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Seasonal variability of planktonic copepods in Tunis North Lagoon (Tunisia, North Africa)

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Abstract: This paper describes temporal and seasonal variations in the composition and abundance of the planktonic copepod community in the North lagoon of Tunis and the influence of selected environmental factors (temperature, salinity, suspended particulate matter and chlorophyll *a* concentrations) on this community. Samples were collected weekly from March 2001 to September 2002. Total planktonic copepod abundance showed low densities and high variability, lacking any clear seasonal pattern. In total, 24 species were identified. According to their occurrence and numerical abundance during the study period, *Oithona nana*, *Acartia clausi* and *Euterpina acutifrons* constituted the dominated species of the planktonic copepod community in the lagoon. There was a significant correlation between the abundance of copepods and environmental factors in the case of *Acartia latisetosa*, *Oithona plumifera*, *Labidocera brunescens*, *Euterpina acutifrons*, *Clausocalanus arcuicornis* and *Corycaeus speciosus*.

Résumé : *Variabilité saisonnière des copépodes planctoniques de la lagune nord de Tunis (Tunisie, Afrique du Nord).* L'objet de ce papier est de décrire les variations temporelles et saisonnières de la composition et de l'abondance des copépodes planctoniques dans la lagune nord de Tunis ainsi que l'influence de quelques facteurs environnementaux sélectionnés (température, salinité, matière en suspension et concentration en chlorophylle *a*). L'échantillonnage a été réalisé chaque semaine durant la période allant de mars 2001 à septembre 2002. L'abondance des copépodes planctoniques a montré des densités faibles et une grande variabilité sans rythme saisonnier clair. 24 espèces au total ont été identifiées. En se basant sur la permanence et l'abondance numérique durant la période d'étude, *Oithona nana*, *Acartia clausi* et *Euterpina acutifrons* constituent les espèces dominantes de la communauté des copépodes planctoniques de la lagune. Une corrélation significative entre l'abondance des copépodes et les facteurs environnementaux a été observée pour les espèces suivantes : *Acartia latisetosa*, *Oithona plumifera*, *Labidocera brunescens*, *Euterpina acutifrons*, *Clausocalanus arcuicornis* and *Corycaeus speciosus*.

Keywords: Tunis North Lagoon, Planktonic copepods, Seasonal variations, Environmental factors.

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Introduction

Coastal marine areas such as lagoons have peculiar functional and structural characteristics; they generally show large temporal and spatial variations in hydrochemical characteristics and considerable biological diversity (Castel et al., 1996). This variability may be reflected in the dynamics of the populations, particularly planktonic ones (Gowen et al., 1998; Calbet et al., 2001). Among environmental factors affecting the spatial and temporal structure of zooplankton communities, physical ones (salinity and temperature) play a major role in coastal areas (Siokou-Frangou, 1996; Christou, 1998; Calbet et al., 2001). Copepods are major secondary producers and play a key role in the transfer of primary production to the higher trophic levels such as carnivorous zooplankton and economically important planktivorous fishes (Daan, 1989). In coastal marine waters copepods generally constitute 80% to 90% of the total zooplankton (Daan, 1989; Thor, 2000; Calbet et al., 2001). The ecological investigations of the zooplankton communities in Tunisian coastal waters have demonstrated that the copepods are by far the most dominant group within the mesozooplankton (Daly-Yahia & Romdhane, 1994; Daly-Yahia et al., 2001; Daly-Yahia et al., 2004). One of the characteristics of the Tunis Bay, that communicates with the North Lake of Tunis via a channel “Kerreddine canal”, is the stability of its neritic community dominated by *Oithona nana*, *Centropages kroyeri*, *Acartia clausi* and *Euterpina acutifrons*, which is regularly replenished by an oceanic community introduced by intrusions of branch currents from the Atlantic Ocean (Daly-Yahia et al., 2004).

