RESPONSE OF THE BENTHIC MACROFAUNA TO SEASONAL
NATURAL AND ANTHROPOGENIC CONSTRAINTS WITHIN
TUNISIAN LAGOONAL AND COASTAL AREAS (SOUTH-WESTERN
MEDITERRANEAN)

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ABSTRACT. – Two Tunisian lagoons and a coast location, diversely subject to anthropogenic activities and differing according to their degree of communication with the sea, were studied seasonally. The principal environmental variables (temperature, salinity and dissolved oxygen) were measured in situ. Jointly, main benthic macrofauna factors and the AZTI Marine Biotic Index (AMBI) were determined and analyzed. Results show that the seasonal fluctuations of the benthic communities structure differ in the three studied sites and are controlled mainly by the pollution and the hydrodynamic flow. In the first almost enclosed area (southern lagoon of Tunis) where measured environmental factors are more fluctuating and anthropogenic activities are important, the benthic community is more affected all year. The total abundance varies from 1279 to 7547 ind./m² and the specific richness from 31 to 61 species, however the evenness does not exceed 0.25 all year. In the other almost enclosed area (lagoon of Ghar El-Melh) which is less exposed to anthropogenic activities, fauna synthetic factors are less fluctuating, the abundance varies from 362 to 959 ind./m², the specific richness from 29 to 52 species and the evenness from 0.33 to 0.61. Also, in this site, first signs of degradation appear only in autumn in most stagnant waters. However, in the bay of Tunis and despite the strong anthropogenic pressures, the benthic community seems to be in satisfactory environmental conditions due, certainly, to the stronger hydrodynamic flow. In this coastal area, fauna synthetic factors are clearly less fluctuating between the two studied seasons, winter and summer. They are respectively 236-799 ind./m² for the abundance, 50-54 species for the specific richness and 0.43-0.73 for the evenness.

INTRODUCTION

Coastal areas, in general, are very productive and ecologically very important. These last decades, they are more and more affected by increasing man-made activities, especially in half closed areas, as lagoons and estuaries. This can affect the ecosystem and destabilize the organization of the communities, especially the benthic invertebrates which are in permanent contact with the sediment and polluting components (Pearson & Rosenberg 1978, Borja et al. 2000, Ben Souissi 2002, Basset et al. 2006). In front of the inability of the physical-chemical approaches to measure the real impact of pollution on the marine biodiversity (Dauer 1993, Carvalho et al. 2006), scientists note the importance of the biological tools, such as biotic indices and biodiversity factors, to establish the ecological state of the communities (Afli & Glémarec 2000, Quintino et al. 2006). Actually, macrobenthic invertebrates are widely used to qualify, notably, the consequences of oil spills and other environmental constraints in Europe and North America (Dauvin 1998, Feder & Blanchard 1998, Smith & Simpson 1998, Jewett et al. 1999, Simboura & Zenetos 2002).

Several works in the world have studied the assessment of environmental quality of coastal-transitional areas using benthic macrofauna, but only few ones have been interested in the inter-annual trend of the quality assessment. However, the seasonal trend was rarely broached, although it may provide interesting responses to the community reactions to environmental/anthropogenic constraints. In fact, the seasonal variability of the environmental factors, which is normally regular and cyclic, allows the different populations to achieve their biological cycle (Glémarec 1993). However, abnormal fluctuations of these factors and anthropogenic pressures (disturbance) can break the ecological balance and direct the general long-term trend of the ecosystem (Holling 1973).

The aim of this work is to study the community response of the benthic macrofauna to seasonal natural/anthropogenic variations in three lagoonal and coastal sites diversely exposed to anthropogenic pressures and differing according to their communication with the sea (Fig. 1). The first site (Bay of Tunis) is a marine area open to the sea. The two others are almost-enclosed lagoons of which one (southern lagoon of Tunis) is more subject to...
intensive anthropogenic activities. To achieve this objective, principal biotic indices and fauna synthetic parameters were used. Nevertheless, it is very difficult to differentiate between environmental and anthropogenic constraints responsible for fauna variations in such transitional and coastal ecosystems only with current available data (Downes et al. 2002). Thus, this study was restricted to analyze the effects of all natural and anthropogenic constraints without distinguishing clearly the part of each.

