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Morphometry, energetics and diversity of free-living nematodes from coasts of Bizerte lagoon (Tunisia): an ecological meaning

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Abstract: Analyses of water quality in the Bizerte lagoon showed their relative low oxygenation during September 2002 compared to December 2001. Sediment variables appeared directly dependent on the silt/clay distribution and sewage from the metallurgic factory "El Fouledh". Nematode abundances were negatively influenced by silt/clay, organic matter, metals and chlorophyll *a* content. The individual nematode body size was clearly related to the distribution of two dominant species, *Terschellingia longicaudata* (Linhomoeidae) and *Paracomesoma dubium* (Comesomatidae). Shannon-Wiener diversity index values were the lowest in the South-Western stations characterized by higher level of organic matter and a weaker effect of pollution, in "Baie des carrières" and "Menzel Jemil" areas. The sediment metals were the key factors controlling the respiration rate of meiobenthic nematodes.

Résumé : *Morphométrie, énergétique et diversité des nématodes libres des côtes de la lagune de Bizerte (Tunisie) : signification écologique.* Les analyses des eaux collectées dans la lagune de Bizerte en septembre 2002 ont montré notamment leur plus faible oxygénation comparées à celles de décembre 2001. Les variables sédimentaires se sont avérées directement dépendantes de la distribution des particules fines et des rejets du complexe métallurgique "El Fouledh". Les effectifs des nématodes étaient négativement influencés par la richesse des sédiments en fraction fine, matière organique, métaux et chlorophylle *a*. La taille individuelle des nématodes était nettement tributaire de la distribution de deux espèces principales, *Terschellingia longicaudata* (Linhomoeidae) et *Paracomesoma dubium* (Comesomatidae). Les valeurs minimales de l'indice de diversité Shannon-Wiener ont été observées pour les stations Sud-Ouest caractérisées par des sédiments riches en matière organique et un moindre effet de la pollution au niveau des régions "Baie des carrières" et "Menzel Jemil". La teneur en métaux des sédiments est le facteur clé qui semble contrôler les taux individuels respiratoires des nématodes.

Keywords: Meiobenthic nematodes • Diversity • Body size • Respiration rates • Bizerte lagoon

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Introduction

The Bizerte lagoon (longitude 9°48’-9°56’E and latitude 37°08’-37°14’N) is the third largest lagoon in Tunisia (150 km^2) and constitutes one of the first local lentic ecosystems for fisheries and mussel production. This water body is connected to the Mediterranean Sea and to the Ichkeul Lake by straight channels (Fig. 1). Unfortunately, since few decades, a clear regression of its fisheries and mussel resources has been shown. In fact, the study area is situated near the industrial and urban zones of Bizerte, Menzel Bourguiba, Menzel Abderrahmen and Menzel Jemil, and three open-dumping type municipal/industrial solid waste landfills are operating near the above cities. Furthermore Bizerte lagoon is an important site of aquaculture activity related to the presence of three mussel culture zones, Menzel Jemil park being the more productive site. Pollution results from Menzel Bourguiba landfill and “El Fouledh” metal factory, from a natural silt/clay imput from Ichkeul lake (Menzel Bourguiba-Tinja), from Northern side of the lagoon (Bizerte-Menzel Abderrahmen-Menzel Jemil), the South-Eastern agriculture zone and from the activities along Mediterranean Sea-Menzel Bourguiba’s harbour.

Meiobenthic nematodes have been widely used as an efficient tool to determine the effects of anthropogenic and natural disturbances and have been shown to be sensitive to many classes of pollutants because of their direct benthic life style, high abundances, high turnover and the lack of larval dispersion and short generation times (Mahmoudi et al., 2005). However, for more than 20 years, investigations have focussed on biodiversity of free-living nematodes and little attention have been payed to the morphometry (Tita et al., 1999) or energetic significance of this faunistical

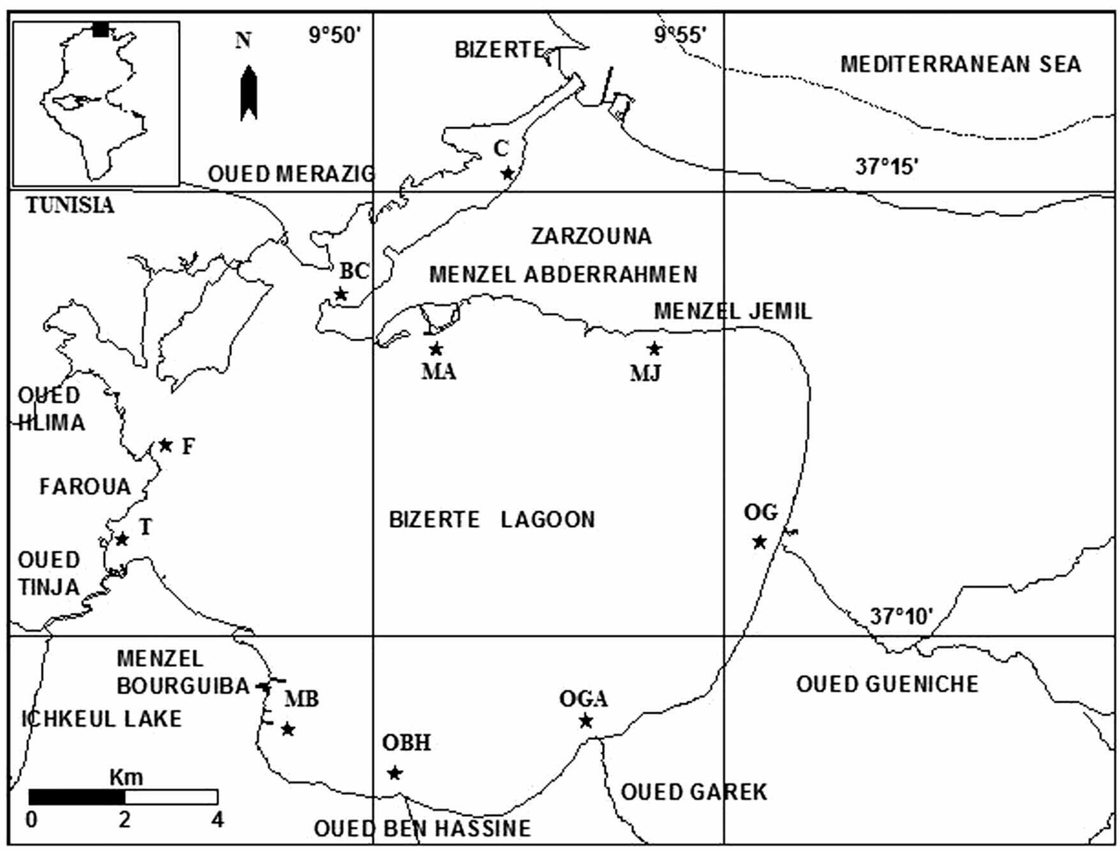

Figure 1. The study area and the ten prospected sites. Canal (C), Baie des carrières (BC), Faroua (F), Oued Tinja (T), Menzel Bourguiba (MB), Oued Ben Hassine (OBH), Oued Garek (OGA), Oued Gueniche (OG), Menzel Jemil (MJ), Menzel Abderrahmen (MA).

Figure 1. La zone d’étude et les dix stations prospectées. Canal (C), Baie des carrières (BC), Faroua (F), Oued Tinja (T), Menzel Bourguiba (MB), Oued Ben Hassine (OBH), Oued Garek (OGA), Oued Gueniche (OG), Menzel Jemil (MJ), Menzel Abderrahmen (MA).

compartment (Heip et al., 2001). The current study aimed to (i) describe the composition of the meiobenthic communities in the Bizerte lagoon, (ii) study some morphological and physiological characteristics of their nematode assemblages, and (iii) relate these meiobenthic features to some environmental variables and to the presence of some chemical pollutants in order to identify the environmental factors that are potentially responsible for nematode patterns.

Material and Methods

Environmental data

Sediment-overlying waters and bottom sediments were taken during rainy (morning periods of December 21, 22 and 23, 2001) and dry seasons (morning periods of September 10 and 11, 2002) at ten coastal sites situated near sewage zones into Bizerte lagoon (C, BC, F, T, MB, OBH, OGA, OG, MJ and MA) (Fig. 1). Salinity, temperature and dissolved oxygen of waters were measured *in situ* by using a multiparameter WTW 340i. Methods of Strickland & Pearsons (1965) were used to measure the water concentrations of phosphates, nitrates and nitrites. Water loads of chlorophyll *a* were measured fluorimetrically (Lorenzen & Jeffrey, 1980).

Sediments were dredged by using a Van Veen grab sampler (0.1 m^2) and deep frozen till analyses of chlorophyll *a* (Danovaro et al., 2002) and total hydrocarbons (Danovaro et al., 1995). Other sediment sub-samples were dried at 45°C and used for quantifying total organic matter by ignition at 450°C for 6 hours (Fabiano & Danovaro, 1994). Silt/clay fraction (< 63 µm) and mean grain size were respectively determined by wet sieving dried sediments and cumulative curves were calculated on the coarser fraction (Buchanan, 1971). For measure of metals (namely Zn, Cu, Fe, Mn, Ni and Pb) in the silt/clay fraction, a sediment sub-sample was digested in aqua regia (HCl-HNO_3-H_2O) at 95°C. Analysis was made by an Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES) and Mass Spectrometry (ICP-MS) (Yoshida et al., 2002).

Meiobenthic sampling and treatments

At each sampling site, meiobenthos was collected by using three plexiglas hand-cores (section area 10 cm^2) down to 20 cm, preserved in 4% neutralized formalin and stained with Rose Bengal (0.2 $g.l^{-1}$). The sediment was then washed through 1 mm and 40 µm sieves and the fraction retained by the 40 µm was used to extract meiobenthos by centrifugation with Ludox-HS40 (Mirto & Danovaro, 2004). Then, meiobenthic groups were identified and counted at higher taxonomic level.

