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Impact of management on the diversity of macrobenthic communities in Tunis north lagoon: systematics

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Abstract: One hundred eighty nine species of benthic macroinvertebrates, belonging to eleven different zoological groups, were collected in the Tunis north lagoon after regular surveys carried out in twenty six stations. Among the collected species, the Bivalves *Musculista senhousia* and *Pinctada radiata,* the Nudibranches *Spurilla neapolitana*, *Hypselodoris villafranca*, the Opisthobranch *Bursatella leachii* and the Polychaetes *Pariospilus affinis* and *Paradoneis lyra* were found for the first time in this lagoon. The latter polychaete species were recorded for the first time in Tunisian inshore area. This study revealed the persistence of some species that previously constituted stable populations of the lagoon and also the installation of some new species. The pioneer species *Ficopomatus enigmaticus* disappeared from this water plane. Moreover, we noted the persistence in the whole lagoon of many species that indicate an unbalanced environment, such as *Neanthes caudata*, *Heteromastus filiformis, Cirriformia tentaculata*, *Capitella capitata*, *Ruditapes decussatus*, *Loripes lacteus* and *Cerastoderma glaucum.* The multivariate analyses did not show an increasing biological gradient from marine water input area towards the inner parts of the lagoon. However, they revealed homogeneity of the communities dominated by disturbance-indicating species. The latter observation could be due to the influence of edaphic factors, particularly sediment organic matter content. The area close to the sea is dominated by species of marine affinity. At phyla level, the most significant variations of abundance averages were shown within Cnidaria and Nemertini groups. In spite of the water quality improvement that led to the decrease of the organic matter content several years after management, the Tunis north lagoon is still polluted.

Résumé : *Impact des aménagements sur la diversité de la macrofaune benthique de la lagune nord de Tunis : systématique.* Des prospections régulières, effectuées durant une année au niveau de 26 stations, réparties dans la lagune nord de Tunis, ont permis de collecter 189 espèces de macrofaune benthique appartenant à onze groupes zoologiques différents. Parmi les espèces nouvellement rencontrées dans le plan d'eau, il convient de mentionner, entre autres les Bivalves *Musculista senhousia* et *Pinctada radiata*, les Nudibranches *Spurilla neapolitana*, *Hypselodoris villafranca*, l'Opisthobranche *Bursatella leachii*; les polychètes *Pariospilus affinis* et *Paradoneis lyra*, deux espèces dont les familles sont mentionnées pour la première fois en Tunisie. L'ensemble de nos résultats révèle la persistance dans la lagune de certaines espèces qui, au cours des années, ont formé des populations stables et l'installation d'espèces nouvelles dans ce plan d'eau mais aussi

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la disparition de l'espèce pionnière *Ficopomatus enigmaticus*. Nous avons également noté la permanence dans toutes les parties de la lagune des espèces indicatrices de perturbation, à savoir *Neanthes caudata*, *Heteromastus filiformis*, *Cirriformia tentaclata*, *Capitella capitata, Ruditapes decussatus*, *Loripes lacteus* et *Cerastoderma glaucum.* Les analyses multivariées ont montré d'une part l'absence de gradient biologique croissant depuis la zone d'entrée des eaux marines vers l'intérieur et d'autre part une homogénéité des peuplements, dominés par les espèces indicatrices de perturbation, responsables du regroupement des stations. Cette homogénéité serait donc liée à l'influence prépondérante des facteurs édaphiques, particulièrement la matière organique dans le sédiment. Le peuplement au niveau de la zone proche de la mer est largement dominé par les espèces à affinité marine, ce qui la distingue du reste de la lagune. Au niveau des phylums, les variations les plus importantes des abondances moyennes sont observées chez les Cnidaires et les Némertiens. Enfin, la lagune nord de Tunis demeure, malgré l'amélioration notable de la qualité de ses masses d'eau et le dragage de plusieurs dizaines de mètres cube de vase, relativement polluée.

Keywords: Diversity ● Communities ● Macrobenthic fauna ● Management ● Impact ● Tunis north lagoon ● Systematics

Introduction

Lagoons represent 0.2% of the Mediterranean surface and about 3% of its continental shelf. Moreover, these areas constitute one of the most productive humid zones in the Mediterranean basin. They are characterized in both space and time by a strong variability in their physicochemical parameters and by the nutritive matter richness of their waters (Pérès, 1967; Pearce & Crivelli, 1994; Skinner & Zalewski, 1995).

This richness considerably contributes to a great attraction of migrating species which have a good commercial value (e.g. fishes, crustaceans). However, excessive supply of waste waters or agricultural manures might generate an important algal production. The algae death and decomposition lead to an environmental disturbance with significant decrease of dissolved oxygen that increases the faunal mortality. Thus, coastal lagoons are typical, but unbalanced ecosystems with relative variations of long or short periods in comparison with the open sea (Marzano et al., 2003). After severe disturbances, the restoration of benthic communities in brackish lagoons may take a long time (Munari et al., 2003) and the protection of natural inheritances in all sanctuaries, parks and reserves is in general insufficient. Serious management of species and marine spaces is then obligatory. However, such management can not be purgative or weak; it requires operational rigors and measurements (inventories, plans of management, etc.).

Tunis lagoon, located in the neighborhood of Tunis City, was undoubtedly one of the most polluted and eutrophic Mediterranean lagoons since it received great quantity of waste waters (Zaouali, 1977). This eutrophication had led to a progressive degradation and ecological disturbances marked by radical changes of sediments and lagoon fauna (or flora) decreasing the specific diversity with a proliferation of the opportunist polychaete *Ficopomatus enigmaticus*. In front of this problem, a project improving water's circulation was elaborated and applied (Ben Maiz, 1993 & 1994). The project aimed to improve the ecological factors in particular hydrological ones. Moreover, researches carried out on benthic macro-invertebrate communities in Tunis north lagoon are few and very old (Molinier & Picard, 1954; Zaouali, 1974 & 1981; Zaouali & Levy, 1981; Zaouali & Baeten, 1983 & 1984). Comparative analyses, evaluating the management impact on the structure of macroinvertebrate communities living in this lagoon, were extremely interesting.

The present study aims to characterize the whole macroinvertebrate populations in the Tunis lagoon and to quantify the restoration works impact on these communities. Indeed, sedentary and sessile organisms are in close contact with the sediment and can then better describe the ecological conditions of aquatic ecosystems. The goals of this comparative analysis are i) proving the changes in the populations' structure and distribution and ii) checking the probable existence of relationships between the diversity and the good functioning of the restored ecosystem (stability, performance).

Materials and Methods

Study area

The Tunis north lagoon is a shallow water plane located in the North-East of Tunisia at the bottom of Tunis Gulf, in the proximity of both Rades and La Goulette harbors and Tunis south lagoon. After cleaning the water and the establishment of a natural renewal system adapted to the lagoon conditions in 1984-1988 (Ben Maiz, 1993 & 1994), the aspect of Tunis north lagoon has radically changed in comparison with its status during the last centuries. The surface, previously estimated at 2.800 hectares (Zaouali, 1977) became 2.600 hectares after restoration works (Arjen & Oostinga, 1992). Consequently, new hydrological conditions have been created; the depth at the northern part (dredged) varies from 2 to 4 metres and hardly reaches one metre in the southern part. Moreover, physicochemical parameters have been monitored in Tunis north lagoon in many studies carried out before and after the management. (Table 1).

Field sampling and processing

Four exploring surveys have been carried out from May 2003 to February 2004 with the use of a small flat-bottomed coastal boat. A total of twenty six sampling stations precisely localized have been chosen (Fig. 1). In each station we have measured the depth, determined the sediment type, calculated the sediment organic matter content and taken the values of the following physico-chemical parameters: temperature, salinity, dissolved oxygen, and pH (Table 2).

Substrate samples (0.25 m^2) were taken using a core bit and a quadrat to collect infaunal and epifaunal species by picking up, respectively 0.15 m^2 and 0.1 m^2. In each station, a rate of three cores and three quadrats samples were carried out during each campaign. The collected samples were immediately sieved with a 1 mm mesh sieve to reduce the quantity of sediment. The sieving residuals were fixed in 5% formalin salt solution to keep organisms intact until their identification. Samples' sorting was carried out at the laboratory and the rose Bengal coloration was added to better visualize the small animals. Species identification and individuals' counting were made under a binocular magnifying glass with the use of suitable guides and illustrated articles.