Study sites

Lagoon of Ghar El-Melh

The lagoon of Ghar El-Melh covers approximately 30 km² surface. Its depth is, on average, about 0.8 m and does not exceed 2 m, except at the entrance of the canal (Chakroun 2004). In winter, the lagoon is provisioned with freshwater by some non-permanent watercourses (wadis), such as Elkherba and Echarchara. This site seems relatively spared from human activities since there are no notable settlements surrounding, except a small village (village of Ghar El-melh) in the north. However, in summer with the arrival of visitors and tourists, this lagoon has known some eutrophication conditions induced by the development of dinoflagellates (Romdhane & Chakroun 1986), mainly the genus *Alexandrium*, which have reached in 1995/1996 approximately 1.5 x 10⁶ cells/L concentration (Romdhane et al. 1998).

Southern lagoon of Tunis

The southern lagoon of Tunis is commonly called “lac sud de Tunis”. At the time of the field surveys, this site has covered about 15 km² and has communicated with the sea by the canal of Radès and with the shipping canal by a few developed openings. But about half of its surface was filled up during its latest development. Its depth does not exceed 2 m in all the lagoon (Ben Souissi 2002). The southern lagoon of Tunis has long been the major receptacle of urban/industrial discharges from the City of Tunis, from its north suburbs and also from other diverse pollution sources, as ports and power stations of La Goulette and Radès. Some of them remain until now the major sources of pollution in the site. Consequently, the southern lagoon of Tunis is very productive, and its warm/stagnant waters increase the phytal production, which leads often to eutrophication conditions (Ben Souissi 2002, Hermi & Aissa 2002, Chakroun 2004).

Bay of Tunis

The bay of Tunis covers approximately 350 km². The main wadi feeding it in freshwater is Mélaine wadi which discharges directly and permanently into the bay (Ben Charrada 1997, Ayari & Afli 2008). Its depth is relatively more important, but does not exceed 31 m. As the southern lagoon of Tunis, this site is also subject to urban/industrial development of Tunis City, of its northern and southern suburbs with a settlement estimated in 2004 to approximately 2,250,000 inhabitants (Zaabi & Afli 2005, Zaabi 2006).
2006). However the bay of Tunis is more open to the sea and water movements, controlled by currents generated by north-western winds, are clearly more important (Ben Charrada 1997, Zarrad 2001, Ayari & Afli 2003, Afli et al. 2008b).

**MATERIAL AND METHODS**

**Sampling and laboratory procedures:** Marine surveys were carried out aboard a research vessel. In the lagoon of Ghar El-Melh and the southern lagoon of Tunis, samples were collected by using a 400 cm² extractor tube buried 20 cm deep. In the bay of Tunis, they were collected by a 0.1 m² van Veen grab which can penetrate approximately 20 cm into the sediment. For all the sites, three samples for biological analysis and another one for granulometric analysis were carried out at each station. Biological samples were fixed aboard in 10 % formalin. The plan of the marine surveys was as following (Fig. 1):

- **Lagoon of Ghar El-Melh:** 15 stations (L1 to L15) were sampled successively in February 1999 (winter), April 1999 (spring), July 1999 (summer) and October 1999 (autumn).
- **Southern lagoon of Tunis:** 9 stations (S1 to S9) were sampled successively in April 1996 (spring), June 1996 (summer), October 1996 (autumn) and January 1997 (winter).
- **Bay of Tunis:** 4 stations (B1 to B4) were sampled only in March 2003 (winter) and September 2003 (summer), i.e. during the cold and warm seasons.

The quantitative sampling tools used in this study and the total volumes of the sediment sampled at each site/season (1.80 m² in the lagoon of Ghar El-Melh, 1.08 m² in the southern lagoon of Tunis and 1.20 m² in the bay of Tunis) allowed to collect almost all macrobenthic species and estimate correctly the main fauna parameters (Cain & Castro 1959, Boudouresque & Belsher 1979, Martín et al. 1993, Gómez Gesteira & Dauvin 2005).