Specific identification, morphometry and energetics of nematodes

At least, one hundred nematodes were randomly collected per sample (Kotta & Boucher, 2001). Nematodes were sorted hazardly according to the importance of the count at each one of the three replicates and mounted on glycerine slides for genera identification by using the pictorial keys of Platt & Warwick (1983 & 1988) and Warwick et al. (1998). Species identification was based on descriptions downloaded from the web site www.vliz.be/database/nemys/developed by nematologists of Ghent University (Belgium). Equally, we measured in mm the total length (L) and the maximum width (Wd) of specimens in order to estimate their biovolume (V) in nanolitre by using the equation (Warwick & Price, 1979):

$$V = 530 \times L \times (Wd)^2 \quad (1)$$

Wet weight (µg ww) of each nematode was obtained by using a specific gravity of 1.13 $\mu g.nl^{-1}$ (Wieser, 1960) and converted to carbon weight assuming a carbon/wet weight ratio of 0.125 (Vanaverbeke et al., 1997). Nematode daily respiration, valid at 20°C, was estimated on the basis of their weight using the logarithmic form of the power law (Sotaert et al., 1997):

$$R = 0.0449\ W^{-0,8544}\ \exp^{[\ln(Q_{10})/10](T-20)} \quad (2)$$

where T is temperature in °C, R is the individual daily respiration in $\mu gC.ind^{-1}.d^{-1}$ and W is the weight in µgC. Conversion to *in situ* temperatures was calculated assuming a Q_{10} value of 2 (variation of metabolic variables for a 10°C increase) (Heip et al., 2001). The metabolic ratio (MR) of each nematode was obtained by dividing individual respiration by individual weight and considering that 0.4 gC metabolized is equivalent to 1 litre consumed O_2 (Crisp, 1971). The individual daily production (P) in $kJ.ind^{-1}.d^{-1}$ was estimated from the log-transformed equation (Schwinghamer et al., 1986):

$$\log R = 0.367 + 0.993 \log P \quad (3)$$

1 gC was considered as equivalent to 45.7 kJ (Salonen et al., 1976).

Univariate measures of biodiversity

Two common indices, Shannon-Wiener index (H') $\log_2$ and Pielou's evenness (J') were used to estimate respectively diversity and equitability of the studied nematode assemblages.

Statistical analyses

Analyses were performed with the Primer 5.0 software developed by the Plymouth Marine Laboratory UK. Using the Bray-Curtis similarities of square-root transformed abundances of meiobenthic groups, an ordination plot was produced by non-metric multidimensional scaling (MDS).

Goodness of fit of the MDS ordination was done at low stress factor (< 0.2). Significance tests for differences between meiofaunal associations were performed by using the one-way ANOSIM test. The contribution of meiobenthic groups to dissimilarities between faunistical associations was investigated by using similarity-percentages procedure (SIMPER). The cluster analysis and affinity between nematode assemblages was established based on the Bray-Curtis similarity. This technique is integrated in the BioDiversity Pro 2.0 software (Natural History Museum UK and Scottish Association for Marine Science). Relationships between nematode and environmental variables along the sampling sites were investigated by using Pearson correlation. Analyses were done with Statistica 5.0 and all data were previously converted to approximate normality by using a log (x + 1) transformation.

Results

Environmental parameters

During both seasons, depth (2-3.9 m) of the sampling sites and water pH (8.20-8.38) did not vary so much. In December 2001, water dissolved oxygen ranged between 6.5 $mg.l^{-1}$ and 13.3 $mg.l^{-1}$. Concentrations were higher during the rainy season when temperatures were lower than during the dry season where this parameter varied between hypoxic (3.9 $mg.l^{-1}$) and normoxic (7.8 $mg.l^{-1}$) (Table 1). In December 2001, nitrites varied by 34 folds, nitrates by 3 folds and phosphates by 8.5 folds according to the sites. In September 2002, nitrites varied between 0 and 0.028 $mg.l^{-1}$. Nitrates varied by 6 folds and phosphates varied by 40 folds. Maximal value of phosphates was approximatively 1.5 folds higher in December 2001 than that recorded in September 2002. For nitrates, maximal value was temporally doubled. Chlorophyll *a* in waters varied by 6 folds in December 2001 and by 20 folds in September 2002.

The predominant fraction of sediment in most of the sampling sites was the coarse and fine sand fraction, especially at the Eastern stations and at station C located in the channel between the Mediterranean Sea and Bizerte lagoon bassin (Table 2). Some stations presented high silt/clay percentages during the rainy season (F and T) and during the dry season (MB, F and T). The station OBH also presented usually a high percentage of silt/clay. In both seasons, the highest values of the sedimentary organic matter were recorded in clayey sediments. Equally, the greatest part of spatial metal loads variability was similar to that of

Table 1. Parameters measured at the sampled waters collected from coasts of Bizerte lagoon in December 2001 (D2001) and September 2002 (S2002). Depth (DP), temperature (T), dissolved oxygen (DO), salinity (Sal), phosphates (PO_4), nitrites (NO_2), nitrates (NO_3), chlorophyll *a* (Chl*a* (W)). Maximum and minimum were respectively indicated with bold and underlined values.

Tableau 1. Paramètres mesurés dans les eaux prélevées le long des côtes de la lagune de Bizerte en décembre 2001 (D2001) et en septembre 2002 (S2002). Profondeur (DP), température (T), oxygène dissous (DO), salinité (Sal), phosphates (PO_4), nitrites (NO_2), nitrates (NO_3), chlorophylle *a* (Chl*a* (W)). Les maxima et les minima sont indiqués respectivement par les valeurs en gras et soulignées.

Sites Parameters		C	BC	F	T	MB	OBH	OGA	OG	MJ	MA
DP (m)	D2001	3.10	3.10	3.20	2.90	3.20	2.80	2.70	2.80	2.90	**3.30**
	S2002	3.20	**3.90**	3.10	2.00	3.10	2.60	3.20	3.20	3.10	2.60
T (°C)	D2001	**14.60**	14.10	11.80	12.20	11.80	12.00	12.50	12.20	11.80	12.20
	S2002	25.20	25.90	25.90	25.70	25.70	**26.00**	24.70	24.30	24.60	24.30
DO ($mg.l^{-1}$)	D2001	6.70	7.90	10.50	11.70	11.10	11.20	11.10	12.20	**13.30**	9.60
	S2002	3.90	6.40	**7.80**	5.40	5.30	4.00	4.70	4.60	4.20	4.10
Sal (psu)	D2001	37.70	38.20	38.70	38.70	38.70	38.70	38.50	38.70	**39.00**	38.90
	S2002	38.20	38.70	39.20	39.40	39.60	39.50	39.60	**40.10**	39.90	39.90
pH	D2001	**8.28**	8.26	8.20	8.22	8.22	8.26	8.22	8.24	8.26	8.27
	S2002	8.21	8.25	8.30	8.26	8.31	**8.38**	8.22	8.28	8.29	8.27
PO_4 ($mg.l^{-1}$)	D2001	0.0114	**0.0323**	0.0085	0.0114	0.0038	0.0114	0.0180	0.0066	0.0038	0.0066
	S2002	0.0163	0.0005	0.0186	0.0145	0.0023	0.0104	0.0046	**0.0203**	0.0046	0.0012
NO_2 ($mg.l^{-1}$)	D2001	0.0165	0.0193	**0.2180**	0.0064	0.0349	0.0138	0.0110	0.0174	0.0800	0.0211
	S2002	0.0055	**0.0280**	0.0000	0.0011	0.0000	0.0048	0.0009	0.0110	0.0028	0.0078
NO_3 ($mg.l^{-1}$)	D2001	0.2914	0.1742	0.1481	**0.3992**	0.1779	0.1872	0.1531	0.1612	0.1357	0.2114
	S2002	0.2460	0.2648	0.1362	0.2241	0.2023	0.5422	0.2011	0.5436	0.3140	**0.6341**
Chl*a* (W) ($mg.m^{-3}$)	D2001	5.70	**32.30**	24.70	16.34	15.20	15.20	17.10	22.80	14.44	7.98
	S2002	11.40	1.14	15.20	11.40	3.80	7.60	3.80	15.20	9.50	**24.70**

Table 2. Sedimentary parameters at the sampling sites at Bizerte lagoon during December 2001 (D2001) and September 2002 (S2002). Silt/clay (S/C), mean grain size (Q_{50}), total organic matter (TOM), hydrocarbons (Hs), zinc (Zn), copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), lead (Pb), chlorophyll *a* (Chl*a*). Data of Yoshida et al. (2002) (*). Maximum and minimum were respectively indicated with bold and underlined values.

Tableau 2. Paramètres sédimentaires mesurés dans les sites prospectés dans la lagune de Bizerte en décembre 2001 (D2001) et en septembre 2002 (S2002). Fraction fine (S/C), médiane sédimentaire (Q_{50}), matière organique totale (TOM), hydrocarbures (Hs), zinc (Zn), cuivre (Cu), fer (Fe), manganèse (Mn), nickel (Ni), plomb (Pb), chlorophylle *a* (Chl*a*). Données de Yoshida et al. (2002) (*). Les maxima et les minima sont indiqués respectivement par les valeurs en gras et soulignées.

Sites / Parameters		C	BC	F	T	MB	OBH	OGA	OG	MJ	MA
S/C (%)	D2001	5.77	45.28	83.32	**84.39**	57.09	57.36	13.32	18.54	14.68	15.02
	S2002	15.71	39.95	**86.95**	80.14	85.29	56.10	38.24	19.24	30.09	23.97
Q_{50} (mm)	D2001	0.65	1.00	0.06	0.06	0.15	**1.05**	0.95	1.02	0.15	0.30
	S2002	0.20	0.20	0.90	**1.22**	0.20	0.14	0.09	0.16	0.75	0.20
TOM (%)	D2001	3.15	11.09	**29.19**	28.61	13.21	8.08	5.25	2.78	5.77	7.71
	S2002	3.05	8.75	17.06	17.07	**19.38**	6.33	10.13	2.44	8.23	4.05
Hs ($mg.g^{-1}$)	D2001	280	0.128	0.030	0.045	**0.450**	0.104	0.043	0.018	0.018	0.015
	S2002	0.118	0.122	0.142	0.133	**0.580**	0.125	0.060	0.064	0.078	0.090
Zn (ppm)	D2001	33.02	21.04	192.64	185.08	**520.52**	103.18	30.20	33.55	53.38	49.64
	S2002	144.8*	186.5*	122.3*	191.4*	**1321.2***	621.1*	107.2*	159.4*	45.7*	104.7*
Cu (ppm)	D2001	6.21	3.63	**25.24**	22.65	24.67	11.07	2.64	2.81	8.29	11.98
	S2002	19.11*	18.17*	12.89*	20.49*	**67.02***	25.52*	8.57*	12.12*	8.64*	16.17*
Fe (%)	D2001	2.63	2.71	2.49	2.76	**4.08**	1.29	0.53	0.41	0.64	0.62
	S2002	1.99*	2.05*	1.85*	2.94*	**4.75***	3.62*	1.76*	2.03*	0.66*	1.11*
Mn (ppm)	D2001	43.04	41.50	156.61	216.21	**766.40**	165.05	131.53	125.92	101.36	114.36
	S2002	154*	203*	163*	208*	**685***	618*	282*	276*	129*	127*
Ni (ppm)	D2001	9.99	11.34	33.80	**37.63**	28.92	19.73	9.92	10.28	17.81	15.49
	S2002	17.8*	16.7*	15.5*	**26.4***	25.7*	15.6*	15*	16.1*	7.2*	11.5*
Pb (ppm)	D2001	26.99	19.90	80.69	79.21	**106.73**	26.19	14.13	17.88	32.92	25.85
	S2002	41.01*	51.74*	39.82*	66.52*	**369.77***	159.94*	25.13*	44.86*	18.56*	74.36*
Chl*a* ($\mu g.g^{-1}$)	D2001	3.603	2.006	5.401	6.219	3.902	3.124	5.243	6.386	2.43	**8.581**
	S2002	2.701	2.988	2.644	2.816	1.783	**7.355**	5.667	**8.013**	5.043	5.267

