Ecological interpretation of the distribution, morphometry and energetics of a population of *Paracomesoma dubium* Filipjev, 1918 (Comesomatidae, Nematoda) from Bizerte Lagoon (Tunisia)

Interprétation écologique de la distribution, de la morphométrie et des données énergétiques d'une population de *Paracomesoma dubium* (Comesomatidae, Nematoda) collectée dans la lagune de Bizerte (Tunisie)

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Résumé

Boufahja F., J. Amorri, H. Beyrem, N. Essid, E. Mahmoudi, P. Aïssa – Interprétation écologique de la distribution, de la morphométrie et des données énergétiques d'une population de *Paracomesoma dubium* (Comesomatidae, Nematoda) collectée dans la lagune de Bizerte (Tunisie)]. *Mar. Life*, 16 (1-2) : 3-13.

En septembre 2002, une population de nématodes *Paracomesoma dubium* a été collectée sur cinq stations côtières dans la lagune de Bizerte. Les variables sédimentaires (matière organique, métaux et chlorophylle *a*) étaient directement influencées par la distribution de la fraction fine et les rejets de l'usine métallurgique *El Fouledh*. La distribution spatiale de cette espèce dominante de nématodes était hautement corrélée à la teneur en chlorophylle *a*, métaux lourds, matière organique et hydrocarbures dans les sédiments. Le spectre de taille et de volume de ce nématode est significativement différent entre les stations, et la longueur moyenne est la plus faible à la station la plus polluée (MB). Chez les adultes, l'accroissement du volume corporel résulte plus de l'accroissement de la largeur que de la longueur lorsque les organismes vivent dans des sédiments fins contaminés. L'augmentation de la médiane granulométrique semble avantager les organismes les plus corpulents présentant des poids et des taux respiratoires et productifs plus importants.

MOTS CLÉS :
Lagune de Bizerte, *Paracomesoma dubium*, taux respiratoires et productifs, matière organique, métaux.

Abstract

Boufahja F., J. Amorri, H. Beyrem, N. Essid, E. Mahmoudi, P. Aïssa – Ecological interpretation of the distribution, morphometry and energetics of a population of *Paracomesoma dubium* Filipjev, 1918 (Comesomatidae, Nematoda) from Bizerte Lagoon (Tunisia). *Mar. Life*, 16 (1-2) : 3-13.

Samples of waters and sediments were collected for biochemical and faunal analyses at five coastal sites in Bizerte lagoon in September 2002. A nematode population of *Paracomesoma dubium* was selected in order to detect the effect of environmental parameters and pollution on nematode body size and metabolic activity. Sediment properties (organic matter, heavy metals and chlorophyll *a*) appeared to be directly influenced by grain size composition and waste discharge from the El Fouledh metallurgic plant. The spatial distribution of this dominant nematode species was strongly correlated with the distribution of chlorophyll *a*, metals, organic matter and hydrocarbons in sediments. The length and volume size spectra were significantly different between most of the stations and the body size was the lowest at the most polluted station (MB). Increase in body volume of adults resulted more from width increase than length increase in contaminated clay sediments. Increase of mean grain size appeared to advantage larger organisms, having larger body size and higher respiration rate.

KEY-WORDS :
Bizerte Lagoon, *Paracomesoma dubium*, respiration and production rates, organic matter, metals.

Introduction

The present study is a part of a research project investigating benthic communities inhabiting the coastal zone of Bizerte Lagoon (Tunisia) in relation to Potentially Toxic Elements (PTEs). The study area (150 km^2) is situated in the North of Tunisia (9°48'- 9°56'E, 37°08'-37° 14'N). Since 1950, it has suffered significant decline in its fisheries and mussel resources, suggested to be a result of domestic and industrial wastewater discharge from surrounding developments (Dellali *et al.*, 2001).

The aim of the study was to define stress indicator species and to investigate how water pollution modifies benthic biomass and productivity. Due to their direct benthic lifestyle, short generation times and high abundance and productivity (Schratzberger, Warwick, 1998), meiobenthic nematodes are considered as efficient bioindicators of the environmental conditions and have been increasingly used as stress indicators. However, in spite of the wide range of morphometric diversity in nematodes, few studies have paid attention to their ecological adaptive significance (Soetaert, Heip, 1989; Ratsimbazafy *et al.*, 1994; Tita *et al.*, 1999; Soetaert *et al.*, 2002).

In the current study, we investigated the body size attributes (total length, maximum width and weight) of the most abundant and frequent species, *Paracomesoma dubium* Filipjev, 1918 (Comesomatidae), at five stations in the Bizerte Lagoon. Morphometry was analysed against physical and chemical characteristics in both water and sediment. Energetic variables were also measured to assess productivity changes with environmental conditions (De Bovée, Labat, 1993; Soetaert *et al.*, 1997; Heip *et al.*, 2001).

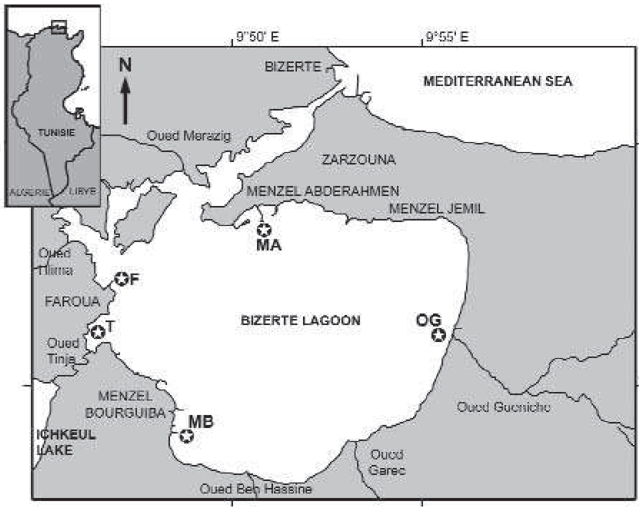


Figure 1
The study area and the five prospected sites (September 2002). Faroua (F), Oued Tinja (T), Menzel Bourguiba (MB), Oued Gueniche (OG), Menzel Abderrahmen (MA).

