthiques de la petite Syrte, golfe de Gabès, Tunisie. Résultats de la campagne de prospection du mois de juillet 1990. Etude préliminaire. Biocénose et thanatocénose récentes. *Marine Life* 3, 47–60.

Zarrad R. (2001) *Contribution à l'étude de l'ichtyoplancton dans le golfe de Tunis.* Diplôme d'Etudes Approfondies, Institut National Agronomique de Tunis, Tunisia.

and

Zghal F. and Bouaziz-Azzouna A. (1982) Annélides Polychètes de Tunisie. *Revue de la Faculté des Sciences de Tunis, Tunisia* 2, 115–120.

Correspondence should be addressed to:
Ahmed Afli
Laboratoire de Biodiversité et Biotechnologies Marines
Institut National des Sciences et Technologies de la Mer 28
Rue de 2 Mars 1934–2025 Salammbô
Tunisia
email: afli.ahmed@instm.rnrt.tn