The temperature, salinity and dissolved oxygen were measured in situ and close to the bottom with respectively a thermometer (precision ± 0.1 °C), a salinometer (± 0.1 psu) and an oxymeter (± 0.01 mg/L). 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 during 48 hours at 60 °C, then washed through a 63 μm in order to eliminate the thin fraction (silt and clay) (Afli & Chenier 2002). The refusal was dried again at 60 °C, after that all samples were sieved on an 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 principal fauna factors were determined at each station/season. The abundance (A) is the average number of individuals per a surface unit, generally carried forward to one m². The specific richness (S) is the cumulated number of species in a station or in a site. The evenness or equitability J (Pielou 1966a, 1966b) permits to describe the distribution of the individuals into the various species.

For the assessment of the environmental quality, the AZTI Marine Biotic Index (AMBI) (Borja et al. 2000) was used (Table I). It is one of the most widely used biotic indices in European countries (Borja et al. 2007, Munari & Mistri 2008). AMBI is calculated on the basis of the 5 ecological groups (EG₁: sensitive species; EG₂: indifferent species, EG₃: tolerant species, EGIV: second-order opportunistic species and EGV: first-order opportunistic species) as following:

\[
\text{AMBI} = \left(0 \times \%\text{EG}_1 + 1.5 \times \%\text{EG}_2 + 3 \times \%\text{EG}_3 + 4.5 \times \%\text{EG}_4 + 6 \times \%\text{EG}_5 \right) / 100
\]

This index 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, specially if it is used jointly with specific richness and abundance (Muniz et al. 2005, Afli et al. 2008a, b). Species were assigned to the 5 ecological groups according to the classification of Afli (1999).

<table>
<thead>
<tr>
<th>Index value</th>
<th>Community health</th>
<th>Site pollution classification</th>
<th>Ecological status</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0 - 1.2</td>
<td>Normal / Impoverished</td>
<td>Unpolluted</td>
<td>High</td>
</tr>
<tr>
<td>1.2 - 3.3</td>
<td>Unbalanced</td>
<td>Slightly polluted</td>
<td>Good</td>
</tr>
<tr>
<td>3.3 - 5.0</td>
<td>Transitional to pollution / Polluted</td>
<td>Meanly polluted</td>
<td>Moderate</td>
</tr>
<tr>
<td>5.0 - 6.0</td>
<td>Transitional to heavy pollution / Heavy polluted</td>
<td>Heavily polluted</td>
<td>Poor</td>
</tr>
<tr>
<td>Azoic</td>
<td>Azoic</td>
<td>Extremely polluted</td>
<td>Bad</td>
</tr>
</tbody>
</table>

Table I. – Summary of characteristics of the AMBI used to qualify the ecological state using benthic communities (modified from Borja et al. (2000)).

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Borja et al. (2000), Afli & Chenier (2002), Simboura & Zenetos (2002), Grall & Glémarec (2003), Afli & Ben Mustapha (2004) and Reiss & Kröncke (2005). Some multidimensional analyses were also performed with the Primer software. Percentages of the ecological groups at the sites/seasons were transformed using the Bray-Curtis similarities of square-root and an ordination plot was produced by the non-metric multidimensional scaling (MDS).

RESULTS

The granulometric analysis show that the sediment in the three studied sites is consisted mainly of mud (Table II), except four stations in the lagoon of Ghar El-Melh (L1, L2, L3 and L4). Fig. 2 shows the seasonal fluctuation of the mean values of temperature, salinity and dissolved oxygen in the three study sites. In general, the largest seasonal variations were observed in the southern lagoon of Tunis compared to the other sites. Higher temperatures were recorded in summer, 27.11 °C in the lagoon of Ghar El-Melh, 29.80 °C in the southern lagoon of Tunis and 24.00 °C in the bay of Tunis. Lower temperatures were recorded in winter, respectively 15.03 °C, 12.40 °C and 14.13 °C. Highest salinities were registered in summer for the lagoon of Ghar El-Melh (44.58 psu) and the bay of Tunis (37.70 psu), and in autumn for the southern lagoon of Tunis (38.35 psu). Lower salinities were recorded in winter for the lagoon of Ghar El-Melh (44.58 psu) and the bay of Tunis (36.18 psu), and in spring for the southern lagoon of Tunis (25.53 psu). High rates of dissolved oxygen were recorded in winter/spring for the lagoon of Ghar El-Melh (7.76-8.03 mg/L), in spring and autumn for the southern lagoon of Tunis (respectively 12.10 and 12.28 mg/L) and in winter for the bay of Tunis (8.46 mg/L). However lower rates were registered in summer for all the studied sites (respectively 5.61 mg/L, 4.74 mg/L and 6.60 mg/L).