Le secteur d'étude et les cinq sites prospectés (septembre 2002). Faroua (F), Oued Tinja (T), Menzel Bourguiba (MB), Oued Gueniche (OG), Menzel Abderrahmen (MA).

Material and methods

Environmental data

Repository water and bottom sediments were collected at five stations [Faroua (F), Tinja (T), Menzel Bourguiba (MB), Oued Gueiniche (OG) and Menzel Abderrahmen (MA)] **(Figure 1)**. Water salinity (Sal), temperature (T) and dissolved oxygen (DO) were measured using a multiparameter WTW 340i probe. Nutrient content was measured in the laboratory according to the methods of Murphy and Riley (1962) for phosphates, Strickland and Pearsons (1965) for nitrates and Bendschneider and Robinson (1952) for nitrites. Chlorophyll *a* content was measured fluorimetrically (Lorenzen, Jeffrey, 1980).

Sediments samples were collected using a Van Veen grab sampler (0.1 m^2) and three replicates were kept frozen for subsequent analyses in the laboratory. Chlorophyll *a* was spectrophotometrically analysed according to Danovaro *et al.* (2002) and total hydrocarbons by infrared spectrophotometric method, as modified by Gruenfeld (1973). Sediments were dried at 45°C and weight standardised for analyses. Total organic matter (TOM) was measured as weight lost after ignition at 450°C for 6 hours (Fabiano, Danovaro, 1994). Grain size was evaluated by separating silt/clay fraction (S/C) (< 63 µm) and the coarse fraction (> 63 µm). Mean grain size (Q_{50}) was determined by using cumulative curves on the coarser fraction, following Buchanan (1971). For measurement of metals (namely Zn, Cu, Fe, Mn, Ni and Pb), a sediment sub-sample was digested in aqua regia (HCl-HNO_3-H_2O) at 95°C. Analysis was made by Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES) and Mass Spectrometry (ICP-MS) (Gil *et al.*, 1999).

Meiobenthic sampling and treatment

Meiobenthos was collected by SCUBA diving by using three plexiglass hand-cores (inner diameter 3.6 cm, surface area 10 cm^2), down to a depth of 20 cm. Samples were preserved in 4% neutralized formalin and stained with Rose-Bengal (0.2 $g.L^{-1}$). Sediments were washed through 1 mm and 40 µm sieves, respectively. The fraction remaining on the latter sieve was resuspended and centrifuged three times with Ludox-HS40 (density

1.31 g cm^{-3}) as described by Heip *et al.* (1985). Nematodes were collected and counted under binocular stereo-microscope WILD-M3B.

Morphometric and energetic characteristics of Paracomesoma dubium

At least one hundred nematodes per site were randomly collected and mounted on slides following the formalin-ethanol-glycerol technique to prevent dehydration for identification to genus using the pictorial keys of Platt, Warwick (1983, 1988) and Warwick *et al.* (1998). Species identification was usually done on the basis of descriptions downloaded from the web site www.vliz.be/database/nemys/ developed by nematologists at Ghent University (Belgium). The importance of a given species within one nematode assemblage was estimated by using the Presence Index which was obtained by multiplying the mean general relative abundance by the frequency (Afli, Glémarec, 2000). One species, *Paracomesoma dubium* (Comesomatidae), had the highest Presence Index (12.51) and was thus selected for morphometric study and calculation of energetic parameters. Five stations in Bizerte Lagoon were selected where *Paracomesoma dubium* was strongly dominant and on the basis of levels of potential pollution recorded in September 2002. Stations at different distances from the main pollution source (El Fouledh metallurgy plant) were selected when *Paracomesoma dubium* was eudominant (relative abundance = 32-100% according to Engelmann, 1978). Station MB is located offshore of the El Foulech metallurgy plant and was considered to be the most polluted. Stations T and OG are respectively situated at the mouth of Tinja and Gueiniche rivers and can receive inputs from seasonal runoff.

At each station, equations of the linear regression between the total nematode length (L) and the maximum width (W) were calculated, the sexual status being recorded (males, females and juveniles). In many nematode species, juveniles have different body proportions than adults (Warwick, 1984). The allometric equation $y = ax + b$ (Ratsimbazafy *et al.*, 1994; Tita *et al.*, 1999), where x is the total length, y is the maximum width, a is the slope and b is the intercept on the ordinate axis, was used to detect any eventual adaptive variability of morphotypes at each station in relation to environmental stress. Length at each station was expressed in 21 size-classes to build a size-frequency histogram.

Biovolume (V) in nanolitres was estimated by using the equation $V = 530\ L\ W^2$ (Warwick, Price, 1979) where the total length (L) and the maximum width (W) are expressed in mm. Wet weight (µg ww) of each specimen was obtained by using the specific gravity of 1.13 µg. nL^{-1} Wieser (1960) and converted into carbon weight assuming a carbon/wet weight ratio of 0.125 (Vanaverbeke *et al.*, 1997).