Data analysis

Communities have been defined quantitatively by some descriptors which integrate the species numerical importance. Specific richness S (number of species in each station), average density (ind.m^{-2}) and Shannon-Weaver's diversity index (Shannon & Weaver, 1963) were calculated at each station (Table 2). The Shannon-Weaver's index (H', log_2 based) allows us to show the individuals distribution (biomass) between the different species. In order to separate the stations in homogenous groups, the Ascending Hierarchical Clustering was applied on the contingency table according to Ward's method (Ward, 1963). Furthermore, the Factorial Correspondence Analysis (FCA) (Hill, 1974) and the Factorial Discriminating Analysis (FDA) taking into account the eleven phyla identified as variables of classification to better distinguish any tiny

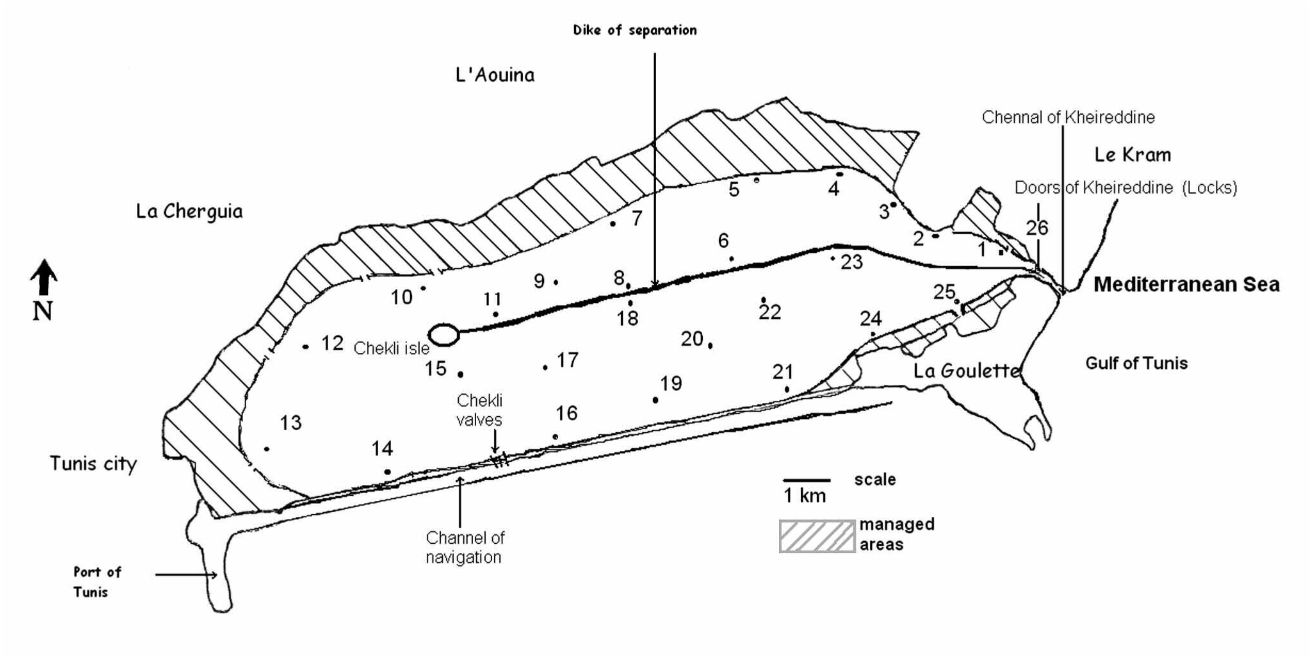

Figure 1. Location of sampling stations in the Tunis north lagoon.
Figure 1. Localisation des stations de prélèvement dans la lagune nord de Tunis.

Table 1. Temporal evolution of some hydrologic parameters' values collected in the Tunis north lagoon before and after the management.

Tableau 1. Evolution temporelle des valeurs de quelques paramètres hydrologiques collectés dans la lagune nord de Tunis avant et après les travaux d'aménagement.

Period of study	Temperature (°C)	Salinity	pH	Dissolved oxygen ($mg.l^{-1}$)	Authors
1929	-	38.6-55.5	-	-	Heldt, 1929
1973-1974	18.8-19.0	25.0-40.0	-	-	Creuzet, 1973; Prunus & Pantoustier, 1974
1975-1981	19.2-19.5	21.7-39.1	6.7-7.7	0.0-20.0	Zaouali1, 1977 & 1981
1989-1996	19.2-19.5	36.0-37.0	8.0-8.5	7.0-8.0	Ben Charrada, 1995

Table 2. Physico-chemical parameters, sediment type, sediment organic matter content, geographical position and values of ecological and diversity indices collected in each station. S: species number in each station; H': Shannon-Weaver's diversity index; MO: sediment organic matter contents; Oxy: dissolved oxygen; T (°C): water temperature; FS: fine and very fine sand; SG: coarse and fine sand; SM: fine sand to mean sand; B: hard substrata; Lat N: latitude north; Long E: longitude east.

Tableau 2. Paramètres physicochimiques, type de sédiment, coordonnées géographiques, matière organique des sédiments et valeurs de quelques indices écologiques et de diversité à chaque station.S : nombre d'espèces récoltées dans chaque station ; H' : indice de diversité de Shannon-Weaver ; MO : matière organique dans le sédiment ; Oxy : oxygène dissous ; T (°C) : température de l'eau ; FS : sable fin à très fin; SG : sable fin à grossier; B : substrat dur ; SM : sable fin à moyen ; Lat N : lattitude Nord ; Long E : longitude Est.

Stations	S	H' (bits)	Mean Density	MO (g)	Salinity	Oxy ($mg.l^{-1}$)	T (°C)	pH	Depth (m)	Lat N	Long E	Sediment type
S1	33	3.43	564	0.013	37.4	7.1	21.2	8.6	0.4-1	36° 49' 42"	10° 18' 31"	SF
S2	55	4.55	1332	0.003	37.1	9.1	21.3	8.7	0.20-1.3	36° 49' 46"	10° 17' 50"	SF
S3	44	3.97	1097	0.012	36	8.3	21.4	8.6	0.3-0.87	36° 50' 00"	10° 17' 22"	SF
S4	36	1.79	4684	0.008	35.5	8.6	21.4	8.7	0.4-0.7	36° 50' 30"	10° 17' 14"	SF
S5	54	4.4	2092	0.01	37.1	7.2	21	8.6	1.7	36°49' 52"	10° 15' 54"	SF
S6	52	3.56	3695	0.003	37.4	7.1	21	6.4	1.1	36° 49' 38"	10° 15' 27"	SG
S7	59	4.3	2393	0.012	37.4	6.3	21	8.5	0.95	36° 49' 59"	10° 14' 34"	SF
S8	32	3.35	975	0.065	37.4	6.7	21.1	8.5	0.9	36° 49' 22"	10° 14' 22"	SF
S9	46	3.85	3653	0.023	37.4	7	21.3	8.5	0.95	36° 49' 30"	10° 13° 44"	SF
S10	68	3.7	4143	0.008	37.5	6.6	20.3	8.5	0.4-1.7	36° 49' 65"	10° 12' 87"	SF
S11	41	3.43	2515	0.036	37.3	6.8	20.5	8.5	1.3	36° 49' 13"	10° 13' 13"	SG
S12	53	3.95	4128	0.014	37.6	6.8	20.7	8.5	0.3-1.5	36° 49' 03"	10° 12' 17"	SF
S13	66	4.81	3173	0.005	38.1	6.5	21.5	8.5	0.4-2.25	32° 48' 40"	10° 12' 18"	SF
S14	54	4	2771	0.185	38.5	6.9	21.8	8.5	0.3-0.7	36° 48' 14"	10° 12' 35"	SF
S15	40	3.47	3559	0.154	37.8	6.5	21.1	8.1	1.25	36° 48' 38"	10° 13' 18"	SG
S16	46	3.928	1801	0.034	38.5	5.6	21.6	8.1	0.6	36° 48' 18"	10° 13' 51"	SF
S17	41	4	2921	0.124	38.4	7.3	21.4	8.4	0.7	36° 48' 38"	10° 14' 17"	SG
S18	54	3.61	3853	0.092	38.4	7.2	21.2	8.4	1.2	36° 48' 49"	10° 14' 34"	SG
S19	40	3.12	1471	0.054	38.8	7.5	21.4	8.5	1	36° 48' 38"	10° 14' 46"	SG
S20	42	4.42	1385	0.266	39	7.3	20.7	8.5	1.15	36° 48' 42"	10° 15' 18"	SG
S21	52	3.71	5139	0.005	38.7	8.1	20.3	8.4	0.5-1.2	36° 48' 46"	10° 15' 34"	SM
S22	39	3.41	2171	0.046	38.6	7.5	20.8	8.6	0.96	36° 48' 43"	10° 15' 17"	SG
S23	44	4.08	1768	0.027	38.7	8.4	20.9	7.5	0.9	36° 49' 19"	10° 16' 09"	SG
S24	39	3.57	2987	0.007	39.9	6.9	21.6	8.5	0.4-0.8	36° 49' 03"	10° 17' 01"	SM
S25	44	3.96	1337	0.026	39.9	7.3	21.1	8.5	0.2-0.95	36° 49' 28"	10° 18' 04"	SM
S26	88	4.57	8723	0.004	37.8	6.6	20.6	8.4	0.4-3	36° 49' 41"	10° 18' 33"	B