The North Lagoon of Tunis was characterized after its restoration (works undertaken between 1984 and 1888) by stable values of pH, oxygen, salinity and low concentrations of nutrients (Ben Charrada, 1992). The complete disappearance of the macroalgae *Ulva rigida* and the increase of the biodiversity of the macroalgal community were reported to be in connection to effects of restoration

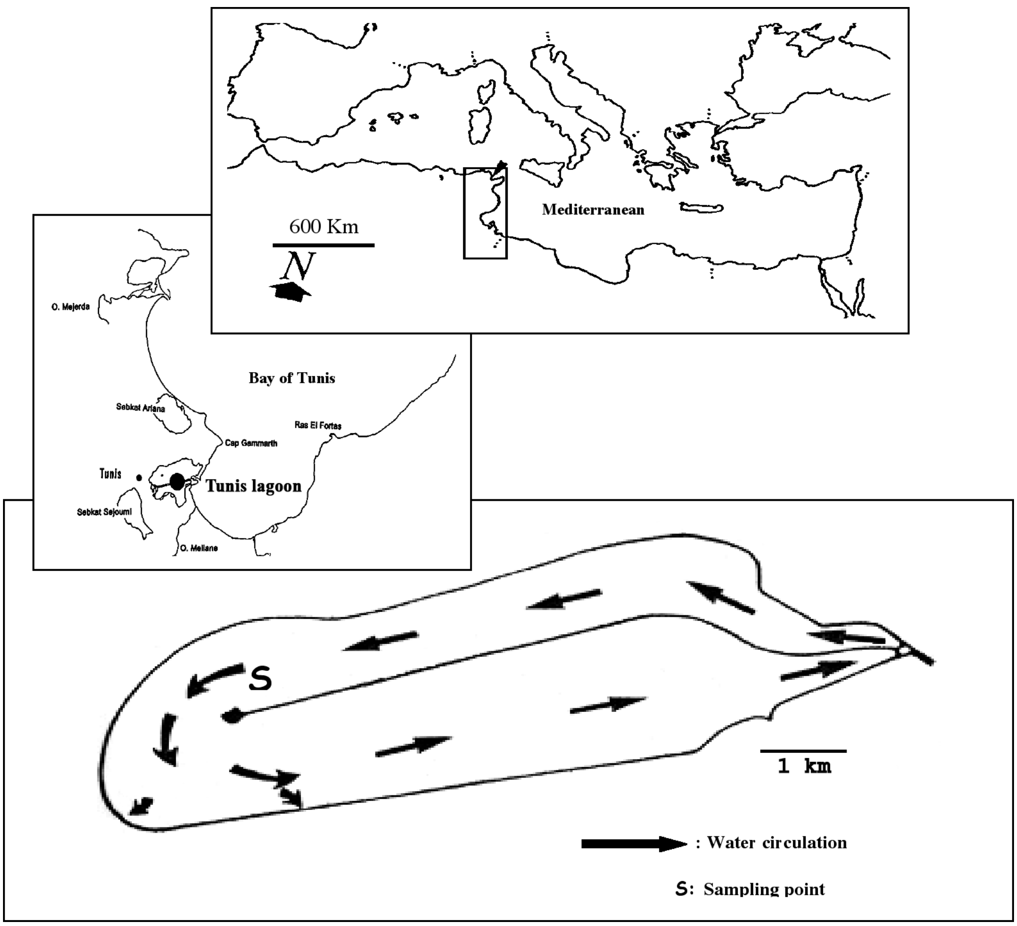

Figure 1. Geographical situation of the Tunis North lagoon
Figure 1. Situation géographique de la lagune Nord de Tunis.

(Trabelsi et al., 2001). The observed positive tendencies were related to the new hydrological regime (laevogyrate water circulation driven by natural tidal forces).

The principal aims of this paper work are to describe the temporal and seasonal variations in the composition and the abundance of pelagic copepods in the North lagoon of Tunis and to assess the influence of environmental factors.

Material and methods

Sampling was carried out from March 2001 to September 2002 at weekly intervals at one sampling station in the North Lagoon of Tunis (SW Mediterranean, Tunisia) (Fig. 1). It is a large and shallow lagoon (2600 ha, average depth about 1.5m) with sandy-muddy bottom mainly covered by *Chaetomorpha linum* and *Ruppia cirrhosa* (Trabelsi et al., 2001). This lagoon was restored in 1988 on the basis of hydrodynamical models by tidal re-circulation (Ben Charrada, 1992).