A linear regression of the log-transformed equation of Warwick and Price (1979) $\log R = \log a' + b \log V$ was used to evaluate the energetic descriptors. R represents the respiration rate in nL O_2. h^{-1}, $\log a'$ is the energetic intensity, V is the body volume in nL and assuming a b value of 0.75 at 20°C. The energetic intensity of -0.197, valid at 20°C, was extrapolated from a closely related comesomatid species, *Sabatieria pulchra* (Warwick, Price, 1979). In addition, conversion to *in situ* temperatures was calculated assuming a Q_{10} (variation of a given metabolic variable when temperature increases by 10°C) value of 2 (Soetaert *et al.*, 1997). Individual production was calculated from individual respiration based on the equation of Schwinghamer *et al.* (1986) and considering that 1 litre O_2 is equivalent to 22.07 kJ (Salonen *et al.*, 1976).

Univariate and multivariate statistical analyses

Non-parametric multiple comparisons of length were calculated between the different stations. Comparisons were made by using the Nemenyi and Dunn test when the null hypothesis (H_0 = no difference at the five stations) is rejected by the Kruskal-Wallis test in order to detect significant differences in these two parameters between stations.

Slopes of the length/width regression equations were compared by Student's t-test (Mayrat, 1959). Relationships between biotic and environmental variables were investigated by using the Pearson coefficient (r) and the Principal Component Analysis (PCA), using StatBox 3.0 software. All data were converted to approximate normality using a log (x+1) transformation prior to analyses.

Results

Environmental parameters

Waters samples

Waters were characterized by high values for temperature (24.3 - 25.9°C) and salinity (39.2 - 40.1 PSU). Dissolved oxygen varied between hypoxic (4.1 mg.L^{-1}) and normoxic (7.8 mg.L^{-1}) levels. pH and nitrites did not vary as much. Nitrate concentrations varied 4.65-folds and phosphates varied 170-folds and the highest values were always observed for water samples collected from the north-eastern sites (MA and OG) of the study area **(Table I)**.

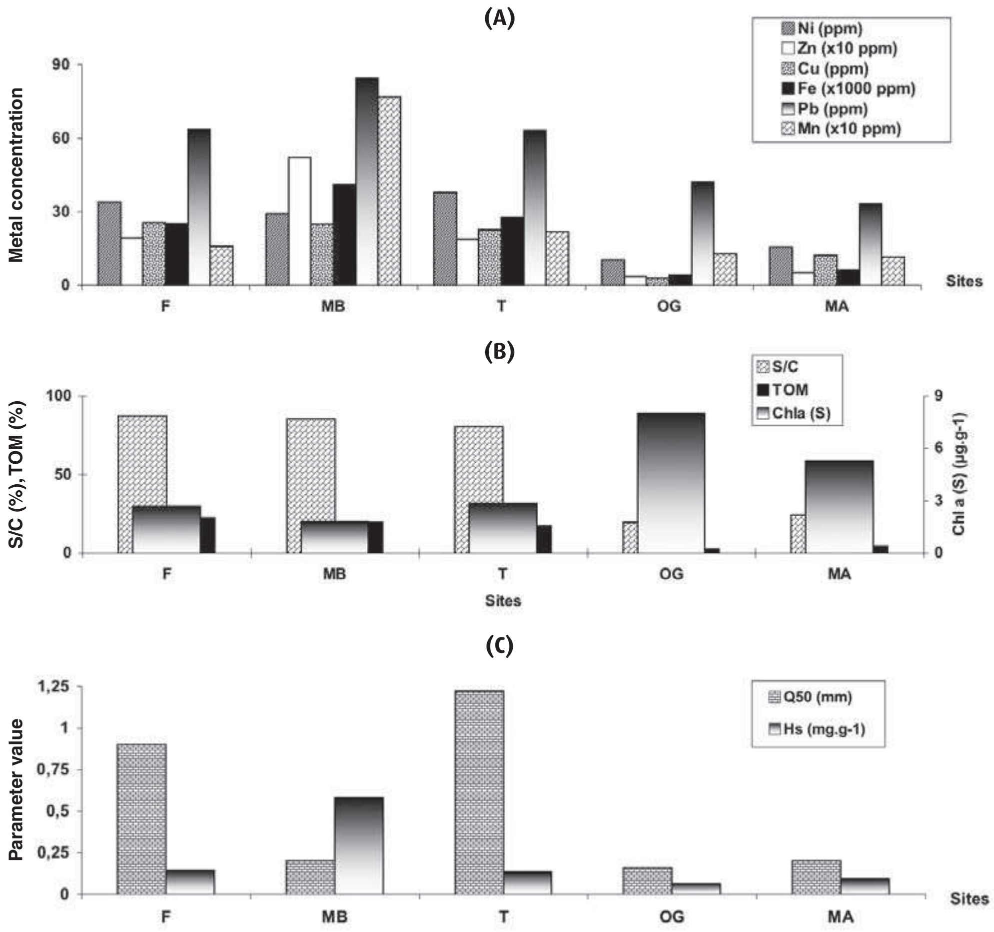


Figure 2
Parameters measured in sediments from prospected sites during September 2002. (A) Metal concentrations: nickel (Ni), zinc (Zn), copper (Cu), iron (Fe), lead (Pb), manganese (Mn). (B) Silt/clay (S/C), total organic matter (TOM), chlorophyll *a* (Chla (S)). (C) Mean grain size (Q_{50}), hydrocarbons (Hs).

Les paramètres mesurés dans les sédiments collectés des sites prospectés en septembre 2002. (A) Concentrations des métaux : nickel (Ni), zinc (Zn), cuivre (Cu), fer (Fe), plomb (Pb), manganèse (Mn). (B) Fraction fine (S/C), matière organique totale (TOM), chlorophylle a *(Chla (S)). (C) Médiane (Q_{50}), hydrocarbures (Hs).*

Chlorophyll *a* in waters varied 6.5-folds and maxima were recorded at sites MA, F, OG and T. Suspended matter varied 4.4-folds and the greatest loads were found at sites T and MB.