iron and maximum concentrations were always recorded in sediments from station MB located off the metallurgic factory "El Fouledh" (Table 2). Maximum hydrocarbons loads were measured in December 2001 at stations MB and C. However, in September 2002, the highest values were observed in clayey sediments sampled from sites MB, F and T. The chlorophyll *a* concentrations were clearly higher in stations OG and OBH in December 2001. During that season, minimum values were recorded at stations BC and MJ. During the dry season, stations OGA and OG showed the maximal concentrations of chlorophyll *a* while the station MB presented the lowest value. The median grain size (Q_{50}) increased from December 2001 to September 2002 in the case of stations F, T, MB and MJ, conversely, a temporal decline characterized the other stations (C, BC, OBH, OGA, OG and MA). In December 2001, sediments from the Western stations (F and T) showed the minimal Q_{50} value (0.06) whereas the South-Eastern stations (OBH, OGA and OG) were characterized by the maximal values (0.95-1.05 mm). An opposite situation characterized these stations during the dry season.

Meiobenthos composition

Four meiobenthic groups were present (Table 3). Nematodes were always the most dominant group and crustaceans, polychaetes and oligochaetes were subdominant. The MDS ordinations on the abundances of meiobenthic groups (Fig. 2) indicated a good fit to the clustering of the studied communities with low stress values (0.07 in December 2001 and 0.06 in September 2002). Three significantly different ($p < 0.05$) meiobenthic associations were individualized by ANOSIM in December 2001 (C-BC, OBH-MJ-F-OG-MA-OGA and MB-T). SIMPER analysis illustrated important dissimilarities between

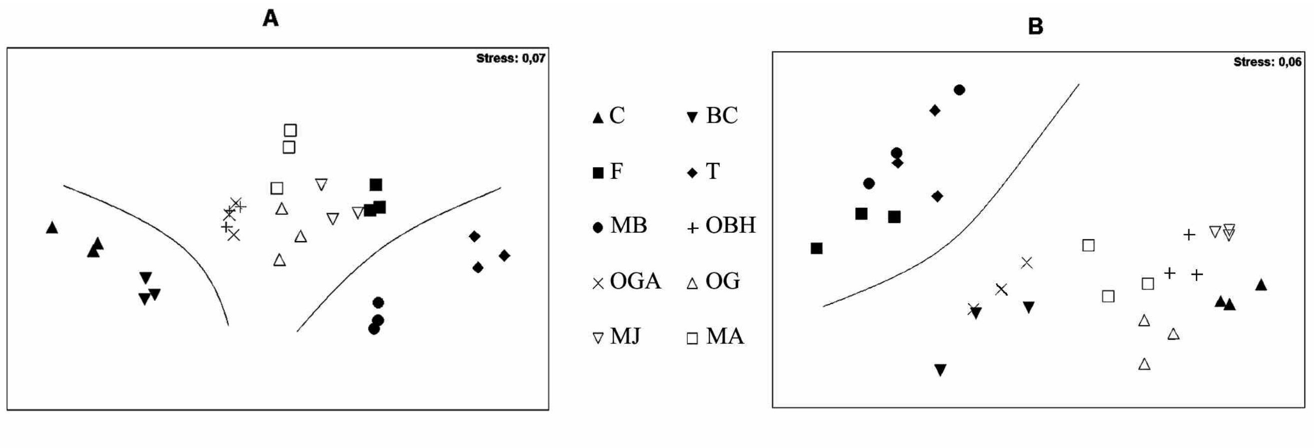

Figure 2. Non-metric MDS ordination of square-root transformed abundances of the four meiobenthic groups (nematodes, crustaceans, polychaetes and oligochaetes) collected during December 2001 (A) and September 2002 (B) from Bizerte lagoon. Canal (C), Baie des carrières (BC), Faroua (F), Oued Tinja (T), Menzel Bourguiba (MB), Oued Ben Hassine (OBH), Oued Garek (OGA), Oued Gueniche (OG), Menzel Jemil (MJ), Menzel Abderrahmen (MA).

Figure 2. Ordination des quatre groupes méiobenthiques (nématodes, crustacés, polychètes et oligochètes) collectés dans la lagune de Bizerte en décembre 2001 (A) et en septembre 2002 (B) selon la méthode MDS non métrique basée sur la transformation racine carrée des abondances. Canal (C), Baie des carrières (BC), Faroua (F), Oued Tinja (T), Menzel Bourguiba (MB), Oued Ben Hassine (OBH), Oued Garek (OGA), Oued Gueniche (OG), Menzel Jemil (MJ), Menzel Abderrahmen (MA).

Table 3. Mean abundance (ind.10 cm^{-2}) of meiobenthic groups collected at the sampling sites in Bizerte lagoon during December 2001 (D2001) and September 2002 (S2002). Crustaceans were composed by copepods, amphipods, isopods and cumaceans. Maximum and minimum were respectively indicated with bold and underlined values.

Tableau 3. Abondance moyenne (ind.10 cm^{-2}) des groupes méiobenthiques collectés au niveau des sites prospectés dans la lagune de Bizerte en décembre 2001 (D2001) et en septembre 2002 (S2002). Les crustacés sont représentés par les copépodes, les amphipodes, les isopodes et les cumacés. Les maxima et les minima sont indiqués respectivement par les valeurs en gras et soulignées.

		Nematodes	Crustaceans	Polychaetes	Oligochaetes	Total meiofauna
C	D2001	**789 ± 133**	**21 ± 12**	**55 ± 27**	23 ± 12	**926 ± 201**
	S2002	**776 ± 515**	**68 ± 70**	22 ± 18	17 ± 15	**874 ± 616**
BC	D2001	726 ± 302	9 ± 10	18 ± 4	12 ± 3	790 ± 333
	S2002	232 ± 114	1 ± 2	5 ± 4	<u>4 ± 4</u>	255 ± 128
F	D2001	292 ± 58	4 ± 3	10 ± 5	9 ± 5	318 ± 75
	S2002	81 ± 84	<u>2 ± 1</u>	4 ± 4	4 ± 5	119 ± 93
T	D2001	198 ± 25	<u>2 ± 1</u>	<u>3 ± 1</u>	<u>9 ± 4</u>	219 ± 34
	S2002	77 ± 56	12 ±10	<u>3 ± 1</u>	10 ± 5	<u>108 ± 93</u>
MB	D2001	<u>192 ± 46</u>	15 ± 13	19 ± 2	12 ± 3	235 ± 66
	S2002	<u>58 ± 33</u>	6 ± 4	8 ± 3	6 ± 2	<u>81 ± 35</u>
OBH	D2001	423 ± 106	12 ± 5	24 ± 11	23 ± 13	488 ± 136
	S2002	449 ± 366	45 ± 5	33 ± 9	28 ± 11	571 ± 313
OGA	D2001	443 ± 171	8.99 ± 6.03	23 ± 2	19 ± 1	502 ± 185
	S2002	223 ± 66	7 ± 8	5 ± 3	5 ± 1	253 ± 86
OG	D2001	373 ± 24	14 ± 13	12 ± 5	15 ± 5	421 ± 56
	S2002	542 ± 255	6 ± 6	**37 ± 23**	14 ± 5	626 ± 77
MJ	D2001	291 ± 64	6 ± 1	23 ± 153	10 ± 8	356 ± 101
	S2002	507 ± 73	51 ± 19	12 ± 31	**92 ± 17**	895 ± 108
MA	D2001	313 ± 48	8 ± 8	30 ± 42	**32 ± 11**	393 ± 92
	S2002	389 ± 121	24 ± 5	16 ± 33	5 ± 4	508 ± 121

Table 4. Morphometric and energetic data of nematode assemblages inhabiting the prospected sites into Bizerte lagoon in December 2001 (D2001) and September 2002 (S2002). Mean individual length MIL (µm), mean individual width MIWd (µm), mean individual weight MIW (µgC.ind^{-1}), mean individual respiration MIR (nl O_2.h^{-1}.ind^{-1}), mean individual production MIP (10^{-3} J.d^{-1}.ind^{-1}), metabolic ratio MR (nl O_2.h^{-1}.µgC^{-1}), assemblage respiration R (ml O_2.d^{-1}.m^{-2}), assemblage biomass B (mgC.m^{-2}), assemblage production P (J .d^{-1}.m^{-2}), assemblage productivity P/B (d^{-1}). Maximum and minimum were respectively indicated with bold and underlined values.

Tableau 4. Données morphométriques et énergetiques des assemblages nématologiques peuplant les sites de prospection dans la lagune de Bizerte en décembre 2001 (D2001) et en septembre 2002 (S2002). Longueur individuelle moyenne MIL (µm), diamètre individuel moyen MIWd (µm), poids individuel moyen MIW (µgC.ind^{-1}), respiration individuelle moyenne MIR (nl O_2 h^{-1}. ind^{-1}), production individuelle moyenne MIP (10^{-3} J.Jour^{-1}.ind^{-1}), rapport métabolique MR (nl O_2.h^{-1}.µgC^{-1}), respiration R (ml O_2.Jour^{-1}.m^{-2}), biomasse B (mgC.m^{-2}), production P (J.Jour^{-1}.m^{-2}) et productivité P/B de l'assemblage (Jour^{-1}). Les maxima et les minima sont indiqués respectivement par les valeurs gras et soulignées.