The registered values for macrofauna factors are averaged by site (Fig. 3). In general, the largest seasonal variations of A and S were observed in the southern lagoon of Tunis where J is lower all year compared to the other

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>% muds (&lt; 63 µm)</td>
<td>L1 L2 L3 L4 L5 L6 L7 L8 L9 L10 L11 L12 L13 L14 L15</td>
<td>S1 S2 S3 S4 S5 S6 S7 S8 S9</td>
<td>B1 B2 B3 B4</td>
</tr>
<tr>
<td>0.0  0.0  7.0  4.0 66.8 77.3 95.0 91.3 92.0 79.2 92.1 93.0 95.0 93.7 96.0</td>
<td>92.0 52.0 58.0 23.0 30.0 40.0 57.0 95.0 70.0</td>
<td>67.7 86.9 76.4 19.5</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 2. – Seasonal variability of the principal physical-chemical variables at the study sites. Error bars explain mean standard deviations.
For the lagoon of Ghar El-Melh, higher seasonal mean values were recorded in winter (S = 52 species, A = 959 ind./m² and J = 0.61). The lowest value for A (362 ind./m²) was registered in summer and for J (0.33) in spring, however, for S registered values do not vary much between autumn, spring and summer. For the southern lagoon of Tunis, highest values were recorded in spring (S = 61 species, A = 7547 ind./m² and J = 0.25) and lowest values for S and J in summer (respectively 31 species and 0.18) and for A (1279 ind./m²) in winter. As for the bay of Tunis, registered values were higher in summer (S = 54 species, A = 799 ind./m² and J = 0.73) than in winter (S = 50 species, A = 236 ind./m² et J = 0.43).

Calculated proportions of the ecological groups are presented by station (Fig. 4). In the lagoon of Ghar El-Melh, EGIII dominates with 57 % all year, but in autumn the other groups are more strongly represented (73 %). Similarly, in the southern lagoon of Tunis, EGIII dominates with about 65 % all year, but in spring EGV becomes almost the unique group present at S7, S8 and S9 (90 %). However for the bay of Tunis, there is no clear dominance of one group and, contrarily to the other sites, EG1 is present at all sampled stations.

The spatiotemporal distribution of the ecological status based on the calculated values of the AMBI (Fig. 5) shows that in the lagoon of Ghar El-Melh and the bay of Tunis all the stations are classified in a high/good state, except L6, L12, L13 and L15 in the first site which were classified in autumn in a moderate state. For the southern lagoon of Tunis, only S1, S2 and S3 were classified all year in a high/good state. The other stations were classified in moderate/poor state at least in one season of the year, but only S7 is classified in a moderate/poor state all year.

On the other hand, the small stress value of the MDS (0.06) established on the transformed percentages of the ecological groups at the sampled sites/seasons (Fig. 6), indicates a good fitting solution according to Kruskal (1964). Samples are grouped by site and the values of the AMBI calculated on the basis of the averaged data are reported for each site/season. The lagoon of Ghar El-Melh, with mean values of the AMBI, occupies the middle position and autumn sample (L-Aut) is clearly separated from the others. The southern lagoon of Tunis, located right, corresponds to the higher values of the AMBI (ecological status Good-Moderate), and the bay of Tunis, located left, corresponds to the lower values (ecological status Good).

**DISCUSSION**

The granulometric analysis shows that the sedimentary texture in the three sites is overall fine, except the four stations in the lagoon of Ghar El-Melh, near the canal communicating the lagoon with the sea (L1, L2, L3, and L4) where the current is relatively strong (Chakroun 2004) which allows the mud to move out. In general, fine sediments accumulate more pollutants and organic matter (Bianchi & Massé 1975) and are, therefore, more susceptible to anoxic conditions which limit the development of sensitive species (Chapman 1996, Cameleo et al. 1996, Dauer et al. 2000). Thus and considering the sedimentary texture, the studied sites are more susceptible to accumulate pollutants and organic matter, and anoxic conditions can easily happen in such eutrophic areas (Romdhane et al. 1998).