Sediment samples

Most heavy metals, except Ni, had high spatial variability and maximum concentrations, as expected **(Figure 2A)** were always recorded in sediments from site MB, located off the El Fouledh metallurgy plant. Sediments were muddy at the south-western coastal sites (F, T and MB) with a proportion of silt/clay usually greater than 80% **(Figure 2B)**. The sediment of the last two stations (OG and MA) was mainly composed of fine clay sand. Organic and hydrocarbon contents had the highest values at sites OG and MA **(Figures 2B and 2C)** and maxima in clay sediments (Stations F, MB and T), where the organic loads ranged from 17.07 to 22.14% and hydrocarbon concentrations fluctuated between 0.133 and 0.580 $mg.g^{-1}$. The lowest concentration of chlorophyll *a* **(Figure 2B)** was recorded in sediments collected at site MB (1.78 $\mu g.g^{-1}$), whereas the highest value was recorded at station OG (8.01 $\mu g.g^{-1}$). Stations F, T, MB were characterized by muddy sediments whereas stations OG and MA had coarser sediment and were considered as less polluted.

Morphometrics and energetics of *Paracomesoma dubium*

Measurements (abundance, dominance, sample size, maturity, length and width) and calculated metabolic data (weight, individual and population respiration, productivity, metabolic ratio) of *Paracomesoma dubium* are presented in **Table II**. The lowest size and the highest metabolic ratio were obtained from individuals collected at the most polluted station MB. The least disturbed populations OG and MA were characterized by maximum biomass, respiration and production in contrast to those inhabiting station MB which displayed the minimum values. The minimum values of the metabolic indices, *i.e.* metabolic ratio for both juveniles and adults **(Figure 3)** and productivity, characterized the population at MA, although maxima was always recorded at population MB.

Maturity of the five sub-populations showed considerable variation in the the ratio Juveniles/Adults ($0.62 < J/A < 2.3$). Juveniles were dominant at station MB (2.3) and at station F ($J/A = 1.3$). Adult males and females were more numerous than juveniles at stations T, OG, MA.

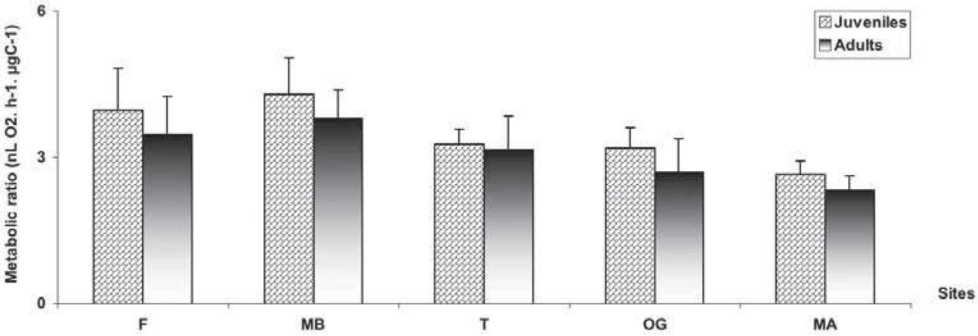


Figure 3
Spatial variability of the metabolic ratio of juveniles and adults of *Paracomesoma dubium* (Bizerte Lagoon, September 2002).

Variabilité spatiale du rapport métabolique des juvéniles et des adultes de Paracomesoma dubium *(lagune de Bizerte, septembre 2002).*

Table I

Sites Parameters	F	T	MB	OG	MA
Latitude N	37° 12' 310	37° 11' 181	37° 08' 348	37° 10' 569	37° 13' 437
Longitude E	9° 48' 067	9° 47' 230	9° 49' 066	9° 55' 207	9° 51' 457
DP (m)	3.10	2.00	3.10	**3.20**	2.60
T (°C)	**25.90**	25.70	25.70	24.30	24.30
DO (mg.L^{-1})	**7.80**	5.40	5.30	4.60	4.10
Sal (psu)	39.20	39.40	39.60	**40.10**	39.90
pH	8.30	8.26	**8.31**	8.28	8.27
PO4 (mg.L^{-1})	0.0186	0.0145	0.0023	**0.2030**	0.0012
NO2 (mg.L^{-1})	0.0000	0.0011	0.0000	**0.0110**	0.0078
NO3 (mg.L^{-1})	0.1362	0.2241	0.2023	0.5436	**0.6341**
Chl*a* (W) (mg.m^{-3})	15.20	11.40	3.80	15.20	**24.70**
SM (mg.L^{-1})	2.20	9.70	9.20	3.80	2.80

Parameters measured in the sampled waters (Bizerte Lagoon, September 2002). Depth (DP), temperature (T), dissolved oxygen (DO), salinity (Sal), phosphates (PO^4), nitrites (NO^2), nitrates (NO^3), chlorophyll *a* (Chla (W)), suspended matter (SM). Maximum and minimum are respectively indicated with bold and underlined values.

Paramètres mesurés dans les eaux collectées (lagune de Bizerte, septembre 2002). Profondeur (DP), température (T), oxygène dissous (DO), salinité (Sal), phosphates (PO^4), nitrites (NO^2), nitrates (NO^3), chlorophylle a (Chla (W)), matière en suspension (SM). Les maxima et les minima sont respectivement indiqués par des valeurs en gras et soulignées.