Sites Parameters		C	BC	F	T	MB
MIL	D2001	**2189.92 ± 56.73**	1569.95 ± 173.14	1309.79 ± 177.08	1543.07 ± 133.44	1483.46 ± 94.81
	S2002	1070.07 ± 298.61	1397.33 ± 612.96	2075.52 ± 573.33	**2392.21 ± 844.50**	1647.03 ± 564.02
MIWd	D2001	**65.76 ± 2.89**	47.81 ± 3.14	44.03 ± 6.09	61.37 ± 1.11	54.60 ± 5.41
	S2002	45.43 ± 11.86	45.00 ± 17.77	**62.39 ± 16.96**	59.13 ± 24.09	53.51 ± 19.68
MIW	D2001	**1.05 ± 0.08**	0.38 ± 0.11	0.33 ± 0.10	0.62 ± 0.04	0.50 ± 0.11
	S2002	0.21 ± 0.16	0.34 ± 0.43	0.79 ± 0.57	0.86 ± 0.85	0.51 ± 0.67
MIR	D2001	1.57 ± 2.24	**1.66 ± 1.98**	1.22 ± 1.43	1.17 ± 1.69	1.15 ± 1.42
	S2002	2.32 ± 0.24	**2.62 ± 0.44**	2.19 ± 0.28	2.14 ± 0.32	2.30 ± 0.29
MIP	D2001	0.30 ± 0.44	0.35 ± 0.42	0.36 ± 0.43	0.33 ± 0.48	0.34 ± 0.42
	S2002	0.40 ± 0.04	0.40 ± 0.06	0.33 ± 0.04	0.34 ± 0.05	0.36 ± 0.04
MR	D2001	1.49 ± 2.51	4.29 ± 1.74	3.61 ± 1.31	1.89 ± 3.41	2.29 ± 1.19
	S2002	19.44 ± 16.99	**32.36 ± 51.60**	6.62 ± 9.39	7.90 ± 14.36	10.94 ± 10.52
R	D2001	**29.72 ± 4.99**	28.96 ± 12.03	8.54 ± 1.69	5.58 ± 0.70	5.31 ± 1.26
	S2002	**43.18 ± 28.65**	14.54 ± 7.19	4.23 ± 4.40	3.97 ± 2.89	3.18 ± 1.80
B	D2001	**829.29 ± 139.40**	280.87 ± 116.73	98.37 ± 19.56	122.96 ± 15.49	96.34 ± 22.85
	S2002	162.88 ± 108.08	78.65 ± 38.92	63.72 ± 66.13	66.50 ± 48.53	29.40 ± 16.66
P	D2001	243.37 ± 40.91	**259.41 ± 107.8**1	106.33 ± 21.15	66.13 ± 8.33	66.16 ± 15.69
	S2002	**310.26 ± 205.88**	92.53 ± 45.79	26.61 ± 27.62	26.29 ± 19.18	20.75 ± 11.76
P/B	D2001	0.006	0.020	0.023	0.011	0.015
	S2002	0.041	0.025	0.009	0.008	0.015

		OBH	OGA	OG	MJ	MA
MIL	D2001	1564.88 ± 147.11	1397.91 ± 93.01	1438.11 ± 32.55	1342.48 ± 188.00	1455.61 ± 165.50
	S2002	1893.57 ± 1042.56	1417.08 ± 665.01	1901.68 ± 793.79	995.10 ± 326.84	2304.26 ± 1100.47
MIWd	D2001	59.44 ± 5.83	54.29 ± 4.36	49.45 ± 1.05	39.37 ± 0.71	44.82 ± 0.96
	S2002	58.89 ± 29.62	46.86 ± 19.69	45.38 ± 16.94	36.39 ± 12.08	53.78 ± 22.27
MIW	D2001	0.52 ± 0.12	0.44 ± 0.08	0.39 ± 0.03	0.21 ± 0.01	0.36 ± 0.03
	S2002	**0.96 ± 1.21**	0.37 ± 0.44	0.44 ± 0.60	0.14 ± 0.24	0.74 ± 0.92
MIR	D2001	1.17 ± 1.44	1.28 ± 1.61	1.25 ± 1.78	1.31 ± 1.86	1.26 ± 1.75
	S2002	2.43 ± 0.53	2.07 ± 0.37	1.81 ± 0.27	2.22 ± 0.22	1.67 ± 0.25
MIP	D2001	0.34 ± 0.42	0.34 ± 0.44	0.35 ± 0.50	**0.38 ± 0.55**	0.31 ± 0.49
	S2002	0.37 ± 0.08	0.40 ± 0.07	0.38 ± 0.05	**0.44 ± 0.04**	0.35 ± 0.05
MR	D2001	2.25 ± 1.16	2.86 ± 1.81	3.15 ± 5.14	**6.03 ± 9.40**	3.50 ± 4.41
	S2002	20.79 ± 28.89	26.92 ± 43.70	13.13 ± 15.34	31.54 ± 29.54	7.30 ± 9.41
R	D2001	11.91 ± 2.99	13.62 ± 5.26	11.20 ± 0.73	9.19 ± 2.01	9.23 ± 1.42
	S2002	26.18 ± 21.36	11.09 ± 3.25	23.55 ± 11.09	26.99 ± 3.91	15.57 ± 4.85
B	D2001	220.29 ± 55.35	197.90 ± 76.47	147.87 ± 9.63	63.50 ± 13.94	141.27 ± 21.84
	S2002	**431.04 ± 351.75**	82.63 ± 24.24	238.62 ± 112.33	70.93 ± 10.27	287.60 ± 89.68
P	D2001	144.70 ± 36.36	155.12 ± 59.94	132.66 ± 8.64	113.08 ± 24.82	109.34 ± 16.90
	S2002	166.13 ± 135.57	89.33 ± 26.20	206.08 ± 97.01	222.93 ± 32.29	136.03 ± 42.42
P/B	D2001	0.014	0.017	0.019	**0.038**	0.016
	S2002	0.008	0.023	0.018	**0.068**	0.010

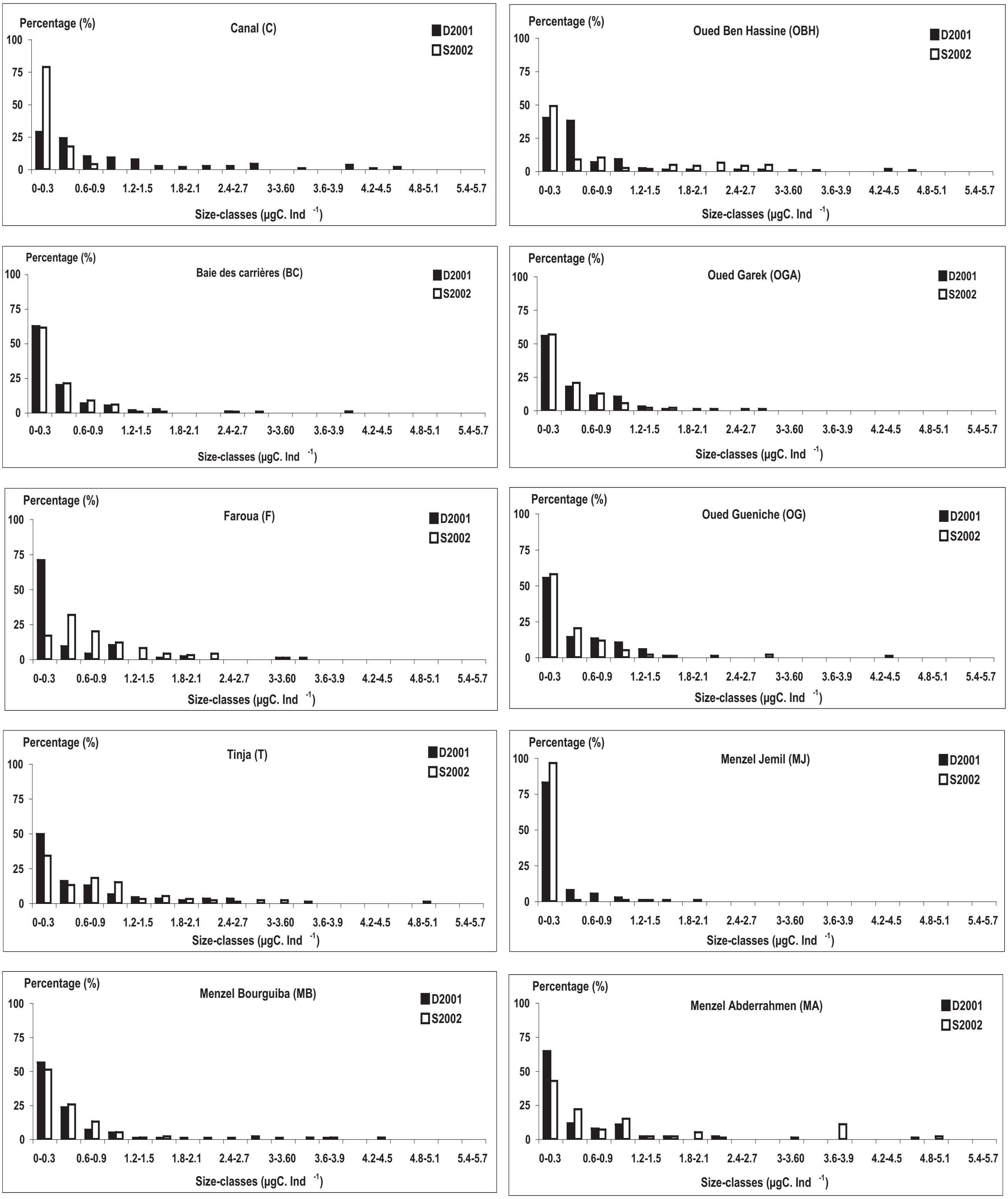

Figure 3. Size spectra of the ten nematode assemblages collected from coasts of Bizerte lagoon during December 2001 (D2001) and September 2002 (S2002).

Figure 3. Spectres de taille des dix assemblages de nématodes récoltés le long des côtes de la lagune de Bizerte en décembre 2001 (D2001) et en septembre 2002 (S2002).

the first association and the others (35.51% with the second and 57.07% with the third association in which nematode contributions were 91.38% and 92.91%, respectively). Equally, the second and the third association differed by 29.23%, contributions of nematodes and polychaetes being 85.25 and 6.56%, respectively. During the dry season, only two meiobenthic associations were detected *i.e.* C-OBH-MJ-OG-MA-BC-OGA and F-MB-T. SIMPER analysis indicated a strong dissimilarity equal to 67.32%. Mainly nematodes (86.69%) and crustaceans (5.53%) contributed to this dissimilarity.