Measurements of temperature, salinity and suspended particulate matter concentrations were done every cruise using standard methods according to F.A.O (1975). Suspended particulate matter concentrations (SPM) were measured by filtration through a Whatman GF/C membrane and determining the dry weight of the residue. Chlorophyll-*a* was measured by filtering 1l of surface water using GF/C Whatman filters, and further spectrophotometric analyses of the acetone 90% extracts following the protocol of Lorenzen (1967).

Samples for copepods study were collected at one sampling station with horizontal tows using a cylindrical plankton net (70 µm mesh, 30 cm mouth diameter and 120 cm total length). A flowmeter was mounted at the center of the mouth opening. The net was towed near the surface (0~1 m) at an average speed of 1 $m.s^{-1}$ for 5 min. The contents of the cod ends were preserved with formalin (4% final concentration) for further quantitative and qualitative analyses.

The potential relations between environmental parameters and copepod community were tested for significant parametric correlation ($p < 0.05$) by Pearson's correlation coefficient using monthly average values.

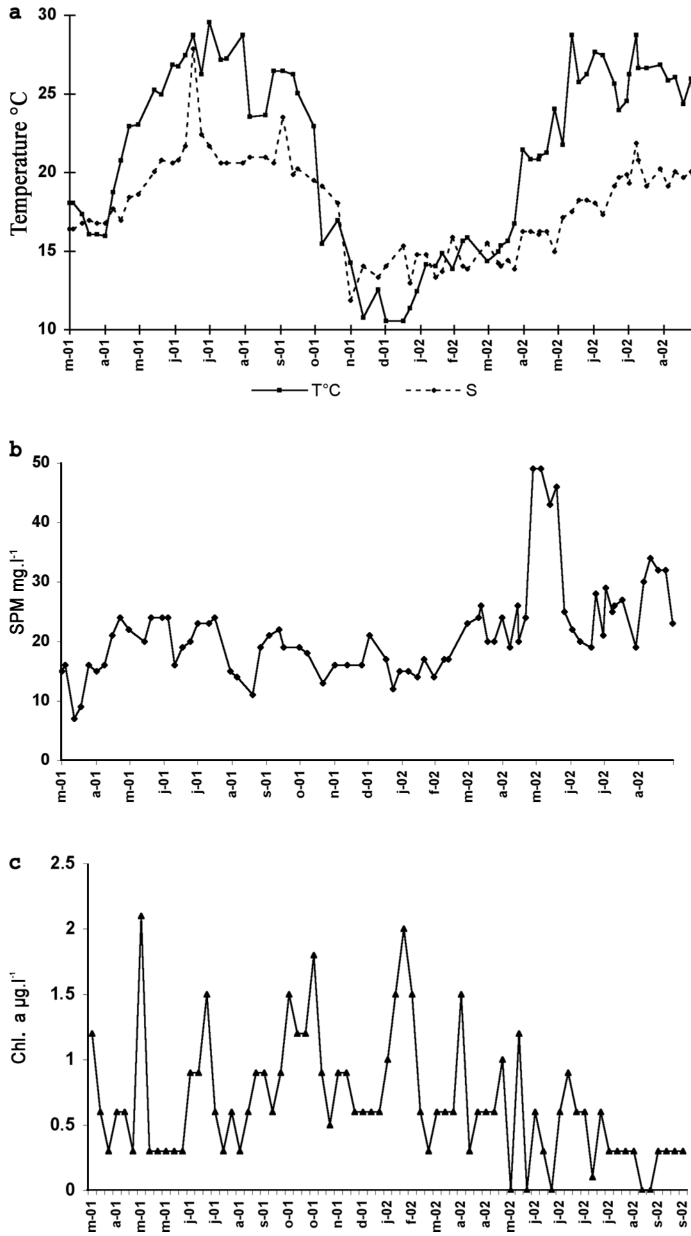

Figure 2. A. Weekly patterns of surface temperature (dashed lines) and salinity (solid line). **B.** Weekly patterns of SPM. **C.** Weekly patterns of Chlorophyll-*a* concentrations. Tunis North lagoon, March 2001 to September 2002.