Table II

Site	F	MB	T	OG	MA
Ab (ind. 10 cm^{-2})	64.96 ± 61.34	22.62 ± 12.81	34.02 ± 24.83	**180.27 ± 84.86**	138.79 ± 43.28
R.Ab (%)	**73.27**	39.24	44.00	33.24	35.71
n (individuals)	42 J and 32 A	28 J and 12 A	17 J and 27 A	12 J and 19 A	14 J and 16 A
MIL (µm)	2128.48 ± 550.31	1639.00 ± 428.04	**2533.77 ± 495.67**	2130.80 ± 445.37	2410.16 ± 390.91
MIWd (µm)	64.11 ± 17.25	54.35 ± 14.60	**72.72 ± 19.29**	54.41 ± 10.84	68.41 ± 11.84
MIW (µgC. ind^{-1})	0.85 ± 0.61	0.45 ± 0.34	**1.22 ± 0.79**	0.57 ± 0.31	0.98 ± 0.45
MIR (nL O2 .h-1. ind^{-1})	2.90 ± 2.25	1.75 ± 1.42	**3.68 ± 2.65**	1.55 ± 0.98	2.35 ± 1.31
MIP (10^{-3} J .d-1. ind^{-1})	0.54 ± 0.42	0.32 ± 0.26	**0.69 ± 0.49**	0.44 ± 0.24	0.29 ± 0.18
MR (nL O_2. h^{-1}.µgC^{-1})	3.74 ± 0.86	**4.14 ± 0.73**	3.20 ± 0.57	2.88 ± 0.42	2.47 ± 0.30
R (mL O_2. d^{-1}. m^{-2})	4.52 ± 4.26	0.95 ± 0.53	3.00 ± 2.19	6.70 ± 3.15	**7.82 ± 2.44**
P (J .d-1.m^{-2})	35.07 ± 33.12	7.23 ± 4.09	23.47 ± 17.13	**79.31 ± 37.33**	40.24 ± 12.55
B (mgC. m^{-2})	55.21 ± 52.13	10.17 ± 5.76	41.50 ± 30.29	102.75 ± 48.37	**136.01 ± 42.41**
P/B (d^{-1})	0.013	0.015	0.012	**0.016**	0.006

Morphometric and energetic data of *Paracomesoma dubium*, dominant species within five prospected nematode assemblages (F, MB, T, OG and MA) from the coastal domain of Bizerte lagoon during September 2002. Abundance (Ab); relative abundance (R.Ab) ; number of individuals used for evaluating the morphometric and energetic data of *Paracomesoma dubium* (n); juveniles (J); adults (A); mean individual length (MIL), mean individual width (MIWd), mean individual weight (MIW), mean individual respiration (MIR), mean individual production (MIP), metabolic ratio (MR), population respiration (R), population production (P), population biomass (B), population productivity (P/B). Maximum and minimum are respectively indicated with bold and underlined values.

Données morphométriques et énergétiques de Paracomesoma dubium, *espèce dominante au sein des cinq assemblages nématologiques prospectés (F, MB, T, OG and MA) dans le domaine côtier de la lagune de Bizerte en septembre 2002. Abondance (Ab) ; Abondance relative (R.Ab) ; nombre des individus utilisés pour l'évaluation des données morphométriques et énergétiques de* Paracomesoma dubium *(n) ; juvéniles (J) ; adultes (A) ; longueur individuelle moyenne (MIL), diamètre individuel moyen (MIWd), poids individuel moyen (MIW), respiration individuelle moyenne (MIR), production individuelle moyenne (MIP), rapport métabolique (MR), respiration de la population (R), production de la population (P), biomasse de la population (B), productivité de la population (P/B). Les maxima et les minima sont respectivement indiqués par des valeurs en gras et soulignées.*