Table 3. Checklist of benthic macroinvertebrate species collected in the Tunis north lagoon before and after its restoration .
[A]: Group of authors who worked in the Tunis north lagoon several years before the water plane cleaning (Wesenber-Lund, 1939; Vuillemin 1952; Heldt 1953; Molinier & Picard 1954; Pérès 1954). *****: Species not recorded before and found, for the first time, in the Tunis north lagoon. ******: Invertebrates families found, for the first time, in Tunis north lagoon and in Tunisia. *******: Exotic or non exotic species found for the first time in Tunis north lagoon and in Tunisia. **?**: Genus previously recorded but not identified at the species level. We ask this question: Do they concern species newly quoted in this present study?

Tableau 3. Liste des espèces de macroinvertébrés benthiques, récoltées dans la lagune nord de Tunis, avant et après son aménagement. [A]: Auteurs ayant travaillé au nord du lagon de Tunis plusieurs années avant le plan de nettoyage de l'eau (Wesenber-Lund, 1939 ; Vuillemin 1952 ; Heldt 1953 ; Molinier & Picard 1954 ; Pérès 1954). *****: Espèces non signalées auparavant et observées, pour la première fois dans la lagune nord de Tunis durant cette étude. ******:Familles d'invertébrés signalées pour la première fois dans la lagune nord de Tunis et en Tunisie. *******:Espèces exotiques (ou non) observées pour la première fois dans la lagune nord de Tunis et en Tunisie. **?**: Genres rapportés précédemment mais non identifiés au niveau de l'espèce : s'agit-il des mêmes espèces que celles identifiées dans cette étude ?

Phylum / **Family**	Species	Authors and years of study [A] (1939-1954)	Zaouali (1974; 1981)	Zaouali & Baeten (1984)	This work
PORIFERA					
Chondrosiidae	*Chondrosia reniformis** Nardo, 1833		absent	absent	present
Axinellidae	*Axinella damicornis** (Esper, 1794)		absent	absent	present
	*Axinella verrucosa** (Esper, 1794)		absent	absent	present
Spongiidae	*Cacospongia scalaris** Schmidt, 1862		absent	absent	present
CNIDARIA					
Kirchenpaueriidae	*Ventromma halecioides* (Alder, 1859)	present	absent	absent	absent
Ceriantharidae	*Cerianthus membranaceus** (Spallanzani, 1784)		absent	absent	present
Actiniidae	*Condylactis aurantiaca** (Delle Chiaje, 1825)		absent	absent	present
	Anemonia contarinii (Andres, 1883)	present	absent	lost	absent
	*Anemonia viridis** (Forskå, 1775)		absent	absent	present
	*Anthopleura ballii** (Cocks, 1850)		absent	absent	present
Aiptasiidae	*Aiptasia mutabilis* (Gravenhorst, 1831)	present	absent	absent	present
Sagartiidae	*Cereus pedunculatus* (Pennant, 1777)	present	absent	absent	present
PLATHELMINTHES					
Notoplanidae	*Leptoplana alcinoi** Schmidt, 1861		absent	**?**	present
NEMERTINI					
Lineidae	*Cerebratulus fuscus** (McIntosh, 1873-74)		absent	absent	present
	*Lineus ruber** (O.F.Müller, 1774)		absent	absent	present
	*Micrura aurantiaca** (Grube, 1855)		absent	absent	present
Drepanophoridae	*Drepanophorus spectabilis** Quatrefages,1846		absent	absent	present
SIPUNCULA					
Phascolosomatidae	*Phascolosoma granulatum** (Leuckart, 1828)		absent	absent	present
MOLLUSCA					
Ischnochitonidae	*Lepidochitona cinera** (Linnaeus, 1767)		absent	absent	present
	Lepidochitona caprearum (Scchi, 1836)	present	absent	absent	absent
Chitonidae	*Chiton olivaceus** Spengler, 1797		absent	absent	present
Fissurellidae	*Fissurella nubecula** (Linnaeus, 1758)		absent	absent	present
	*Diodora italica** (Defrance, 1820)		absent	absent	present
Trochidae	*Gibbula adansoni** (Payraudeau, 1826)		absent	absent	present
	Gibbula varia (Linnaeus, 1758)		absent	emerged	absent
	Monodonta turbinata (Born, 1780)	present	absent	lost	absent
	Tricolia pulla (Linnaeus, 1758)		absent	emerged	absent
Patellidae	*Patella ceorulea* Linnaeus, 1758	present	absent	absent	absent
Littorinidae	*Littorina neritoides* (Linnaeus, 1758)	present	absent	absent	absent
Hydrobiidae	*Hydrobia ulvae** (Pennant, 1777)		absent	absent	present
	Ventrosia ventrosa (Montagu, 1803)		present	present	absent
Potamididae	*Pirenella conica* (Blainville, 1826)		absent	lost	absent
Cerithiidae	*Bittium reticulatum* (da Costa, 1778)		absent	emerged	absent
	Cerithium vulgatum Bruguière, 1792		absent	emerged	present

Naticidae	*Neverita josephina** (Linnaeus, 1758)	absent	absent	present
Muricidae	*Hexaplex trunculus** (Linnaeus, 1758)	absent	absent	present
Buccinidae	*Buccinulum corneum** (Linnaeus, 1758)	absent	absent	present
	*Pisania striata** (Gmelin 1791)	absent	absent	present
Nassariidae	*Cyclope neritea* (Linnaeus, 1758)	absent	present	present
	*Nassarius reticulatus** (Linnaeus, 1758)	absent	absent	present
	Nassarius corniculum (Olivi, 1792)	absent	present	present
	*Nassa costulata** (Renier, 1804)	absent	absent	present
	*Nassarius cuvieri** (Payraudeau, 1826)	absent	absent	present
	*Nassarius mutabilis** (Linnaeus, 1758)	absent	absent	present
Pyrenidae	*Mitrella minor** (Scacchi, 1836)	absent	absent	present
Mangeliidae	*Raphitoma purpurea** (Montagu G., 1803)	absent	absent	present
Bullidae	*Bulla striata** Bruguière, 1792	absent	absent	present
Atyidae	*Haminoea hydatis* (Linnaeus, 1758)	absent	emerged	absent
	*Haminoea navicula** (da Costa, 1778)	absent	absent	present
Aplysiidae	*Aplysia depilans** Gmelin, 1791	absent	absent	present
Notarchidae	*Bursatella leachii**** de Blainville, 1817	absent	absent	present
Elysiidae	*Elysia sp**	absent	absent	present
Calmidae	*Calma glaucoides** (Alder & Hancock, 1854)	absent	absent	present
Chromodorididae	*Hypselodoris villafranca** (Risso, 1818)	absent	absent	present
Dorididae	*Doris verrucosa** Linnaeus, 1758	absent	absent	present
Aeolidiidae	*Spurilla neapolitana** (Delle Chiaje, 1841)	absent	absent	present
Nuculidae	*Nucula nitidosa** Winckworth, 1930	absent	absent	present
Mytilidae	*Modiolus barbatus** (Linnaeus, 1758)	absent	absent	present
	*Musculista senhousia**** (Benson in Cantor, 1842)	absent	absent	present
	*Mytilus galloprovincialis** Lamarck, 1819	absent	absent	present
Arcidae	*Arca noae** Linnaeus, 1758	absent	absent	present
	*Striarca lactea** (Linnaeus, 1758)	absent	absent	present
Pteriidae	*Pinctada radiata**** (Leach, 1814)	absent	absent	present
Limidae	*Limaria hians** (Gmelin, 1791)	absent	absent	present
Ostreidae	*Ostrea edulis** Linnaeus 1758	absent	absent	present
Cardiidae	*Cerastoderma glaucum* (Poiret, 1789)	present	present	present
Lucinidae	*Loripes lacteus* (Linnaeus, 1758)	absent	dispaue	present
Chamidae	*Chama gryphoides** Linnaeus, 1758	absent	absent	present
Veneridae	*Dosinia lupinus** (Linnaeus, 1758)	absent	absent	present
Paphiidae	*Ruditapes decussatus* (Linnaeus, 1758)	absent	present	present
	Venerupis aurea (Gmelin, 1791)	absent	lost	absent
	*Tapes rhomboides** (Pennant, 1777)	absent	absent	present
	*Irus irus** (Linnaeus, 1758)	absent	absent	present
Donacidae	*Donax semistriatus** Poli, 1795	absent	absent	present
Scrobiculariidae	*Abra tenuis* (Montagu, 1803)	absent	present	present
	*Scrobicularia plana** (da Costa, 1778)	absent	absent	present
Tellinidae	*Gastrana fragilis* (Linnaeus, 1758)	absent	lost	present
	*Tellina tenuis** da Costa 1778	absent	absent	present
Mactridae	*Mactra stultorum** (Linnaeus, 1758)	absent	absent	present
Gastrochaenidae	*Gastrochaena dubia** (Pennant, 1777)	absent	absent	present
ANNELIDA				
Polynoidae	*Harmothoë lunulata** (delle Chiaje, 1841)	absent	**?**	present
	*Lagisca extenuata** (Grube, 1840)	absent	absent	present
Sigalionidae	*Sigalion mathildae** (Audouin & H.M. Edwards, 1834)	absent	absent	present
Nephtydae	*Nephthys caeca** (Quatrefages, 1865)	absent	absent	present
	*Nephthys hombergii** Savigny 1818	absent	absent	present
Phyllodocidae	*Phyllodoce lamelligera** Johnston, 1865	absent	absent	present
Goniadidae	*Glycinde armigera** Moore, 1911	absent	absent	present
Glyceridae	*Glycera rouxi*i* Audouin & H.M.Edwards, 1833	absent	absent	present
	*Glycera convoluta** Keferstein, 1862	absent	absent	present
	*Glycera tesselata** Grube 1863	absent	absent	present
Onuphidae	*Diopatra neapolitana** delle Chiaje, 1841	absent	absent	present
Eunicidae	*Eunice aphroditois** (Pallas, 1788)	absent	absent	present