Figure 2. A. Variations hebdomadaires de la température (ligne discontinue) et de la salinité (ligne continue). **B.** Variations hebdomadaires des matières en suspension. **C.** Variations hebdomadaires de la concentration en chlorophylle *a*. Lagune Nord de Tunis de mars 2001 à septembre 2002.

Results

Environmental factors

The weekly patterns of surface water temperature, salinity, SPM and Chlorophyll-*a* concentrations are presented in

Table 1. Taxonomic composition and monthly average densites of planktonic copepods (adults + copepodids) in the North lagoon of Tunis.

Tableau 1. Composition taxonomique et distribution moyenne mensuelle des densités des copépodes planctonique (adultes + copépodites) dans la lagune nord de Tunis.

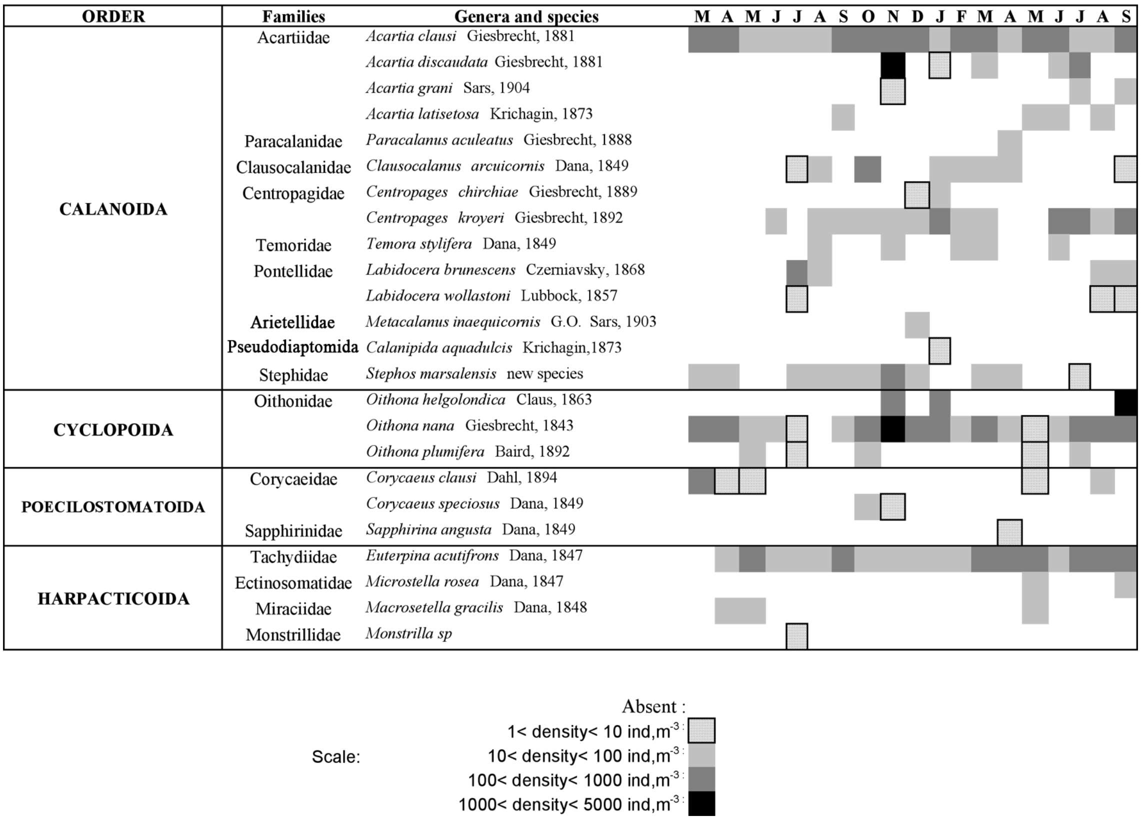

figure 2. The weekly values of temperature ranged from 10.5°C to 29.5°C. Surface water salinity fluctuated between 35 in the last week of November 2001 and 43.8 in the second week of July 2001 (Fig. 2A). Average salinity was about 38.3 during the whole study period. The maximum SPM value obtained was 49 mg.l^{-1} (Fig. 2B). This value was registered at the end of spring (last week of April 2002) and the beginning of summer (first week of June 2002) coinciding with the period of macro-algae degradation in the North lagoon of Tunis. Chlorophyll-*a* concentrations were very low with a seasonal average of 0.66 µg.l^{-1}. However, three sporadic peaks exceeding 1.5 µg.l^{-1} were found throughout the period of study (Fig. 2C) during the first week of May 2001 (2.1 µg.l^{-1}), October 2001 (1.8 µg.l^{-1}) and February 2002 (2 µg.l^{-1}).

Temporal variations in copepod abundance and species composition

Total mesozooplankton abundance was variable within the study period (Fig. 3A), ranging between 200 and 76,320 ind.m^{-3}, with an average of 9,336 ind.m^{-3}. The temporal dynamics of mesozooplankton were characterized by four major peaks (Fig. 3A). The first peak occurred in the last week of March 2001 with a density reaching 39,500 ind.m^{-3}. The second peak, the peak of highest abundance, was observed during the second week of August 2001 with 76,320 ind.m^{-3}. The third autumnal peak (November 2001) had a density of 54,800 ind.m^{-3}. The fourth peak was observed in September 2002 with 47,120 ind.m^{-3}. All these peaks resulted from a high contribution of nauplii (Fig. 3C). Copepods (from nauplii to adults) dominated the mesozooplankton community throughout the period of investigation (Fig. 3A), averaging 68.3 % of the total mesozooplankton (range: 4.5-99.4%).

Copepod nauplii constituted the bulk of the community representing 55.8% of total mesozooplankton abundance (range: 2.3-95.9%). The lowest contribution of copepods nauplii to total mesozooplankton was especially detected during spring-summer 2002 (Fig. 3C), coinciding with low values of chlorophyll-a concentrations (Fig. 2C).