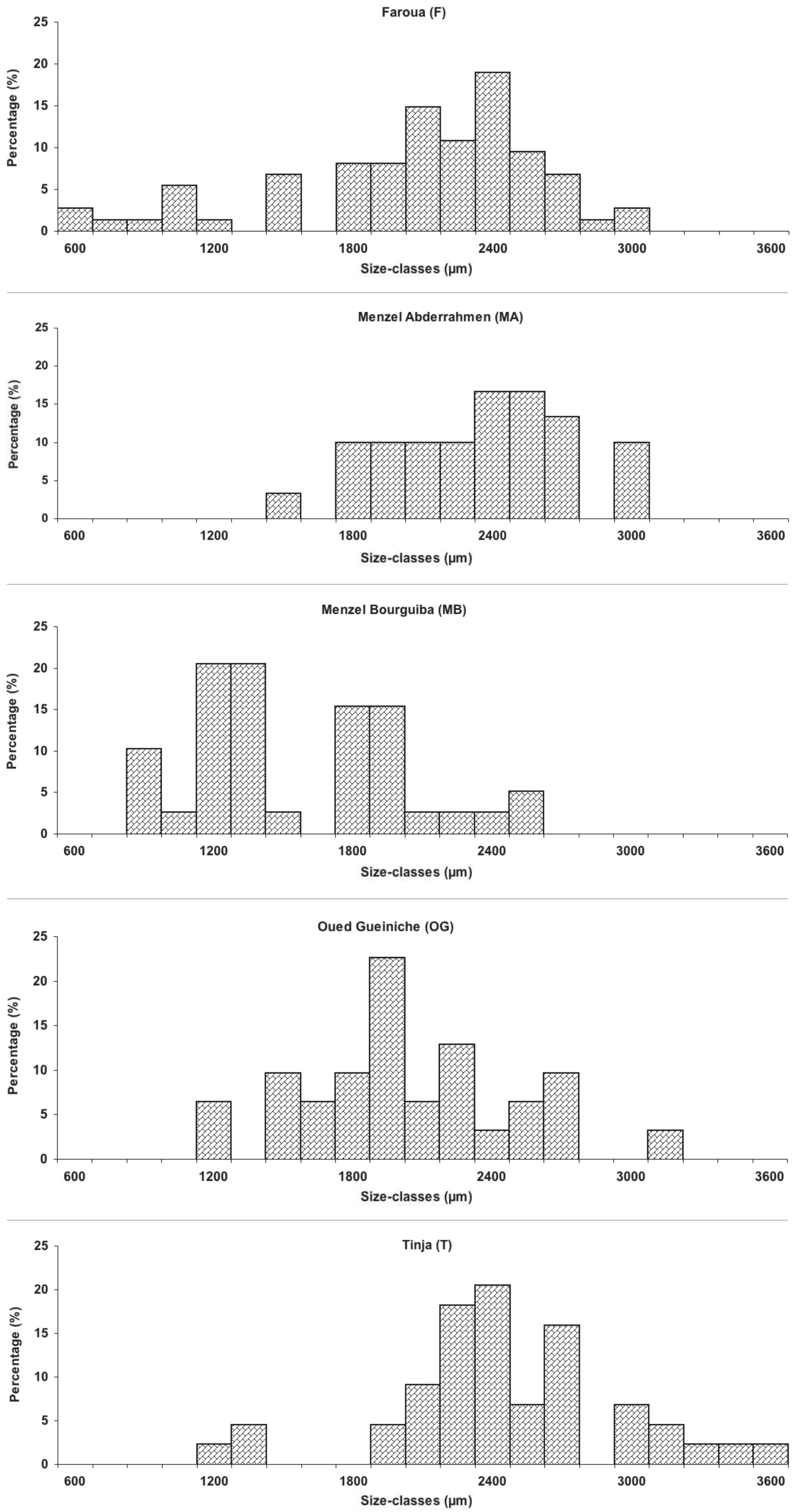


Figure 4
Size and volume spectra expressed as a percentage of each class of nematodes at the five stations in Bizerte Lagoon.

Spectres de longueur et de volume exprimés en pourcentage de chaque classe de nématodes à chacune des stations prospectées dans la lagune de Bizerte.

Table III

Kruskal-Wallis test: H (N = 218, df = 4) = 61.22, P = 0.000

Total length	F	MB	T	OG	MA
F		**0.000**	**0.003**	1.000	0.278
MB			**0.000**	**0.006**	**0.000**
T				**0.007**	1.000
OG					0.222
MA					

Non-parametric multiple comparisons of total length of *Paracomesoma dubium* using the Nemenyi and Dunn test. Values indicate probabilities (P). Bold values designate significant differences at $P < 0.05$.

Comparaisons non-paramètrique multiple de la longueur totale de Paracomesoma dubium *en utilisant le test de Nemenyi et Dunn. Les valeurs indiquent les probabilités (P). Les valeurs en gras désignent les différences significatives à P < 0.05.*

Table IV

Juveniles / Adults	F	MB	T	OG	MA
F		0.33 NS	1.54 NS	0.58 NS	0.52 NS
MB	0.91 NS		0.95 NS	0.13 NS	0.16 NS
T	1.02 NS	0.11 NS		0.43 NS	0.19 NS
OG	1.01 NS	0.34 NS	0.19 NS		0.27 NS
MA	1.00 NS	0.34 NS	0.20 NS	0.00 NS	

Pairwise Student t-test comparisons of the slopes characterizing *Paracomesoma dubium* morphotypes for juveniles and adults. The threshold of significance for $P < 0.05$ being equal to 1.96. Not significant (NS).

Comparaisons par le test t de Student des pentes caractérisant les morphotypes des juvéniles et des adultes de Paracomesoma dubium. *Le seuil de signification (P < 0.05) est égal à 1.96. Différence non significative (NS).*

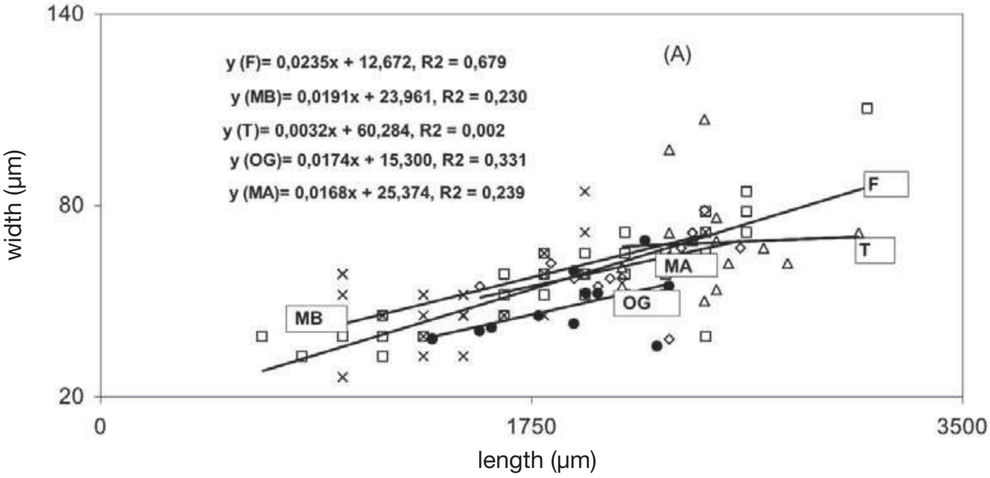
Size spectra at the five stations, expressed as a percentage of each size class, are shown in **figure 4**. Station MA and T displayed the highest size range and Station MB the lowest size range. Multiple comparisons of size spectra were tested by Kruskal-Wallis test on the five subpopulations. The null hypothesis (H_0 = no difference of the length spectra at the 5 stations) is rejected at $p < 0.000$ **(Table III)**. Station MB has a size spectrum significantly different from all other sites and the median size is significantly lower **(Table III)** with a high proportion of small individuals in the length class 1200-1500 µm. This result means that the station effect on size spectra is highly significant and that environmental conditions influence body size and potentially maturation of adults.