	*Marphysa bellii** (Audouin & H.M. Edwards, 1833)		absent	absent	present
	*Marphysa fallax** Marione & Bobretzky, 1875		absent	absent	present
Lumbrineridae	*Lumbrineris impatiens** (Claparède, 1868)		absent	absent	present
Arabellidae	*Arabella iricolor** (Montagu, 1804)		absent	absent	present
Hesionidae	*Hesione pantherina** (Risso, 1826)		absent	absent	present
Syllidae	*Typosyllis variegata** (Grube, 1860)		absent	absent	present
	*Syllis gracilis** Grube,1840		absent	absent	present
	*Brania clavata** (Claparède, 1863)		absent	absent	present
Nereidae	*Hediste diversicolor* (O. F. Müller, 1776)		absent	lost	absent
	Perinereis cultrifera (Grube, 1840)	present	absent	absent	present
	*Platynereis dumerilii**(Audouin & H.M.Edwards,1833)		absent	absent	present
	*Neanthes caudata** (delle Chiaje, 1828)		absent	absent	present
Iospilidae**	*Pariospilus affinis**** Viguier, 1911		absent	absent	present
Orbiniidae	*Naineris laevigata** (Grube, 1855)		absent	absent	present
	*Orbinia cuvieri** Audouin & H.M. Edwards, 1834		absent	absent	present
	*Orbinia latreillii** Audouin & H.M. Edwards, 1833		absent	absent	present
	Orbinia foetida (Claparède, 1868)	present	absent	absent	present
Spionidae	*Aonides paucibranchiata* Southern, 1914	present	absent	absent	present
	*Malacoceros vulgaris** (Johnston, 1828)		absent	absent	present
	Scolelepis fuliginosa (Claparède, 1868)		absent	lost	present
	*Polydora armata** Langerhans, 1880		absent	absent	present
	Polydora coeca (Oested, 1843)		absent	present	absent
	*Polydora ciliata** (Johnston, 1838)		absent	absent	present
	Polydora hoplura Claparède, 1870	present	absent	absent	absent
	Boccardia polybranchia (Haswell, 1885)	present	absent	absent	absent
	*Pygospio elegans** Claparède, 1863		absent	absent	present
Paraonidae**	*Paradoneis lyra**** (Southern, 1914)		absent	absent	present
Magelonidae	*Magelona papillicornis** Müller, 1858)		absent	absent	present
Cirratulidae	*Cirriformia tentaculata** (Montagu, 1808)		absent	absent	present
	*Cirratulus cirratus** (O. F. Müller, 1776)		absent	absent	present
Opheliidae	*Ophelia bicornis** Savigny, 1818		absent	absent	present
	Polyophthalmus pictus Dujardin, 1839		absent	present	present
Capitellidae	*Capitella capitata* (Fabricius, 1780)	present	absent	emerged	present
	*Heteromastus filiformis** (Claparède, 1864)		absent	absent	present
	*Notomastus latericeus** M. Sars, 1851		absent	absent	present
Arenicolidae	*Arenicola claparedii** Levinsen, 1883		absent	absent	present
	*Arenicola marina** (Linnaeus, 1758)		absent	absent	present
Maldanidae	*Euclymene palermitana** (Grube, 1840)		absent	absent	present
	*Euclymene santanderensis** (Rioja,1917)		absent	absent	present
Scalibregmidae	*Scalibregma inflatum** Rathke,1843		absent	absent	present
Pectinariidae	*Amphictene auricoma** (O.F.Müller, 1776)		absent	absent	present
Terebellidae	*Eupolymnia nebulosa** (Montagu, 1818)		absent	absent	present
	Amphitrite rubra (Risso, 1828)		absent	emerged	present
	*Lanice conchylega** (Pallas, 1766)		absent	absent	present
Sabellariidae	*Sabellaria alveolata** (Linnaeus, 1767)		absent	absent	present
Serpulidae	*Serpula vermicularis** Linnaeus 1767		absent	absent	present
	Hydroïdes dianthus (Verril, 1873)	present	absent	lost	present
	*Hydroïdes dirampha** (Möerch, 1863)		absent	absent	present
	Hydroïdes elegans (Haswell, 1883)		absent	emerged	present
	Hydroïdes norvegica Gunnerus, 1768	present	absent	emerged	present
	Ficopomatus enigmaticus (Fauvel, 1923)	present	present	present	absent
	*Vermiliopsis infundibulum** (Philippi, 1844)		absent	absent	present
	Vermiliopsis striaticeps (Grube, 1862)		absent	lost	absent
	Dexiospira spirillum (Linnaeus, 1758)	present	absent	absent	absent
	Janua corrugatus (Montagu, 1903)	present	absent	absent	absent
	*Spirorbis militaris** (Claparède, 1870)		absent	absent	present
Sabellidae	*Amphiglena mediterranea** (Leydig, 1851)		absent	absent	present
	*Chone duneri** Malmgren, 1867		absent	absent	present
	*Oriopsis armandi** (Claparède, 1864)		absent	absent	present