Morphometry and energetic variables of nematodes

Measurements (length and width) and calculated energetic data (weight, respiration, productivity and metabolic ratio) of nematodes collected in December 2001 are presented in Table 4. The lowest individual width and weight and the highest individual production and metabolic ratio were obtained for nematodes collected at the station MJ. However, the highest individual weight and morphometric variables, and the lowest individual production and metabolic ratio characterized stations C and T. Size spectra at the ten prospected stations, expressed as a percentage of each size-class, are shown in Figure 3. The mode of the abundance spectrum was always 0-0.3 μgC.ind^{-1} in all stations. This size-class accounted for 82.75% of the nematodes from station MJ. The size classes larger than 0.3 μg.ind^{-1} were responsible for 71.31 and 50.52% of the total relative abundance in stations C and T, respectively. The undisturbed station C was characterized by the highest biomass, respiration and production in contrast to stations MB, T and MJ which displayed the lowest values of these parameters. Finally, productivity P/B varied between 0.038 (MJ) and 0.006 d^{-1} (C).

In September 2002, body length and maximum width (Table 4) were higher at stations MA, T and F and lower at station MJ. The larger nematodes were collected from station OBH (0.96 ± 1.21 μgC.ind^{-1}). Body weight showed the same spatial pattern than body proportions *i.e.* total length and maximum width. Two modal peaks of relative abundance in different size-classes were distinguished; the first in the size class 0.3-0.6 μgC.ind^{-1} at station F and the second in the size class 0-0.3 μgC.ind^{-1} at the other stations. Stations OBH, T, F and MA displayed the largest size range and station MJ the lowest size range. Indeed, size-class 1.2-3.6 μgC.ind^{-1} was rare in most stations but accounted for 26.77, 19.8, 19 and 10.89% of the total relative abundance in stations OBH, F, T and MA, respectively. The station MJ had a size spectrum totally different from all other sites with a very high proportion (96.39%) of small individuals belonging to the size-class 0-0.3 μg.ind^{-1}. Peaks of productivity and metabolic ratio were recorded at stations MJ, C and BC as a consequence to their higher mean individual productions (0.4 to 0.44.10^{-3}J.d^{-1}.ind^{-1}) and their lower mean individual weights (0.14 to 0.34 μgC.ind^{-1}).

The size-frequency distributions at stations C, MJ, OBH, F and MA explained clearly the temporal weight variability. For the two first assemblages, individual weight decreased between December 2001 and September 2002 due to an increase of small nematodes with a body weight lower than 0.3 μgC.ind^{-1}. A temporal individual weight increase was recorded in the stations OBH, F and MA. In the OBH assemblage, size spectra showed a greater contribution of larger species (size-class = 1.2-3.6 μgC.ind^{-1}) during the dry season (26.77%) than during the rainy season (6.66%). At station F and MA, the decline of proportion of small individuals in size-class 0-0.3 μgC.ind^{-1} in September 2002 was associated to an increase individual weight.

The temporal increase of individual respiration of nematodes (all assemblages), their individual production and their metabolic ratio was due both to the temporal increase of the individual weight and the temporal increase of water temperature.

In both seasons, a temporal increase of the total nematode biomass, respiration and production was noticeable at station OBH, OG, MJ and MA, whereas stations BC, F, T, MB and OGA were characterized by a decrease of these variables. C assemblage was the only exception with biomass higher in December 2001 than in September 2002, nevertheless, assemblage respiration and production remained lower. At stations C, BC, OGA and MJ, productivity was lower in December 2001 than in September 2002, and higher at stations F, T, OBH, OG and MA. For the MB assemblage, no temporal variation of productivity was recorded (P/B = 0.015 d^{-1}).

Composition and diversity of nematode assemblages

The relative abundances of the 80 species identified during both season are shown in Table 5. Three orders (Monhysterida, Chromadorida and Enoplida), 68 and 61 nematode species belonging to 16 and 20 families were found during December 2001 and September 2002 respectively. 48 species were present in both seasons.

In December 2001, Xyalidae and Comesomatidae were the most important families (Table 5). In September 2002, Comesomatidae was the most common family in Bizerte lagoon and was represented in all lagoonal sites. Cyatholaimidae was the most dominant family inhabiting the Eastern coastal sediments of Bizerte lagoon (stations OG and OGA), whereas only Anticomidae and Oncholaimidae, very abundant in the assemblage MB, were recorded in sediments from the South-Western side of the study area. In December 2001, *Terschellingia longicaudata* had the highest general dominance, *Dorylaimopsis mediterraneus* had the second and *Paracomesoma dubium* had the third. During the dry season, *Terschellingia longicaudata* was the most dominant and followed by *Paracomesoma dubium* and *Neothonchus chamberlaini*.

In both seasons, *Terschellingia longicaudata* and *Paracomesoma dubium* were consistently dominant maintaining stable assemblages (MJ and MA-T respectively) throughout the period with maximum proportion during the dry season and minimum proportion during the rainy season. As well, *Terschellingia longicaudata* increased at stations F and BC during the rainy season. However, this species is replaced by *Paracomesoma dubium* during the dry season. At stations OG and OGA, *Dorylaimopsis mediterraneus* increased in the rainy season but declined in September 2002 to the profit of *Paracomesoma dubium* and *Marylynnia sp*. At station OBH, *Halichoanolaimus dolichurus* (11.48% in December 2001), dramatically decreased in September 2002 (0.86%) when *Comesoma sp.* became dominant (23.27%). *Sabatieria lepida* (23.95% in December 2001) desappeared during the dry season and was replaced by *Paracomesoma dubium* (39.24%). In December 2001, the most abundant species at station C were *Paramonhystera pilosa* and *Dorylaimopsis mediterraneus* but in September 2002 *Terschellingia longicaudata* becomes more dominant.

In December 2001, the clustering procedure (Fig. 4) distinguished, at the lowest level of similarity (47.14%), four groups of stations (F-MJ-BC, C-OG-T-OGA-MA, MB, OBH). Linhomoeidae and mainly *Terschellingia longicaudata* characterized the nematode assemblages of sites F, MJ and BC whereas Comesomatidae (*Paracomesoma dubium* and *Dorylaimopsis mediterraneus*) and Xyalidae (*Paramonhystera pilosa*) were the most frequent and abundant families at sites C, T, OGA, OG and MA. The MB assemblage was mainly characterized by *Sabatieria lepida* whereas *Halichoanolaimus dolichurus* was the most abundant species in the station OBH. The Bray-Curtis cluster analysis produced, in September 2002, three major hierarchical agglomerative clusters (Fig. 4). The first one characterizes OGA station (similarity level = 32%). The other assemblages included nematodes from the following sites, F-T-MA-OG-MB and C-MJ-BC-OBH (similarity level = 36.06%). In fact, this pattern resulted essentially from the spatial distribution of two species, *Paracomesoma dubium* and *Terschellingia longicaudata*.

The diversity and equitability indices for the ten assemblages are reported in Table 5. The assemblages OBH and BC showed respectively the highest and the lowest values of Shannon-Wiener index and evenness in December 2001. Medium diversity was found in other stations. In September 2002, highest Shannon-Wiener index and evenness was recorded at the site OGA and the minimum was observed at the site F. As a result, maximum diversity and evennes were consistently recorded at the South-Eastern stations of Bizerte lagoon (OBH or OGA) and minimum values at stations located in the transition zone between the Mediterranean Sea and the Bizerte lagoon (BC) or from Ichkeul lake to Bizerte lagoon (F).

Pearson correlations

Depth and water pH were not used in the statistical analyses because of their spatio-temporal stability. In December 2001, the abundance of nematodes was positively correlated to mean grain size ($r = -0.74$, $p = 0.014$) and negatively correlated to all measured sediment metals except Pb ($-0.85 \le r \le -0.71$, $0.002 \le p \le 0.021$). Abundance was correlated to the sediment silt/clay content ($r = -0.89$, $p < 0.001$), total organic matter ($r = -0.92$, $p < 0.001$) and to sedimentary chlorophyll *a* ($r = -0.65$, $p = 0.041$) only in September 2002.

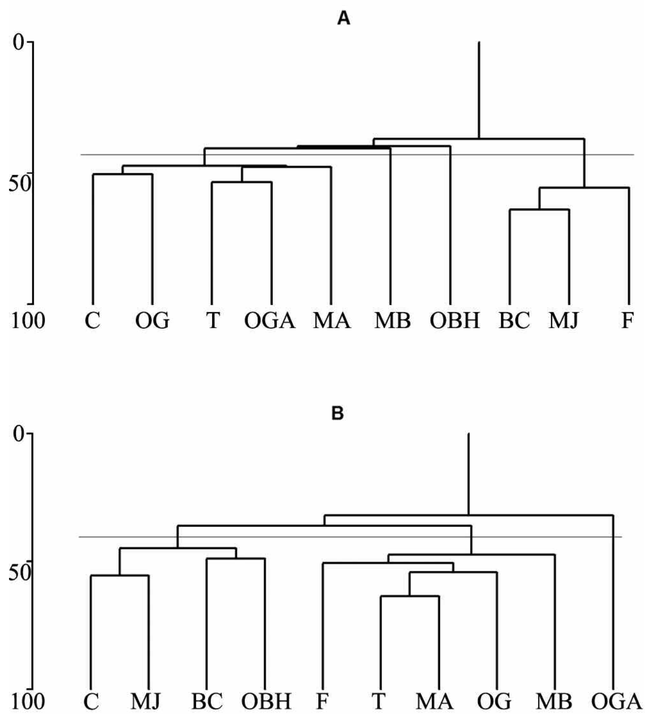

Figure 4. Dendrograms for hierarchical clustering of the studied nematode assemblages from coasts of Bizerte lagoon during December 2001 (A) and September 2002 (B), using group-average linking of Bray-Curtis similarities. Canal (C), Baie des carrières (BC), Faroua (F), Oued Tinja (T), Menzel Bourguiba (MB), Oued Ben Hassine (OBH), Oued Garek (OGA), Oued Gueniche (OG), Menzel Jemil (MJ), Menzel Abderrahmen (MA).

Figure 4. Dendrogrammes de la classification hiérarchique des assemblages nématologiques récoltés dans la lagune de Bizerte en décembre 2001 (A) et en septembre 2002 (B) en utilisant la similarité de Bray-Curtis. Canal (C), Baie des carrières (BC), Faroua (F), Oued Tinja (T), Menzel Bourguiba (MB), Oued Ben Hassine (OBH), Oued Garek (OGA), Oued Gueniche (OG), Menzel Jemil (MJ), Menzel Abderrahmen (MA).

Table 5. Check list of species, diversity and equitability within each studied nematode assemblage in sediments from coastal zone of Bizerte lagoon during December 2001 (D2001) and September 2002 (S2002). Orders and families were indicated respectively with bold capital and small underlined letters. Dominance (D); Mean General Dominance (MGD); species absent (-); Shannon-Wiener index (H'), Pielou's evenness (J'). Bold values indicate the dominance of the most abundant species.