The cyclopoids (including poecilostomatoids), which

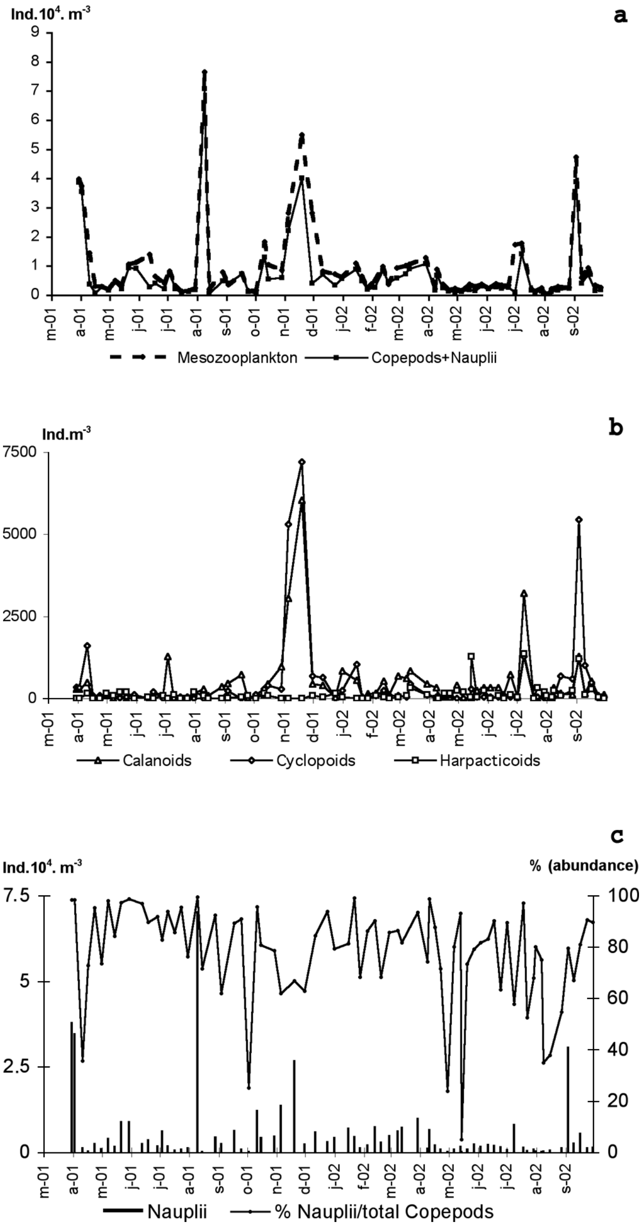

Figure 3. A. Weekly patterns of abundance of Mesozooplankton in Tunis North lagoon. **B.** Weekly pattern of abundance of calanoids, cyclopoids and harpacticoids in Tunis North lagoon. **C.** Percentage (in abundance) of nauplii in total planktonic copepods in Tunis North lagoon.

Figure 3. A. Variations hebdomadaires de l'abondance du Mesozooplancton dans la lagune Nord de Tunis. **B.** Variations hebdomadaires de l'abondance des Calanoïdes, Cyclopoïdes et Harpacticoïdes dans la lagune Nord de Tunis. **C.** Pourcentage (en abondance) des nauplii par rapport à l'abondance des copépodes totaux dans la lagune Nord de Tunis.

were represented mostly by *Oithona nana* (87%), dominated the copepod community during spring 2001, autumn 2001 & 2002. However, calanoids were the main contributors of the copepod community in summer 2001 & 2002, in winter 2002 and spring 2002 (Fig. 3B). The largest abundance of harpacticoids was recorded during spring 2002.

Finally, 24 species of copepods belonging to 16 families were identified (Table 1). Calanoida was the most diverse order (14 species), followed by harpacticoida (4), cyclopoida (3) and poecilostomatoida (3). The copepod taxonomic composition was dominated by small neritic species. According to their occurrence and abundance, *Oithona nana*, *Acartia clausi* and *Euterpina acutifrons* dominated the planktonic copepod community followed by *Centropages kroyeri, Stephos marsalensis, Oithona helgolandica, Acartia discaudata, Acartia grani*, *Acartia latisetosa, Centropages chirchiae, Temora stylifera, Clausocalanus arcuicornis, Labidocera brunescens* and *Oithona plumifera*.