	*Sabella pavonina** Savigny,1820		absent	absent	present
ARTHROPODA					
Cyclopidae	*Cyclops* sp.*		absent	absent	present
Ectinosomidae	*Microsetella norvegica** (Boeck, 1865)		absent	absent	present
Cypridinidae	*Cypridina mediterranea** Costa, 1845		absent	absent	present
Chthamalidae	*Chthamalus stellatus* (Poli, 1791)	present	absent	absent	absent
Balanidae	*Balanus amphitrite* Darwin, 1854	present	absent	present	present
Nebaliidae	*Nebalia bipes** (O.Fabricius, 1780)		absent	absent	present
Alpheidae	*Athanas nitescens** (Leach, 1814)		absent	absent	present
Hyppolytidae	*Thoralus cranchii** (Leach, 1817)		absent	absent	present
Processidae	*Processa acutirostris** (Nouvel & Holthuis, 1957)		absent	absent	present
Callianassidae	*Callianassa tyrrhena** (Petagna, 1792)		absent	absent	present
Diogenidae	*Dardanus arrosor** (Herbst, 1796)		absent	absent	present
Porcellanidae	*Porcellana longicornis** (Linnaeus, 1767)		absent	absent	present
Portunidae	*Carcinus mediterraneus**** Czerniavsky, 1884		absent	absent	present
Xanthidae	*Pilumnus hirtellus** (Linnaeus, 1761)		absent	absent	present
	*Xantho poressa** (Olivi, 1792)		absent	absent	present
Grapsidae	*Brachynotus sexdentatus* (Risso, 1827)		absent	emerged	present
Mysidae	*Mesopodpsis slabberi* (Van Beneden, 1861)	present	absent	absent	absent
	Diamysis bahirensis (G. O. Sars, 1877)	present	absent	absent	absent
Tanaidae	*Tanais dulongii** (Audouin, 1826)		absent	absent	present
Janiridae	*Jaera nordmanni** (Rathke, 1837)		absent	absent	present
Sciphacidae	*Armadilloniscus littoralis**** Budde-Lund, 1885		absent	absent	present
Idoteidae	*Idotea balthica* (Pallas, 1772)		present	lost	absent
	Idotea chelipes (Pallas, 1766)		present	present	present
Sphaeromatidae	*Sphaeroma ephippium* Costa, 1882	present	present	lost	present
	Sphaeroma serratum (Fabricius, 1787)	present	present	lost	present
	*Sphaeroma walkeri** Stebbing, 1905		absent	absent	present
	*Cymodoce truncata** Leach, 1814		absent	absent	present
	Paracerceis sculpta (Holmes, 1904)		absent	present	present
Leucothoidae	*Leucothoe spinicarpa** Abildgaard, 1789		absent	absent	present
Gammaridae	*Elasmopus rapax** Costa, 1853		absent	absent	present
	*Elasmopus pocillimanus** (Bate, 1862)		absent	absent	present
	Lysianassa plumosa Boeck, 1871		absent	present	absent
	*Maera inaequipes** (A. Costa, 1857)		absent	absent	present
	Gammarus aequicauda (Martinov, 1931)		present	present	present
	Gammarus insensibilis Stock, 1966		present	present	present
	*Cymadusa filosa** Savigny, 1816		absent	absent	present
	Cymadusa hirsuta Chevreux, 1900		absent	emerged	present
	Melita palmata Montagu, 1804		absent	emerged	present
Talitridae	*Hyale perrieri** Lucas, 1849		absent	absent	present
	Orchestia sp.	present	absent	absent	absent
Corophiidae	*Corophium volutator* (Pallas, 1766)		present	present	present
	Corophium acherusicum Costa, 1857		present	lost	present
	*Apocorophium acutum** (Chevreux, 1908)		absent	absent	present
	*Erichthonius brasiliensis** (Dana, 1855)		absent	absent	present
	Erichthonius difformis H.M.Edwards, 1830		absent	lost	present
	Leptocheirus pilosus Zaddach, 1844		absent	present	absent
Caprellidae	*Caprella acanthifera** Leach, 1814		absent	absent	present
	*Caprella aequilibra** Say, 1818		absent	absent	present
Amphithoidae	*Amphithoë vaillanti** Chevreux, 1911		absent	absent	present
	*Microdeutopus chelifer** (Bate, 1862)		absent	absent	present
	Microdeutopus gryllotalpa A. costa, 1853		absent	lost	present
Ammotheidae	*Achelia echinata** Hodge, 1864		absent	absent	present
Chironomidae	*Chironomus sp.*		absent	present	present
Dermestidae	*Dermestes lardarius** Linnaeus, 1758		absent	absent	present
Lepismatidae	*Lepisma saccharina** Linnaeus, 1758		absent	absent	present

BRYOZOA					
Vesiculariidae	*Zoobothryon verticillatum* (delle Chiaje, 1828)		absent	lost	absent
	Bowerbankia gracilis Leidy, 1855		absent	present	absent
Membraniporidae	*Conopeum seurati* (Canu, 1928)		absent	present	absent
Bugulidae	*Bugula stolonifera* Ryland, 1960		absent	lost	absent
	*Bugula neritina** (Linnaeus, 1758)		absent	absent	present
Scrupariidae	*Scruparia ambigua** (D'Orbigny, 1841)		absent	absent	present
Cellariidae	*Cellaria salicornoides** (Carvalho, 1971)		absent	absent	present
Cheiloporinidae	*Cryptosula pallasiana* Moll, 1803		absent	emerged	present
ECHINODERMATA					
Amphiuridae	*Amphipholis squamata* (delle Chiaje, 1828)		absent	lost	present
Ophiactidae	*Ophiactis virens** (M. Sars, 1857)		absent	absent	present
TUNICATA					
Clavelinidae	*Clavelina lepadiformis** (O. F. M ¸ller, 1776)		absent	absent	present
Cionidae	*Ciona intestinalis* (Linnaeus, 1767)		absent	emerged	present
Pyuridae	*Pyura microcosmus** (Savigny, 1816)		absent	absent	present
Styelidae	*Styela plicata* (Leseur, 1823)	present	absent	absent	present
	Botryllus schlosseri (Pallas, 1766)	present	absent	absent	absent
Molgulidae	*Molgula manhattensis (*De Kay, 1843)	present	absent	absent	absent

heterogeneity among samples, were also used. Before statistical treatment, species abundances log ($x + 1$) were transformed (Makra & Nicolaidou, 2000; Nanami et al., 2005) and multidimensional analyses were done using R2.2.0 ADE4 Software.

Results

Hydrological parameters

The mean values of physicochemical parameters and relative characteristics of each station are recorded in Table 2. The salinity mean value reached 38 (min: 35.5, max: 39.9) whereas the temperature mean value was 21.1°C (min: 20.3, max: 21.8). The mean value of dissolved oxygen was 7.2 mg.l^{-1} (min: 5.6, max: 9.1), that of the pH reached 8.4 (min: 6.4, max: 8.7).

Faunal composition

A total of 189 species belonging to eleven phyla were identified (Table 3). Annelid polychaetes counted 64 species and were better represented (33.9% of total species number), followed by molluscs with 51 species (27.0%) and arthropods with 48 species (25.4%). The other eight phyla counted only 26 species (13.8%). Four nudibranch species: *Calma glaucoides*, *Hypselodoris villafranca*, *Doris verrucosa* and *Spurilla neapolitana*, seven exotic species: *B. leachii*, *M. senhousia*, *P. radiata, Hydroïdes dianthus*, *H. dirampha*, *H. elegans* and *Sphearoma walker* and two first recorded species among the Tunisian polychaetes fauna (*Pariospilus affinis*, *Paradoneis lyra*) were collected during the sampling period.

139 species were collected for the first time after management (Table 3). Among them, there were 54 polychaetes, 33 molluscs, 33 arthropods, 4 cnidaria, 2 tunicata, 4 porifera, 1 plathelminth, 4 nemertini, 1 echinodermata, 2 bryozoa and 1 sipunculida.

A total of 55747 individuals belonging to 182 countable species were examined. Molluscs represent the most abundant phylum, followed by Annelids and Arthropods. The specific richness observed within intralagoon stations fluctuated from a minimum of 32 (S1, S8) to a maximum of 68 species (S10, S13). The highest value was recorded at the lagoon/marine station S26 (Table 3). However, average densities were lower in S1, S2, S3 (located very close to the marine water input) and in S8 than in the remainder intralagoon stations.

The most frequent (number of stations containing the species/total number of stations) and dominating (individuals number/station) species in the communities were the following: *Condylactis aurantiaca*, *Anthopleura ballii*, *L. impatient*, *P. cultrifera*, *N. laevigata*, *C. capitata*, *N. caudata*, *H. filiformis*, *Notomastus latericeus*, *C. vulgatum*, *Tapes rhomboides*, *Loripes lacteus*, *Tellina tenuis*, *Cymodoce truncata*.