Tableau 5. Liste des espèces, diversité et équitabilité de chacune des communautés nématologiques étudiées dans la zone côtière de la lagune de Bizerte en décembre 2001 (D2001) et en septembre 2002 (S2002). Les ordres et les familles sont indiqués respectivement par les lettres en gras et minuscules soulignées. Dominance (D), Dominance Générale Moyenne (MGD) ; espèce absente (-), indice de Shannon-Wiener (H'), équitabilité de Pielou (J'). Les valeurs en gras représentent les dominances des espèces les plus abondantes.

Sites		C	BC	F	T	MB	OBH	OGA	OG	MJ	MA	
Orders, families and species		D (%)	D (%)	D (%)	D (%)	D (%)	D (%)	D (%)	D (%)	D (%)	D (%)	MGD(%)
MONHYSTERIDA	**D2001**	**29.71**	**67.59**	**44.14**	**44.00**	**33.91**	**31.52**	**45.88**	**35.03**	**58.29**	**25.92**	**42.67**
	S2002	**57.70**	**37.86**	**5.94**	**6.00**	**3.94**	**31.00**	**24.72**	**16.01**	**73.26**	**20.79**	**18.36**
Linhomoeidae	D2001	5.2	46.32	41.65	5.00	4.58	14.88	0.91	4.05	41.74	6.72	18.34
	S2002	30.80	15.31	5.94	1.00	-	19.82	10.59	8.48	67.03	9.90	24.50
Desmolaimus sp.	D2001	-	-	-	-	-	-	-	-	0.97	-	0.14
	S2002	-	-	0.99	-	-	0.86	1.76	-	-	0.99	0.97
Eleutherolaimus stenosoma	D2001	-	0.92	-	1.00	-	-	-	-	-	2.88	0.40
Filipjev, 1922	S2002	-	0.72	-	-	-	0.86	-	-	-	-	0.16
Linhomoeus undulatus	D2001	-	-	-	-	1.83	7.01	-	-	-	-	0.82
Wieser, 1959	S2002	-	-	-	-	-	-	4.42	2.83	-	-	0.75
Megadesmolaimus falcatus	D2001	-	1.85	0.83	-	-	3.5	-	-	-	-	0.75
Gelach, 1963	S2002	-	-	-	-	-	-	-	2.83	-	-	0.31
Metalinhomoeus numidicus	D2001	-	-	1.66	-	-	-	-	0.81	-	-	0.19
Aïssa & Vitiello, 1977	S2002	-	-	-	1.00	-	-	2.65	0.94	-	2.97	0.69
Paralinhomoeus aff. tenuicaudatus	D2001	-	-	-	-	-	-	-	-	-	-	-
Bütschli, 1874	S2002	-	-	-	-	-	-	1.76	-	-	4.95	0.69
Terschellingia communis	D2001	-	-	-	-	-	-	-	-	0.97	-	0.06
De Man, 1888	S2002	-	-	-	-	-	-	-	-	0.89	-	0.13
Terschellingia longicaudata	D2001	4.34	**43.55**	**39.16**	4.00	2.75	3.50	0.91	0.81	**39.8**	1.92	15.38
De Man, 1907	S2002	**30.80**	14.59	4.95	-	-	17.24	-	1.88	**66.14**	0.99	21.09
Terschellingia sp.	D2001	0.86	-	-	-	-	0.87	-	2.43	-	1.92	0.63
	S2002	-	-	-	-	-	0.86	-	-	-	-	0.10
Xyalidae	D2001	24.51	16.65	2.49	37.00	25.67	16.64	44.97	30.98	10.67	17.28	22.63
	S2002	21.13	15.27	-	1.00	2.94	6.02	14.13	4.71	6.23	8.91	10.56
Ammotheristus sp.	D2001	-	-	-	-	4.58	-	-	-	-	-	0.21
	S2002	-	-	-	-	-	-	-	-	-	-	-
Cobbia sp.	D2001	-	-	-	-	-	1.75	-	1.62	-	-	0.33
	S2002	-	-	-	-	-	-	-	-	-	-	-
Daptonema fallax	D2001	4.34	-	-	-	16.51	-	7.33	13	6.79	-	4.12
Lorenzen, 1971	S2002	-	1.45	-	-	-	-	-	-	-	-	0.10
Daptonema hirsutum	D2001	-	-	-	-	-	0.87	-	-	-	-	0.09
Vitiello, 1967	S2002	-	-	-	-	-	-	-	-	-	-	-
Daptonema normandicum	D2001	-	5.55	0.83	21.00	-	5.26	**20.23**	4.98	-	4.80	5.68
De Man, 1890	S2002	2.88	0.72	-	1.00	1.96	3.44	-	2.83	2.67	-	2.10
Daptonema proprium	D2001	-	3.70	0.83	1.00	-	-	-	-	-	4.80	1.14
Lorenzen, 1971	S2002	3.84	0.72	-	-	-	-	-	-	2.67	-	1.34
Daptonema trabeculosum	D2001	-	-	-	9.00	-	-	5.50	-	-	1.92	1.19
Schneider, 1906	S2002	2.88	-	-	-	-	-	-	0.94	-	-	0.80
Paramonohystera pilosa	D2001	**20.17**	7.40	-	6.00	4.58	7.89	4.58	9.76	0.97	2.88	8.30
Boucher, 1972	S2002	10.57	4.37	-	-	-	2.58	7.07	-	-	1.98	3.81
Steineria pilosa	D2001	-	-	-	-	-	-	1.83	0.81	-	-	0.27
Cobb, 1914	S2002	-	-	-	-	-	-	1.76	0.94	-	-	0.27
Stylotheristus mutilus	D2001	-	-	0.83	-	-	-	2.75	-	2.91	-	0.57
Lorenzen, 1973	S2002	0.96	5.83	-	-	0.98	-	-	-	0.89	1.98	1.01
Theristus pertenuis	D2001	-	-	-	-	-	0.87	-	-	-	-	0.09
Stekhoven, 1935	S2002	-	-	-	-	-	-	-	-	-	-	-
Theristus sp.	D2001	-	-	-	-	-	-	2.75	0.81	-	2.88	0.59
	S2002	-	2.18	-	-	-	-	5.30	-	-	4.95	1.08

Sphaerolaimidae	D2001	-	-	-	-	1.83	-	-	-	-	-	0.08
	S2002	-	-	-	-	-	-	-	-	-	-	-
Sphaerolaimus macrocirculus	D2001	-	-	-	-	1.83	-	-	-	-	-	0.08
Filipjev, 1918	S2002	-	-	-	-	-	-	-	-	-	-	-
Axonolaimidae	D2001	-	4.62	-	2.00	1.83	-	-	-	5.88	1.92	1.58
	S2002	5.76	7.28	-	1.00	-	5.16	-	0.94	-	0.99	2.83
Axonolaimus sp.	D2001	-	1.85	-	-	1.83	-	-	-	-	-	0.41
	S2002	-	4.37	-	-	-	1.72	-	-	-	-	0.53
Odontophora villoti	D2001	-	-	-	-	-	-	-	-	-	-	-
Luc & De Coninck, 1959	S2002	-	-	-	-	-	-	-	0.94	-	0.99	0.26
Parodontophora quadristicha	D2001	-	2.77	-	2.00	-	-	-	-	5.88	1.92	1.16
Stekhoven, 1950	S2002	5.76	2.91	-	1.00	-	3.44	-	-	-	-	2.02
Siphonolaimidae	D2001	-	-	-	-	-	-	-	-	-	-	-
	S2002	-	-	-	3.00	-	-	-	1.88	-	0.99	0.49
Siphonolaimus sp.	D2001	-	-	-	-	-	-	-	-	-	-	-
	S2002	-	-	-	3.00	-	-	-	1.88	-	0.99	0.49
CHROMADORIDA	**D2001**	**51.23**	**19.43**	**55.86**	**54.00**	**59.68**	**54.47**	**45.88**	**54.41**	**33.95**	**61.60**	**45.99**
	S2002	**38.46**	**60.69**	**92.08**	**67.00**	**57.86**	**65.56**	**71.76**	**75.53**	**24.07**	**55.51**	**54.01**
Comesomatidae	D2001	38.23	14.83	16.65	47.00	41.36	20.22	27.59	28.44	22.31	34.67	27.66
	S2002	12.49	42.47	88.12	48.00	42.18	51.79	22.08	38.89	8.02	40.66	30.57
Comesoma sp.	D2001	10.43	-	-	4.00	0.91	0.87	-	-	-	-	2.36
	S2002	-	1.45	0.99	-	-	**23.27**	-	-	-	-	3.25
Dorylaimopsis mediterraneus	D2001	13.91	1.85	9.16	5.00	8.25	5.26	14.72	**17.07**	10.67	14.45	9.97
De Zio, 1968	S2002	6.73	-	2.97	1.00	0.98	-	6.19	3.77	5.35	3.96	3.98
Metacomesoma sp.	D2001	-	-	-	-	-	-	-	-	-	-	-
	S2002	-	-	-	-	1.96	-	-	-	-	-	0.03
Paracomesoma dubium	D2001	6.95	10.21	6.66	**31.00**	8.25	1.75	11.96	4.06	4.85	**17.34**	9.14
Filipjev, 1918	S2002	0.96	**19.88**	**73.27**	**44.00**	**39.24**	18.19	7.07	**33.24**	1.78	**35.71**	17.84
Paracomesoma sp.	D2001	-	-	-	-	-	-	-	-	-	-	-
	S2002	-	-	-	1.00	-	-	-	-	-	-	0.02
Sabatieria granifer	D2001	0.86	0.92	-	-	-	-	-	-	3.88	-	0.61
Wieser, 1954	S2002	-	9.48	-	-	-	5.17	1.76	-	-	-	1.47
Sabatieria granulosa	D2001	-	-	-	-	-	-	-	7.31	0.97	-	0.74
Vitiello & Boucher, 1971	S2002	-	-	-	-	-	-	-	-	-	-	-
Sabatieria lepida	D2001	-	1.85	-	2.00	**23.95**	0.87	-	-	1.94	2.88	2.02
Vitiello, 1976	S2002	-	6.56	1.98	-	-	-	-	1.88	0.89	0.99	1.05
Sabatieria pulchra	D2001	-	-	0.83	-	-	-	-	-	-	-	0.05
Schneider, 1906	S2002	3.84	5.10	8.91	2.00	-	0.86	-	-	-	-	1.62
Sabatieria punctata	D2001	-	-	-	5.00	-	0.87	-	-	-	-	0.33
Kreis, 1924	S2002	-	-	-	-	-	3.44	1.76	-	-	-	0.58
Sabatieria splendens	D2001	6.08	-	-	-	-	-	-	-	-	-	1.18
Hopper, 1967	S2002	-	-	-	-	-	-	-	-	-	-	-
Setosabatieria hilarula	D2001	-	-	-	-	-	10.6	0.91	-	-	-	1.20
De Man, 1922	S2002	-	-	-	-	-	0.86	5.30	-	-	-	0.47
Vasostoma sp.	D2001	-	-	-	-	-	-	-	-	-	-	-
	S2002	0.96	-	-	-	-	-	-	-	-	-	0.22
Chromadoridae	D2001	6.08	1.84	10.83	4.00	11	3.5	3.65	5.68	5.82	18.29	6.14
	S2002	6.72	-	2.97	10.00	2.94	7.75	1.76	16.86	7.13	7.92	7.83
Actinonema longicaudatum	D2001	6.08	-	-	-	-	-	-	4.06	-	-	1.56
Steiner, 1918	S2002	-	-	-	-	-	-	-	-	-	-	-
Chromadorina germanica	D2001	-	-	2.50	-	-	-	-	-	-	-	0.18
Bütschli, 1874	S2002	-	-	-	-	-	-	-	-	-	-	-
Metachromadora macroutera	D2001	-	-	5.83	-	-	-	-	-	-	-	0.42
Filipjev, 1918	S2002	-	-	0.99	5.00	2.94	0.86	-	-	-	0.99	0.42
Neochromadora poecilosomoides	D2001	-	-	2.5	-	1.83	-	0.91	-	0.97	-	0.43
Filipjev, 1918	S2002	-	-	0.99	-	-	-	-	-	0.89	-	0.15
Prochromadorella longicaudata	D2001	-	0.92	-	2.00	-	-	1.83	-	3.88	2.88	0.96
Kreis, 1929	S2002	2.88	-	-	-	-	5.17	1.76	10.27	5.35	3.96	4.43
Prochromadorella neapolitana	D2001	-	0.92	-	-	9.17	3.5	0.91	1.62	-	-	1.21
De Man, 1876	S2002	-	-	-	-	-	-	-	1.88	-	-	0.30
Ptycholaimellus ponticus	D2001	-	-	-	2.00	-	-	-	-	0.97	15.41	1.36
Filipjev, 1922	S2002	3.84	-	0.99	5.00	-	1.72	-	4.71	0.89	2.97	2.51