For the bay of Tunis, the lack of measures of environmental variables concerning spring and autumn prevents us from discussing the seasonal evolution. But according to Souissi et al. (2000), seasonal fluctuation of the principal physical-chemical variables in this site is clearly lower. All year, the temperature is comprised between 14-28 °C, the salinity between 37-37.8 psu and the dissolved oxygen between 6-9 mg/L (Souissi et al. 2000).
On the basis of all these data (Fig. 2), the southern lagoon of Tunis seems, overall, subjected to strong seasonal environmental fluctuations compared to the lagoon of Ghar El-Melh and the bay of Tunis.

The main characteristics of the principal biotic and abiotic variables are resumed in Table III. If the lagoon of Ghar El-Melh and the southern lagoon of Tunis have some common environmental characteristics, such as the low depth, the low degree of communication with the sea and the low hydrodynamism, the southern lagoon of Tunis is subjected to additional environmental constraints, like intensive anthropogenic activities and strong seasonal fluctuations of physical-chemical factors (Ben Souissi 2002, Chakroun 2004, Afli et al. 2008c). This is well reflected in the main infaunal parameters. Indeed, despite the apparent enrichment of the infaunal community in the
southern lagoon of Tunis, some signs of deterioration are clearly obvious. Firstly, the abundance and the specific richness are strongly fluctuating from one season to another (A varies from 1279 to 7547 ind./m² and S from 31 to 61 species) and principal species dominate clearly all year since the evenness is less than 0.25 all year. The tolerant hydrobiid snail *Hydrobia acuta* (EGIII) represents, alone, about 72 % of the mean annual abundance in the site and reaches 31067 ind./m² at S8 in summer, followed by *Hydrobia ventrosa* with only 10 %. Hydrobiid snails, in general, occur widely in estuaries and coastal lagoons and are euryhalin, eurythermal and can tolerate polluted conditions (Barnes 1979, Britton 1985, Lillebo et al. 1999, Aguirre & urrutia 2002, Cardoso et al. 2002). Secondy, moderate/poor statuses are present all year in this site, essentially facing pollution sources with low hydrodynamism (industrial estate of Jebel Jeloud and shipping canal openings) (Ben Souissi 2002, Chakroun 2004). For the lagoon of Ghar El-Melh, the infaunal community seems to be in a more satisfactory state because, certainly, of the absence of notably environmental constraints and the low fluctuations of the physical-chemical variables. Despite their low values, the abundance and the specific richness are less seasonally fluctuating compared to the southern lagoon of Tunis and only moderate statuses are noted in autumn in the more stagnant areas (western part) which are more exposed to pollutant inputs carried by the wadis Elkherba and Echarchara (Chakroun 2004). It seems that the tourism in summer does not really affect the ecological status of the lagoon of Ghar El-Melh and, maybe, natural conditions and/or the nutrient supply carried by the wadis during this seasonally rainfall are the principal reasons of disturbance.

All year, the community is less dominated by their leader, the tolerant species *abra tenuis* (43 %) and *Cerastoderma glaucum* (18 %). These species develop normally in muddy sediments and can resist to euryhalin conditions and high loads of hydrogen sulphide (Zaouali 1981, Ben Souissi 2002, Chakroun 2004, Casagranda & Boudouresque 2005). However for the bay of Tunis and despite the strong environmental constraints surrounding, the infaunal community seems to be in a satisfactory state since all the sampled stations are classified in high-good status. Certainly its relatively strong hydrodynamism allows to disperse pollutants and mitigate their effects. Also, the specific richness is relatively high and seasonally more stable without, nevertheless, dominance of leader species, the polychaetes *Melinna palmata* (EGIII, 18 %), *Lumbrineris impatiens* (EGII, 15 %), *Chaetozone setosa*