Population structure analysis

The collected species generally belong to different biocoenoses such as the biocoenosis of superficial muddy sands in sheltered areas (e.g. *Cereus pedunculus*, *Gibbula adansoni*, *Cirriformia tentaculata*), euryhaline and eurythermal biocoenosis in brackish waters (e.g. *Cyclope neritae*, *Gastrana fragilis*, *Gammarus sp.*), biocoenosis of

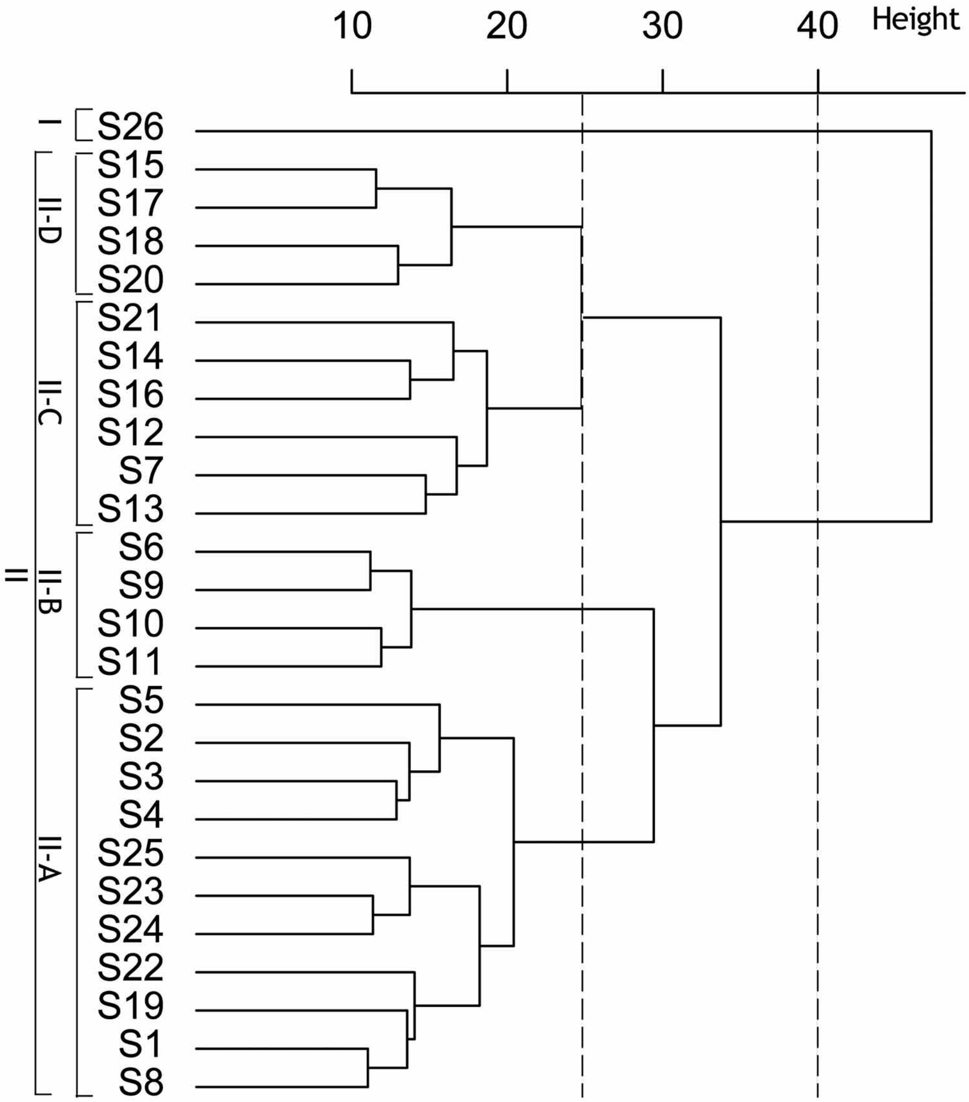

Figure 2. Ascending hierarchical clustering of the studied stations (Ward's method).
Figure 2. Classification ascendante hiérarchique des stations étudiées (méthode de Ward).

invertebrates in very polluted waters (e.g. *Bugula neritina*, *Ciona intestinalis*, *Styela plicata*, *Mytilus galloprovincialis, Ruditapes decussatus*), biocoenosis of fine well-sorted sand (e.g. *Neverita Josephina*, *Nassarius mutabilis*, *Sigalion mathildae*, *Diopatra neapolitana*), biocoenosis of highly polluted sediments (e.g. Spionidae, *Magelona papillicornis*) or biocoenosis of photophilic algae (e.g. Syllidae).

The Shannon-Weaver's diversity index fluctuates from a minimum of 1.79 bits at the station S4 to a maximum of 4.81 bits at the station S13. The factorial analysis of correspondences, as the ascending hierarchical analysis (Fig. 2), showed two grouped stations (I and II) and enabled a simultaneous projection of both species and stations (Fig. 3); the first two axes only explain 37% of the initial information. Axis 1 contains 27% of the initial information and isolates the station S26 (group I). The overwhelming species that present the strongest contributions on this axis are *S. walkeri, Apocorophium acutum, Corophium acherusicum, Styella plicata* and *Raphitoma purpurea*. The axis 1 is thus determined by species of marine and hard substratum affinities. Axis 2 grouped together intralagoon stations (group II). Species having the strongest contribution are respectively *Pygospio elegans*, *Arabella iricolor*, *Neverita josephina* and *Nassarius mutabilis*. The FDA graph revealed that only Cnidaria and Nemertini phyla presented great heterogeneity for species abundances (Fig. 4).

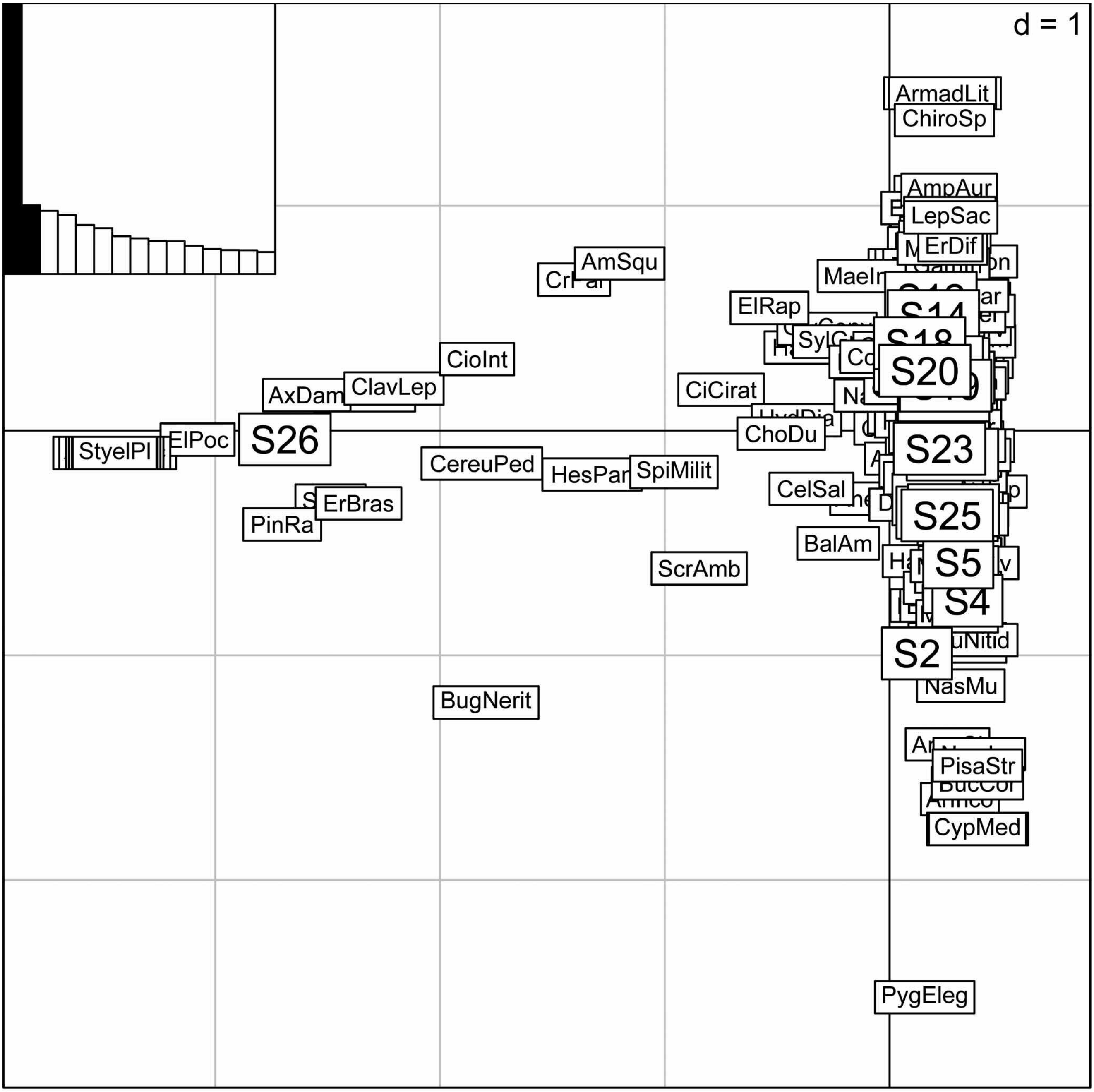

Figure 3. FCA: simultaneous projections of both stations and species according to their mean abundances, on the axes 1 and 2.
Figure 3. AFC : projections simultanées des stations et des espèces sur les axes 1 et 2 selon les abondances moyennes des espèces.