Desmodoridae	D2001	-	-	0.83	-	1.83	-	-	0.81	-	-	0.22
	S2002	-	-	-	4.00	-	-	0.88	4.71	-	0.99	1.03
Chromaspirina pontica	D2001	-	-	0.83	-	-	-	-	-	-	-	0.05
Filipjev, 1918	S2002	-	-	-	-	-	-	-	-	-	-	-
Chromaspirina sp.	D2001	-	-	-	-	-	-	-	-	-	-	-
	S2002	-	-	-	-	-	-	-	0.94	-	0.99	0.26
Desmodora aff. minuta	D2001	-	-	-	-	1.83	-	-	-	-	-	0.08
Wieser, 1954	S2002	-	-	-	4.00	-	-	-	3.77	-	-	
Polysigma sp.	D2001	-	-	-	-	-	-	-	0.81	-	-	0.07
	S2002	-	-	-	-	-	-	-	-	-	-	-
Spirinia sp.	D2001	-	-	-	-	-	-	-	-	-	-	-
	S2002	-	-	-	-	-	-	0.88	-	-	-	0.05
Ethmolaimidae	D2001	-	-	0.83	-	2.75	1.75	-	0.81	4.85	-	0.79
	S2002	16.38	10.94	-	-	2.94	0.86	5.30	-	8.03	-	6.31
Neotonchus chamberlaini	D2001	-	-	0.83	-	2.75	1.75	-	0.81	4.85	-	0.79
Wieser & Hopper, 1966	S2002	16.38	10.94	-	-	2.94	0.86	5.30	-	8.03	-	6.31
Microlaimidae	D2001	-	-	11.66	-	-	-	-	-	-	1.92	0.99
	S2002	-	3.64	0.99	1.00	-	-	-	-	-	-	0.29
Calomicrolaimus honestus	D2001	-	-	11.66	-	-	-	-	-	-	1.92	0.99
Jayasree & Warwick, 1970	S2002	-	3.64	0.99	1.00	-	-	-	-	-	-	0.29
Cyatholaimidae	D2001	5.19	2.76	-	1.00	0.91	16.65	12.82	12.18	-	6.72	6.39
	S2002	2.88	3.64	-	2.00	-	3.44	34.67	8.48	-	1.98	5.36
Acanthonchus aff. rostratus	D2001	1.73	0.92	-	1.00	0.91	4.38	0.91	-	-	4.80	1.52
Wieser, 1959	S2002	-	-	-	-	-	-	3.53	-	-	-	0.23
Cyatholaimus sp.	D2001	-	-	-	-	-	2.63	-	-	-	-	0.27
	S2002	-	-	-	-	-	3.44	5.30	-	-	0.99	0.93
Longicyatholaimus sp.	D2001	-	0.92	-	-	-	-	2.75	8.13	-	-	1.21
	S2002	1.92	-	-	-	-	-	6.19	4.71	-	-	1.62
Marylynnia n. sp.	D2001	2.6	-	-	-	-	5.26	5.50	0.81	-	1.92	1.88
	S2002	0.96	3.64	-	2.00	-	-	**18.77**	3.77	-	0.99	2.50
Metacyatholaimus sp.	D2001	0.86	-	-	-	-	4.38	-	1.62	-	-	0.77
	S2002	-	-	-	-	-	-	0.88	-	-	-	0.05
Paralongicyatholaimus sp.	D2001	-	0.92	-	-	-	-	-	1.62	-	-	0.31
	S2002	-	-	-	-	-	-	-	-	-	-	-
Praecanthonchus sp.	D2001	-	-	-	-	-	-	3.66	-	-	-	0.40
	S2002	-	-	-	-	-	-	-	-	-	-	-
Selachinematidae	D2001	1.73	-	15.06	2.00	1.83	12.35	0.91	2.43	0.97	-	3.29
	S2002	-	-	-	2.00	9.80	0.86	7.07	4.71	0.89	1.98	1.93
Halichoanolaimus dolichurus	D2001	1.73	-	2.50	2.00	-	**11.48**	0.91	1.62	0.97	-	2.13
Ssweljev, 1912	S2002	-	-	-	2.00	9.80	0.86	7.07	4.71	0.89	1.98	1.93
Laimella sp.	D2001	-	-	-	-	1.83	-	-	0.81	-	-	0.16
	S2002	-	-	-	-	-	-	-	-	-	-	-
Synonchiella edax	D2001	-	-	12.56	-	-	0.87	-	-	-	-	0.99
Aïssa & Vitiello, 1977	S2002	-	-	-	-	-	-	-	-	-	-	-
Leptolaimidae	D2001	-	-	-	-	-	-	0.91	4.06	-	-	0.47
	S2002	-	-	-	-	-	0.86	-	1.88	-	1.98	0.65
Diodontolaimus sp.	D2001	-	-	-	-	-	-	0.91	4.06	-	-	0.47
	S2002	-	-	-	-	-	-	-	1.88	-	1.98	0.53
Leptolaimus sp.	D2001	-	-	-	-	-	-	-	-	-	-	-
	S2002	-	-	-	-	-	0.86	-	-	-	-	0.11
ENOPLIDA	**D2001**	**19.06**	**12.98**	**-**	**2.00**	**6.41**	**14.01**	**8.24**	**10.56**	**7.76**	**12.48**	**11.32**
	S2002	**3.84**	**1.45**	**1.98**	**27.00**	**38.20**	**3.44**	**4.52**	**7.52**	**2.67**	**23.70**	**7.48**
Ironidae	D2001	0.86	-	-	-	-	-	-	-	-	-	0.16
	S2002	-	-	-	-	-	-	-	-	-	-	-
Trissonchulus sp.	D2001	0.86	-	-	-	-	-	-	-	-	-	0.16
	S2002	-	-	-	-	-	-	-	-	-	-	-
Encheliidae	D2001	-	-	-	-	-	-	-	-	-	1.92	0.14
	S2002	-	-	-	-	0.98	-	-	0.94	-	-	0.16
Eurystomina ornata	D2001	-	-	-	-	-	-	-	-	-	1.92	0.14
Eberth, 1863	S2002	-	-	-	-	-	-	-	-	-	-	-
Pareurystomina sp.	D2001	-	-	-	-	-	-	-	-	-	-	-
	S2002	-	-	-	-	0.98	-	-	0.94	-	-	0.16