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Table III. – Summary of comparison of environmental and infaunal factors in studied sites. T°C: temperature, S‰: salinity, O₂: dissolved oxygen, A: abundance, S: Specific richness, –: low, +: high, grey hachure: factor/sign of deterioration of the community

<table>
<thead>
<tr>
<th>Environmental variables</th>
<th>Lagoon of Ghar El-Melh</th>
<th>Southern lagoon of Tunis</th>
<th>Bay of Tunis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication with the sea</td>
<td>–</td>
<td>–</td>
<td>+</td>
</tr>
<tr>
<td>Mean depth</td>
<td>–</td>
<td>–</td>
<td>+</td>
</tr>
<tr>
<td>Hydrodynamism</td>
<td>–</td>
<td>–</td>
<td>+</td>
</tr>
<tr>
<td>Fluctuations of T°C, S‰ and O₂</td>
<td>–</td>
<td>+</td>
<td>–</td>
</tr>
<tr>
<td>Anthropogenic sources of disturbance</td>
<td>–</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Infaunal parameters</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean values of A and S</td>
<td>–</td>
<td>+</td>
<td>–/+</td>
</tr>
<tr>
<td>Fluctuations of A and S</td>
<td>–/+</td>
<td>+</td>
<td>–</td>
</tr>
<tr>
<td>Dominance of leader species</td>
<td>–/+</td>
<td>+</td>
<td>–/+</td>
</tr>
<tr>
<td>Apparition of moderate/poor status</td>
<td>autumn</td>
<td>all year</td>
<td>no</td>
</tr>
</tbody>
</table>

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*Vie Milieu, 2009, 59 (1)*
(EGIII, 7 %), Paradoneis fulgens (EGIII, 6 %), Notomastus sp. (EGIII, 6 %) and Maldane glebifex (EGI, 5 %), and the crustacean Apsesudes talpa (EGII, 5 %).

Nevertheless, the interpretation of these results must take into account the particularities of the lagoons in comparison with coastal waters. In fact, these transitional areas are generally more enclosed, more confined and characterized by an important freshwater supply and a low hydrodynamic flow. Hence the seasonal natural variations are clearly larger and often extreme conditions can happen (Afli et al. 2008c). This makes these ecosystems very vulnerable to anthropogenic impacts (Dauer 1993, Lardicci et al. 1997, Afli et al. 2008a). Whereas, coastal areas are less exposed to extreme conditions, and the seasonal variations are more even in these marine waters. Thus, this special situation in lagoonic ecosystems renders the ecological assessment with the use of biotic indices more difficult because these tools use the concept of indicator species that are highly dominant naturally in lagoons and also strong seasonal fluctuations may cause uncertainty in the evaluation of the results. So, sometimes, it is very difficult to differentiate between natural and anthropogenic disturbance in such transitional ecosystems (Dauvin 2007, Elliott & Quintino 2007, Afli et al. 2008b).

In conclusion, biotic indices in general are more and more widely used these last decades. They have proved a great efficiency to detect the first signs of disturbance of marine areas. Nevertheless, the use of biotic indices only could be confusing and does not often reflect reality. It is therefore better to use jointly fauna synthetic variables without neglecting the importance of the analysis of the proportions of the ecological groups and the interpretation of the role of the principal species. In this study, the distribution of the sites/seasons samples in the MDS shows clearly that the analysis of the ecological groups is well consistent with the calculated AMBI since defined groups correspond to limited intervals of AMBI: [2.84, 3.79] for the southern lagoon of Tunis, [2.05, 2.69] for the lagoon of Ghar El-Mellah and [1.92, 1.64] for the bay of Tunis. This supports, once again, the robustness of this biotic index.

On the other hand, the comparison of the ecological state in the two lagoons, shows the high sensitivity of these enclosed ecosystems to anthropogenic activities and pollutant inputs, such as the case of the southern lagoon of Tunis. Thus, in these transitional areas, the importance of the role played by the hydrodynamic flow to mitigate the effect of pollution is highlighted. It is the case of the bay of Tunis which appears to be in a better ecological state compared to the southern lagoon of Tunis, even if the two sites have almost the same strong anthropogenic sources of disturbance.

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