Discussion

The management impact in Tunis north lagoon was demonstrated from relatively recent studies that showed the improvement of water quality and modification in phytobenthic communities with the reduction (or loss) of *Ulva* and proliferation of the filamentous algae *Chetomorpha spp*. (Ben Maiz, 1993; Annabi et al., 2001). Moreover, the comeback and the extension of some phanerogam species such as *Ruppia cirrosa*, *Zoostera spp*., *Cymodocea spp*. and some algae like *Caulerpa prolifera* and *Chetomorpha linum* were noted (Ben Maiz, 1993).

The collected hydrological parameters (Table 2) showed a global amelioration compared to extreme values

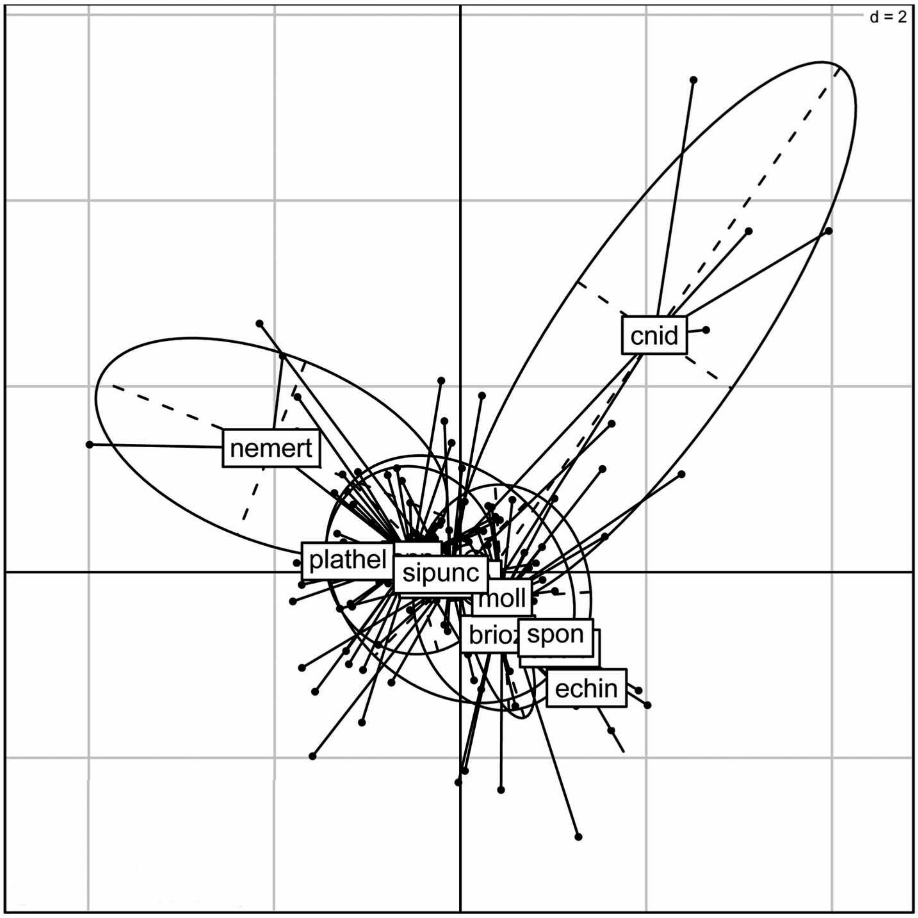

Figure 4. FDA discriminating the phyla according to the species mean abundances. ann: Annelida. cnid: Cnidaria. brioz: Bryozoa. echin: Echinodermata. moll: Mollusca. nem: Nemertini. plathel: Plathelmintha. sipunc: Sipunculida.

Figure 4. AFD discriminant les phylums selon les abondances moyennes des espèces. ann: Annélides. cnid: Cnidaires. brioz: Bryozoaires. echin: Echinodermes. moll: Mollusques. nem: Némertiens. plathel: Plathelminthes. sipunc: Sipunculidés.

previously recorded in preceding studies (Table 1). Mean values of the considered parameters were comparable to those recorded after management (Table 2). The amelioration of ecological parameters is probably due to the new produced hydrodynamic, permanent seawater exchanges and manual removals of floating algae (Ben Charrada, 1995).

The specific richness observed herein is relatively important. It considerably exceeds those previously mentioned elsewhere (Wesenberg-lund, 1939; Vuillemin, 1952; Molinier & Picard, 1954; Zaouali, 1974; Zaouali & Baeten, 1984); this could be due to the considerable sampling effort made upon 26 stations and also to the ecological improvement that allowed attraction and settlement of new species (Table 3). The highest specific richness and density values were recorded in S26, located in the interface Sea/lagoon. Moreover, the specific richness and the average density varied from one station to another; they showed heterogeneity within intralagoon stations (except for S1, S2 and S3). This occurrence could be explained by the interaction of several factors such as hydrodynamics, substrate type, vegetation expansion, nutritive matter contents, etc.

A total of 226 macrobenthic species collected in the Tunis north lagoon are listed in the table 2. Among them, we noted the disappearance of 37 species and the first observation of 139 species. Only 87 species were recorded before drawing the management.

The phyla taxonomic structure is in agreement with the results of other studies carried out in other Mediterranean lagoons (Arvanitidis et al., 1999; Koutsoubas et al., 2000). We pointed out eleven phyla, but neither Sipuncula nor Nemertini have been recorded in the past among Tunis north lagoon infauna. Furthermore, it is remarkable that among communities, Cnidaria and Nemertini showed the most significant variations of their species abundances.

This would be explained by the abundance variations from one station to another.

As given in Table 3, Annelids constitute the most dominant phylum followed by Molluscs and then Arthropods. This was not similar to other studies where Molluscs represented the most dominant phylum (Molinier & Picard, 1954; Zaouali, 1974; Zaouali & Baeten, 1984).

Annelids were only represented by Sedentary and Errantia Polychaetes which counted respectively 40 species (21.2%) and 24 species (12.7%). Molluscs were represented by the class of Polyplacophora (2 species: 1.1%), Gastropods (26 species: 13.8%) and Bivalves (23 species: 12.2%). While Arthropods were represented by Crustaceans (44 species: 23.3%), Insects (3 species: 1.6%) and Pantopoda (1 species: 0.5%).

Concerning classes, we found that Crustaceans and Sedentary Polychaetes were the most represented in terms of species number followed by Gastropods, Errantia Polychaetes and Bivalves. However, in terms of abundance, Molluscs constitute the dominating community.

Moreover, it is worth mentioning that species belonging to Iospilidae and Paraonidae families were recorded here, for the first time, among Tunisian faunal Polychaetes. Accordingly, *Pariospilus affinis*, an errantia and pelagic Mediterranean endemic species, was recorded in Algeria while the cosmopolitan sedentaria *Paradoneis lyra* was found in Atlantic Ocean as well as in Baltic Sea (Fauvel, 1927). Furthermore, Lineidae family has never been recorded in Tunis north lagoon before this study.

Moreover, the alien and reef-forming tubeworm *Ficopomatus enigmaticus* that characterized the lagoon for several years (Vuillemin, 1952) was not found during this study. The disappearance of the latter species might be in relation with the new hydrological conditions, especially the good water circulation and both organic matter and temperature decreases (Table 1). It can then be deducted that the quality improvement of Tunis north lagoon has prevented this annelid maintain, since it is typical of brackish environments and is generally found in confined lagoons (Gravina, 1985). In fact, dense populations of *F. enigmaticus* have been documented in shallow lagoons with very little water exchange, extreme salinity fluctuations and no thermal tolerances (Bianchi & Morri, 1996). Furthermore, it was demonstrated that this species can not survive in marine mediums (Rioja, 1924). The latter results confirmed that the new established conditions in Tunis north lagoon are not favorable for the survival of *F. enigmaticus*.