The regression line between length and width of juveniles and adults of *Paracomesoma dubium* sampled from each one of the five stations are given in **figures 5A and 5B**, respectively. Slope values showed less variation in all studied sub-populations for adults [0.0134 (MA) - 0.0260 (F)] and juveniles [0.0168 (MA) -0.0235(F)] except for juveniles from site T where a lower value was recorded (0.0032). However, pair-wise comparisons **(Table IV)** showed no significant differences ($p < 0.05$) for either juveniles and adults. Positive and significant correlations were noted between slopes of adults and dissolved oxygen in waters ($r = 0.97$), sediment organic matter ($r = 0.74$), Ni ($r = 0.65$), Cu ($r = 0.60$) and Fe ($r = 0.60$). Slopes of juveniles were positively correlated with depth ($r = 0.91$), however this relation is probably casual as the depth range is too narrow to explain such a relation.

Figure 6 and **Table V** show the Principal Component Analysis (PCA) and relative contributions (RC) of variables on axis 1 and axis 2. Inertia of the two main components was 52.40% and 25.25% respectively. Axis 1 shows two groups of variables. The first on the positive part of the axis was composed of Zn (RC = 0.96), Fe (RC = 0.96), silt/clay (RC = 0.93), Pb (RC = 0.93), organic matter (RC = 0.92), metabolic ratio (RC = 0.86), Ni (RC = 0.77) and Cu (RC = 0.69), which contrast on the negative part of the axis with population abundance (RC = 0.86), population biomass (RC = 0.79), population respiration (RC = 0.77) and population production (RC = 0.69). Production was clearly associated with chlorophyll *a* content in sediments (RC = 0.93), water nitrites (RC = 0.91) and water nitrates (RC = 0.88).

On axis 2, two groups of variables were identified. The first on the positive side of the axis consisted of body size descriptors ($0.74 \leq CR \leq 0.95$), individual production (CR = 0.50), individual respiration (CR = 0.45) and mean grain size (CR = 0.68). The second group was negatively limited by depth (CR = 0.64). Shallower sediments (2 m) seem to contain larger and longer organisms but this relation may result from higher mean grain size (1.22 mm at site T).

Finally, on axis 1, populations from sites OG and MA, notably characterized by the highest loads of chlorophyll *a* in sediments and by the maxima of abundance, biomass, respiration and production, were separated from



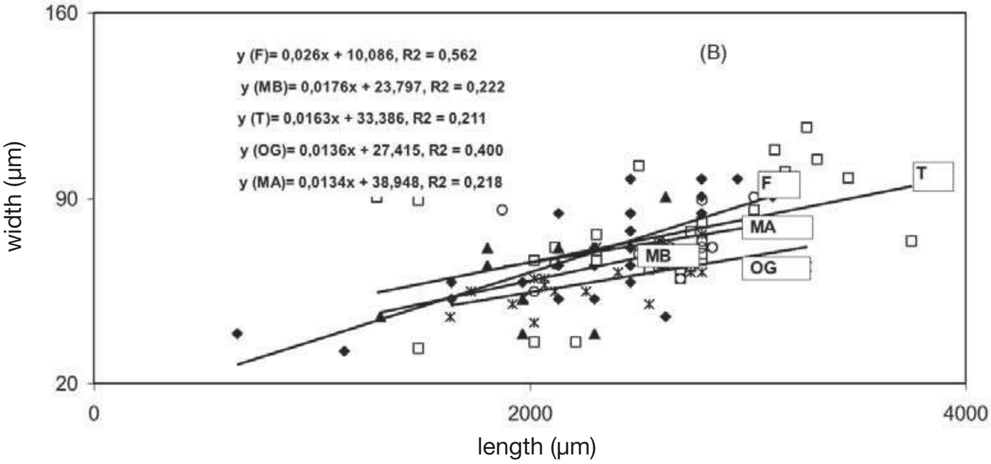


Figure 5
Linear regression between *Paracomesoma dubium* body dimensions (total length and maximum width), adults (A) and juveniles (B) separately.

Régression linéaire entre les dimensions corporelles (longueur totale et diamètre maximal) des juvéniles et des adultes de Paracomesoma dubium.

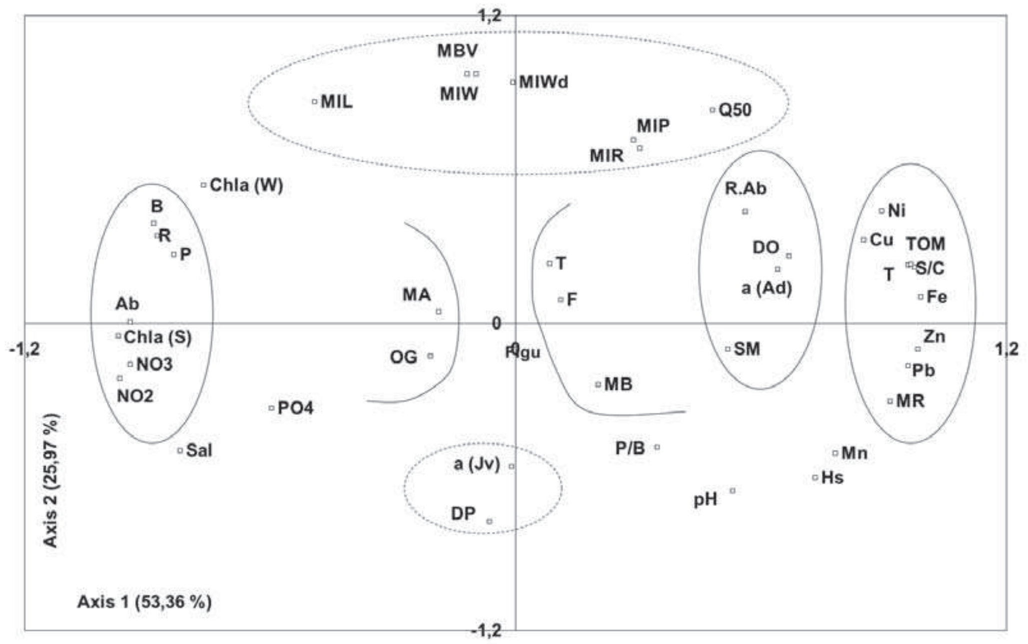


Figure 6
Principal components analysis (PCA) showing the relationships between *Paracomesoma dubium* descriptors and environmental data. Species relative abundance (R.Ab); Slope for juveniles (a (Jv)); Slope for adults (a (Ad)). Abbreviations as figure 2 and table I.