Oncholaimidae	D2001	9.53	12.06	-	1.00	-	3.49	2.75	1.62	6.79	4.80	5.75
	S2002	1.92	-	1.98	26.00	18.62	2.58	4.52	4.70	2.67	21.72	5.77
Filoncholaimus sp.	D2001	-	-	-	-	-	-	-	-	-	-	-
	S2002	-	-	-	-	-	-	0.88	-	-	-	0.05
Metoncholaimus sp.	D2001	0.86	-	-	-	-	-	-	-	-	-	0.16
	S2002	-	-	-	-	-	-	-	-	-	-	-
Oncholaimellus sp.	D2001	-	-	-	-	-	-	2.75	-		2.75	0.51
	S2002	0.96	-	-	-	1.96	0.86	-	-	-	-	0.37
Oncholaimus campylocercoïdes	D2001	-	-	-	-	-	-	-	-	1.94	-	0.13
De Coninck é Stekhoven, 1933	S2002	-	-	-	-	-	-	1.76	1.88	-	0.99	0.53
Prooncholaimus megastoma	D2001	0.86	-	-	-	-	0.87	-	-	-	-	0.25
Eberth, 1863	S2002	-	-	-	-	2.94	-	-	-	-	-	0.05
Viscosia glabra	D2001	1.73	-	-	1.00	-	1.75	-	-	-	-	0.56
Bastian, 1865	S2002	-	-	0.99		13.72	0.86	-	-	-	2.97	0.72
Viscosia sp.	D2001	6.08	12.06	-	-	-	0.87	-	1.62	4.85	4.80	4.31
	S2002	0.96	-	0.99	26.00	-	0.86	1.88	2.82	2.67	17.76	4.02
Anticomidae	D2001	1.73	-	-	1.00	1.83	2.63	0.91	-	-	2.88	1.07
	S2002	-	1.45	-	1.00	19.60	-	-	1.88	-	0.99	0.88
Anticoma acuminata	D2001	1.73	-	-	1.00	1.83	2.63	0.91	-	-	2.88	1.07
Eberth, 1863	S2002	-	1.45	-	1.00	19.60	-	-	1.88	-	0.99	0.88
Thoracostomopsidae	D2001	6.94	0.92	-	-	4.58	7.89	4.58	8.94	0.97	2.88	4.18
	S2002	1.92	-	-	-	-	0.86	-	0.94	-	-	0.71
Enoplolaimus longicaudatus	D2001	0.86	-	-	-	-	-	-	-	-	-	0.16
Southern, 1914	S2002	-	-	-	-	-	-	-	-	-	-	-
Mesacanthion diplechma	D2001	6.08	0.92	-	-	4.58	7.89	4.58	8.94	0.97	2.88	4.01
Southern, 1914	S2002	1.92	-	-	-	-	0.86	-	0.94	-	-	0.71
Ironidae	D2001	-	-	-	-	-	-	-	-	-	-	-
	S2002	-	-	-	-	-	-	-	-	-	0.99	0.11
Thalassironus britannicus	D2001	-	-	-	-	-	-	-	-	-	-	-
	S2002	-	-	-	-	-	-	-	-	-	0.99	0.11
H'	D2001	3.8	2.93	2.98	3.25	3.58	**4.34**	3.84	3.96	3.26	3.90	
	S2002	3,38	3,69	1,64	2,60	2,69	3,59	**4,13**	3,84	2,02	3,50	
J'	D2001	0.85	0.70	0.72	0.78	0.84	**0.90**	0.85	0.85	0.75	0.89	
	S2002	0,79	0,86	0,44	0,65	0,72	0,77	**0,90**	0,81	0,53	0,75	

Increase of Fe content (r = -0.79, p = 0.006), Mn (r = -0.85, p = 0.002), Ni (r = -0.64, p = 0.046) and Zn (r = -0.71, p = 0.021) appeared to control the mean individual respiration (December 2001). During this season, respiration ($-0.87 \leq r \leq -0.69$, $p \leq 0.027$) and production ($-0.87 \leq r \leq -0.74$, $p \leq 0.014$) appeared to be negatively correlated with the metal contents, except Pb, and positively correlated with mean grain size (r = -0.69, p = 0.029 and r = -0.74, p = 0.014, respectively). In September 2002, the silt/clay fraction was positively correlated with the nematode maximum diameter (r = 0.66, p = 0.039). As well, biomass and metabolic variables of the whole nematode assemblage were negatively correlated with the sedimentary organic matter (biomass: r = -0.79, p = 0.007; respiration: r = -0.87, p < 0.001; production: r = -0.90, p < 0.001), silt/clay (respiration: r = -0.85, p = 0.002; production: r = -0.89, p < 0.001) and positively by the sediment chlorophyll *a* (biomass: r = 0.75, p = 0.012; production: r = 0.64, p = 0.048). Shannon-Wiener diversity index was not significantly correlated with the organic matter in sediments (December 2001: r = -0.62, p = 0.058; September 2002: r = -0.63, p = 0.053).

Discussion

A lower oxygenation characterized the dry period because of the higher temperature of waters in comparison with the rainy period. Nitrites were spatially more variable in December 2001 than in September 2002. The opposite situation was observed in the case of nitrates and phosphates. According to the station, the spatio-temporal variability of nutrients appears related to (i) temperature decline witch may reduce the abundance of heterotrophic bacteria (Cavallo & Stabili, 2002), (ii) domestic sewages and (iii) sediment granulometry. Indeed, most of decomposer micro-organisms are attached to sediment silt/clay fraction and particulate organic matter and few characterize the bacterioplankton community (Dumontet et al., 2000). This constitutes an explanation of the highest concentrations of nutrients recorded at station BC, F and T where sediments have high silt/clay and organic matter content. Winds should be considered as an important force driving water currents in the lagoon, which may be partially responsible on the phytoplankton spatial distribution in such lagoon. In fact, the rainy season is characterized by a higher hydrodynamism which may contribute to homogeneize the phytoplankton distribution. This could be an explanation of heterogeneity of the concentration of chlorophyll *a* in waters more pronounced in September 2002 than in December 2001.

Sedimentary organic matter and metals were temporally quite stables and appeared directly influenced by the silt/clay content and sewages from the metallurgic factory "El Fouledh". As a consequence, sediments from South-Western stations (Stations F, T and MB) showed always the highest silt/clay content. The South-Eastern stations (OG, OGA and OBH) were usually characterized by the highest sediment chlorophyll load. Hydocarbons loads were probably affected by sewages of boats coming from the Mediterranean Sea to Menzel Bourguiba's harbour on one hand (December 2001) and silt/clay distribution on the other hand (September 2002).

Meiobenthic composition and diversity found in the coastal domain of Bizerte lagoon corresponds to previous studies published on Tunisia lagoons (Hermi & Aïssa, 2002; Mahmoudi et al., 2003a). Divergence between meiobenthic communities increased usually with increasing of disturbance level as illustrated by stations MB and T where sediments have high metal and organic matter content. Nematode densities were similar to those recorded in two disturbed Tunisian lagoons: Ichkeul lake (winter 1996: 190-849 ind.10 cm^{-2}; summer 1995: 128-644 ind.10 cm^{-2}; summer 1996: 197-733 ind.10 cm^{-2} according to Beyrem & Aïssa, 1998) and Ghar El Melh lagoon (summer 1999: 10-210 ind.10 cm^{-2} according to Mahmoudi et al., 2002a; winter 2000: 12-700 ind. 10 cm^{-2} according to Mahmoudi et al., 2003a). However, the maximal values found in this study appear lower than those recorded by Mahmoudi *et al*. (2002b) and Mahmoudi *et al*. (2003b) at Bou Ghrara lagoon (summer 1999: 21-1700 ind.10 cm^{-2}; winter 2000: 154-5641 ind.10 cm^{-2}).

Two nematode species, *Terschellingia longicaudata* and *Paracomesoma dubium* characterized the lagoon. In December 2001, *Terschellingia longicaudata* was dominant at stations F, BC and MJ and *Paracomesoma dubium* at stations T and MA. Such strong dominance of these species has been recorded at another near Tunisian ecosystem, the Ichkeul Lake by Beyrem & Aïssa (1998). In September 2002, these species were rarer in the OBH and OGA assemblages, but still at the second or third rank. *Sabatieria lepida* was the most abundant form at station MB characterized by the most polluted sediments (December 2001). This species can be considered as a metal-pollution resistant species. In fact, deposit feeder nematodes are known as the most resistant feeding group in the case of metallic pollution (Somerfield et al., 1994). The dominant species at these locations were *Comesoma sp.* (OBH) and *Marylynnia sp.* (OGA). The dominance into any assemplage of the large species *Paracomesoma dubium* (length about 2 mm) appeared to determine high value of the mean individual weight whereas the dominance of the small species *Terschellingia longicaudata* (length about 1 mm) may define low values of mean individual weight. Sediment silt/clay fraction seems to control the nematode body diameters. As suggested by Tita et al. (1999), muddy sediment nematodes tend to have a greater body width and volume and have a burrowing life style.

The calculated respiration rates (1.15 to 2.62 nl $O_2.h^{-1}.ind^{-1}$) were very similar to those found by Warwick & Price (1979) and Tita et al. (1999) (Table 6). In December 2001, this metabolic parameter was negatively correlated to sedimentary Fe, Ni and Mn. Indeed, it is known that nematodes concentrate metals (Fichet et al., 1999; Rzeznik-Orignac, 2004) may deplete respiration. Values of the individual production, ranged between $0.30.10^{-3}$ (station C in December 2001) and $0.44.10^{-3}$ $J.d^{-1}.\ ind^{-1}$ (station MJ in September 2002) and appeared relatively lower than most of the published data with the exception of one epigrowth-feeder species *Chromadorina germanica* ($0.90.10^{-3}$ $J.d^{-1}.\ ind^{-1}$ in Tietjen, 1980). Our results may be explained by the microvorous feeding behaviour of the majority of species. Then, when *Paracomesoma dubium* (epigrowth-feeder) was highly dominant in stations T and MA in the rainy season and in stations F, T, MB, OG and MA in the dry season, individual production values were relatively lower than those obtained when *Terschellingia longicaudata* (microvore) was the unique dominant species.

Increase of water temperature during the dry season also stimulates the individual metabolic respiration, production and metabolic ratio which also result from the spatio-temporal variability of the different species. In December 2001, the lowest values of these parameters were calculated in the South-Western stations (F, T and MB) where heavy metals and organic matter, except Pb, have a negative effect. Cu, Pb and Zn are known to affect nematode mortality of preadult stages, growth and fecundity (Vranken & Heip, 1986). The negative correlations between sedimentary metals contents and chlorophyll *a* (September 2002) could also reduce benthic algal growth as previously shown for the effect of copper on planktonic diatoms (Joux-Arab et al., 2000). This may explain the positive correlation noted in September 2002 between sediment chlorophyll *a* content and nematode abundance, biomass and production, especially when the diatom-cracking species *Paracomesoma dubium* is abundant. Increase of silt/clay content in the South-Western sites reduces oxygen availability and consequently the assemblage respiration and production. Decline of nematode diversity may only be attributed to the organic enrichment of sediments as previously shown by Schratzberger & Warwick (1998).

Table 6. Bibliographic data about mean individual respiration (MIR) and production (MIP) of meiobenthic nematodes.
Tableau 6. Données bibliographiques relatives à la respiration et la production individuelles moyennes (MIR et MIP) des nématodes méiobenthiques.

References	MIR (nl $O_2.h^{-1}.ind^{-1}$)	
Warwick & Price (1979)	0.39 – 3.27	
Tita et al. (1999)	1.12 – 2.26	
References	MIP (10^{-3} $J.d^{-1}.ind^{-1}$)	Feeding group
Tietjen (1980)	0.90 (*Chromadorina germanica*)	Epigrowth-feeder
Schiemer (1982)	5.40 (*Caenorhabditis briggsae*)	Microvore
Marchant & Nicolas (1974)	8.30 (*Rhabditis oxycerca*)	Microvore
Duncan et al. (1974)	4.10 (*Plectus palustris*)	Microvore

Thus, this study demonstrates a negative effect of Potentially Toxic Elements on biotic parameters on all biotic parameters i.e. chlorophyll, distribution and biodiversity of the meiobenthos and metabolism of nematodes.

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