It is worth noting that many immigrant fouling polychaetes of the genus *Hydroides* still persist in the lagoon. These alien tubeworms were recorded in Tunisia, several years ago, within some harbors and lagoons (Zibrowius, 1978). Their permanent establishment would be due to the sediment and water organic matter richness. Their introduction within Tunis north lagoon would be related to marine water inflows and the entering currents which contribute to their dispersal. As for serpulid polychaetes belonging to the same genus, their presence in Tunis north lagoon matches with their successful and rapid invasion. In fact, these polychaetes constitute the earliest documented invaders in the Mediterranean. *H. dianthus* for example, was recorded in Izmir as early as 1865 (Galil & Zenetos, 2002). *H. elegans* has a wide temperature tolerance, what simply contributes to its migration (Qiu & Qian, 1998). As for *H. dirampha*, it is known to be well established in harbors and lagoons throughout the Mediterranean (Kocak et al., 1999).

The motile species *Bursatella leachii*, an invasive gastropod coming from the Red Sea (Eales, 1970) was found in the western part of Tunis north lagoon, far from Kheireddine channel and the marine water input. It was previously recorded in the gulf of Gabes (Zenetos et al., 2000). It can then be concluded that since the latter record, the species has migrated to the northern coasts of Tunisia and that it has recently reached the gulf of Tunis, in particular Tunis north lagoon. It is worth noting that this small surface deposit feeder with grazing habits (Russo, 1987) was mentioned in the Mediterranean several years ago (O'Donoghue & White, 1940).

The north-western Pacific Ocean exotic bivalve, *Musculista senhousia*, was found at the doors of marine water input, attached by its byssal threads to hard substrata. Because of its life history and ecological characteristics and its successful invasion of many parts of the world, this species can rapidly spread and form large mats on the seabed; *M. senhousia* has then the potential to cause adverse ecological effects (Crooks, 1996). According to Creese et al. (1997), this fouling sessile organism is adapted to various habitats and may build important colonies by producing dense mats that lead to an adverse impact on the biodiversity as it reaches high densities that can exclude other infaunal species. However, in the Tunis north lagoon, *M. senhousia* was found without mat forming and with very few individuals avoiding adverse impact on other infaunal organisms.

The invasive species *Pinctada radiata* was found with high densities on the locks of marine water entrances and has began to invade the inner parts of Tunis north lagoon (e.g. rocky blocs flanking the separating dike). We have observed this species in this lagoon since 2003-2004. Its occurrence on this area explained its adaptation to the lagoon conditions and seems to be in relation with the intensification of the lagoon/Sea exchanges. The current actions would be the dominating vector for *P. radiata* larvae migration. The distribution of this erythrean mollusc was almost limited to the Gulf of Gabes and sporadic along the eastern Tunisian coasts. Recently, *P. radiata* was recorded in the bay of Monastir (Irathni, unpublished data), at the proximity of Stah Jaber fishing port (Eastern coast of Tunisia) and in Bizerta lagoon (North coast of Tunisia). According to the latter author, the presence of *P. radiata* in these areas seems to be in relation with the ship activity that exists in Bizerta and Stah Jaber harbours and also with the global warming. The recent record of *P. radiata* in Bizerta lagoon confirms that since its introduction in the gulf of Gabes, the species has continued its dispersal and colonization of new biotopes (North coasts of Tunisia). Its migration seems to be mediated by currents activities, ships (Zibrowius, 1992) or even by being transported, as epibionts, by other species like turtles.

The Indian isopod (Carlton & Iverson, 1981) *Sphaeroma walkeri* was observed only in the doors' locks of Kheireddinne channel. Its occurrence in Tunis north lagoon would be related to water currents that can train juveniles and small-sized individuals from Rades and La Goulette where the species was first recorded (Ben Souissi et al., 2003).

Summarizing, the introduction of new species within Tunis north lagoon seems to be due to various factors. As reported by other authors (Creese et al., 1997), we also think that the global warming affecting the Mediterranean seawater temperature is the main factor promoting the migration of new species which can be mediated by water currents. In the present case, the proximity of Tunis north lagoon to Rades and La Goulette harbors confirms the latter idea. Indeed, sheltered coastal bays and estuaries near major harbors are more disposed to receive marine invaders (Creese et al., 1997). Moreover, it is known that the extension of exotic species in Mediterranean is generally mediated by ships, ballast transport, marine farming products, being epibionts on other motile species (hosts) or simply through the agency of planktonic larvae (Zibrowius, 1992; Galil & Zenetos, 2002). According to Carlton (1987), the transoceanic shipping activity is the major vector for unintentional introductions of invaders.

It is remarkable that in the proximity of marine water input, populations are more diversified with the existence of marine affinity species such as Nudibranchs, Spongia and the majority of abovementioned exotic species; their spread area is limited to this zone (except for *B. leachii* and Serpulid species) where they form dense populations:

1) What makes the presence of marine affinity species limited at the doors of marine water input? ;

2) Do the doors'locks represent an artificial barrier which prevents their progression through the lagoon? ;

3) Does pollution act as a limiting factor, among others, to prevent their settlement in this area? Because of their vigorous, these species might overcome the difficulties and form stable populations adapted to the intralagoon conditions. However, the other parts of the lagoon did not show a specific spatial distribution but they are characterized by the dominance of well adapted strictly-lagoon species (e.g. *L. lacteus*, *Scrobicularia plana*, and so on). Indeed, the faunal composition analysis showed the omnipresence of species which characterize euryhaline and biocoenosis of invertebrates in very polluted waters described by Pérès (1967). Among these species there are some surface deposit feeders (e.g. *N. caudata*, *C. tentaculata*), subsurface deposit feeders (e.g. *C. capitata, H. filiformis, N. latericeus)*, carnivorous (e.g. *H. navicula)* and some suspension feeders (e.g. *C. glaucum, R. decussatus*, *L. lacteus, B. neritana, C. intestinalis*, *S. plicata*). Moreover, the abovementioned species are known to be opportunistic and well developed in both brackish and polluted waters with the persistence of organic matter (Pérès, 1954; Tursi, 1980).

The omnipresence of these opportunistic and pollution indicating species has allowed the similarity between all intralagoon stations. Thus, multidimensional analyses revealed the same result with two major groups (Figs 2 & 3), probably related to salinity variations, sediment type and organic matter contents (Table 2). This is in disagreement with other results mentioned in other lagoons (Nanami et al., 2005). We noted that, both euryhalin and eurytherm species (e.g. *Gammarus sp*., *Maera inaequipes*, *S. serratum*, *Cymadusa sp*., *C. volutator*) proliferate mostly in the southern zone of Chekli Isle where temperature and salinity values are higher (Annabi et al., 2001).

Contrary to what observed in other studies (Guelorget et al., 1994, Paganelli et al., 2005) where the distribution of lagoon benthic invertebrates generally follows an increasing biological gradient of specific richness from the marine water input towards inner parts and a reversed gradient of density, the present study showed the absence of this gradient, indicating a mean density heterogeneity and a random distribution of communities in the lagoon; this may be related to the interaction of several factors such as salinity variations and some edaphic factors in particular organic matter contents.

The comparison of Shannon-Weaver's diversity index values to those of the theoretical maximum diversity ($\log_2 S$) indicated that Tunis north lagoon shows a moderate pollution. The lowest diversity value (H'= 1.79 bits) was recorded in an ancient zone of urban waste water rejections but, the highest diversity (H'= 4.81 bits) was pointed in the station representing an old Tunis town trash rejection. This is in disagreement with other investigations carried out elsewhere (Koutsoubas et al., 2000) where the highest value was recorded in areas close to the Sea. It is worth mentioning that the zone around the station S13 was previously dredged and embanked thereafter. This probably contributed to the reduction of sediment organic matter contents and subsequent recovery of species in this formerly azoic zone. The Shannon-Weaver's diversity index values indicated a slightly disturbed environment and an unbalanced community in the majority of stations. Such results are in agreement with those obtained by Bazairi et al. (2005) and seem to confirm the influence of many environmental factors in the Tunis north lagoon.

Conclusion

This study revealed evident improvement of the physico-chemical parameters and random distribution of both specific richness and population density. The settlement of 139 new species (among them, there are nudibranchs and exotic species) confirmed the permanent seawater inflows. The specific composition showed that the populations' distribution is under the influence of several concomitant factors in particular the salinity and edaphic ones, with the persistence of disturbance-indicating species. Management works contributed to the settlement of new species and their spread around the lagoon. Moreover, organic matter decreases and the good water circulation explain the disappearance of the brackish water polychaete *F. enigmaticus*.

Finally, in spite of the water quality amelioration and the dredging of millions of cubic metres of mud, the Tunis north lagoon is still contaminated even if the intensity of organic pollution strongly decreased after management works.

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