Analyse en composantes principales (ACP) montrant les relations entre les descripteurs de Paracomesoma dubium *et les données environnementales. Abondance relative (R.Ab) ; pente relative aux juvéniles (a (Jv)) ; pente relative aux adultes (a (Ad)). Abréviations identiques à celles de la figure 2 et du tableau I.*

those inhabiting the most disturbed sediments sampled from sites F, T and MB.

Discussion

Low water oxygenation logically characterizes the dry period. Nutrient variability appears to be related to two factors, (i) domestic sewage and (ii) river runoff. Maximum concentrations were always observed at station MA located off Menzel Abderrahmen city or at station OG which receives inputs from Gueiniche river located on the eastern side of Bizerte lagoon which is widely open to an agricultural zone where fertilizers are constantly applied. These factors may provide the explanation of the highest chlorophyll *a* concentrations in both waters and sediments at these stations. These measures probably indicate benthic-pelagic coupling. In fact, it is well known that nutrient availability in waters may stimulate the benthic microalgae growth.

The sediment parameters were directly influenced by two factors; (i) spatial variability of silt/clay and (ii) waste discharge from the El Fouledh metallurgy plant located in the town of Menzel Bourguiba. At most locations, except site MB, concentrations of Cu, Pb and Zn in the coastal domain of Bizerte lagoon were similar to those observed in sediments at Marennes Oléron Bay on the Atlantic coast of France (Rzeznik-Orignac *et al.*, 2003). These sediments cannot be considered as being as heavily contaminated as those recorded in the Fal Estuary in Cornwall (Somerfield *et al.*, 1994). Correlations of metals with organic matter in sediments were high because many heavy metals are generally bound to organic matter and thus to the silt/clay fraction (Bryan, Langston, 1992).

The negative correlations between sedimentary metal content and chlorophyll *a* (r between –0.98 and –0.58) could be the result of the metal effect on benthic algal growth. Copper is known to inhibit the development of the planktonic pennate diatom *Haslea ostrearia* (Joux-Arab *et al.,* 2000) and this effect may also apply to benthic diatoms.

The abundance of *Paracomesoma dubium* was strongly and positively related to sediment chlorophyll *a*. This environmental variable appeared to be strongly and negatively dependent on the metal, organic matter and hydrocarbon content in the sediment. The same trend was observed for biomass, respiration and production estimated at population level. Equally, contaminated sediments appeared to favour organisms with higher metabolic rates. These relations may be easily explained by the trophic ethology of this species. *Paracomesoma dubium* is an epigrowth-feeder and principally feeds on benthic diatoms. Its food is negatively influenced by metals (Joux-Arab *et al.*, 2000). Thus, this study shows a clear separation of two groups of stations, the less disturbed OG-MA and the more disturbed F-T-MB. The abundance of *Paracomesoma dubium* was also remarkably correlated with the dissolved oxygen levels in water samples. Probably due to its larger size (mean length about 2 mm), populations of this species increased when sediments were more oxygenated. Oxygen is absorbed *via* diffusion through the body surface and so body width constitutes the main factor influencing oxygen consumption for nematodes. This may explain slopes relating body dimensions of the adults of *Paracomesoma dubium* to the water oxygen content. Adult slopes are also correlated with metal and organic matter content in sediments. This result means that adult volume increase results more from width than length when these organisms inhabit muddy and contaminated sediments. For juveniles, the absence of significant correlations between this slope and sedimentary parameters (silt/clay, Fe, Cu, Ni, Pb and organic matter) may be due to discontinuous growth between juvenile stages. The volume increase between moults is based mainly on length increase compared with adults that have already achieved their length maxima. This was clearly supported by the very low of slope value recorded at station T.

The mean grain size was correlated with energetic parameters (production and respiration) and body morphometric parameters (width, length, volume and carbon weight). Increase in body width restricts sliding movement through the sediment pore spaces. Smaller organisms, juveniles or adults, collected during this study at station MB have a lower mean individual respiration rate but they also correspond to higher metabolic ratio **(Figure 3)** as previously stated by Gerlach *et al.* (1985) and Tita *et al.* (1999). This general scheme is suggests two different and not mutually exclusive hypotheses: (1) decreasing respiration rates were caused by decrease in sediment oxygen when depth increased; however the depth range is too small to support this hypothesis; (2) the oxygen demand was positively associated with the locomotion effort (Schwinghamer, 1981). As a result, higher body length seems to improve vertical migration (Tita *et al.*, 2001) and consequently to stimulate more increased oxygen consumption.

Thus size and metabolic spectra of this population of *Paracomesoma dubium* demonstrate a clear negative relationship with the increase of loads of PTEs. Body size and, as a consequence, metabolic rates of *Paracomesoma dubium* were significantly affected by the environmental quality at the stations studied. Differences were found in the range of size spectra, with larger adults at stations F, MA and T, where the proportion of juveniles to adults was affected by the heavy metal content. Individual growth also appears to be affected, with a higher proportion of very small juveniles at station MB.

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