There was a distinct change in copepod species composition over the seasons (Fig. 4). We observed a shift from a community mostly dominated by *Oithona nana*, *Acartia clausi* and secondary by *Corycaeus clausi*, *Euterpina acutifrons* and *Stephos marsalensis* in spring 2001 towards a larger contribution of other species in summer 2001 such as *Labidocera brunescens* (summer species from Tunis Bay), *Centropages kroyeri*, *Euterpina actutifrons* with a lower contribution of *Acartia clausi*, *Oithona nana*, *Stephos marsalensis* and other small neritic species like *Clausocalanus arcuicornis*. The autumnal planktonic copepods community was mostly dominated by *Oithona nana* and *Acartia discaudata*. We recorded a secondary contribution of *Acartia clausi*, *Oithona helgolandica, Clausocalanus arcuicornis* and *Stephos marsalensis*. During winter 2002, the copepod populations were dominated by *Acartia clausi* and *Oithona nana* that were associated with *Centropages kroyeri*, *Oithona helgolandica* and *Euterpina actutifrons*. The seasonal variation in copepod abundance showed that *Euterpina acutifrons, Acartia clausi* and *Oithona nana* dominated in spring 2002. In summer 2002, *Oithona nana*, *Euterpina acutifrons*, *Centropages kroyeri*, *Acartia discaudata, Acartia clausi* and *Acartia latisetosa* dominated the planktonic copepod community. During September 2002 the copepod community was numerically dominated by cyclopoids *Oithona helgolandica* associated with *Euterpina acutifrons, Centropages kroyeri*, *Acartia clausi* and *Oithona nana*.

Relationships between copepod abundance and environmental variables (Table 2)

Total planktonic copepod abundance was not correlated with temperature, salinity, SPM and chlorophyll-*a*. With regard to the different copepod species, temperature was correlated ($P < 0.05$) with *Acartia latisetosa* ($r = 0.43$) and *Oithona plumifera* ($r = 0.43$). Other correlations ($P < 0.05$) with salinity were also found for *Labidocera brunescens* (r

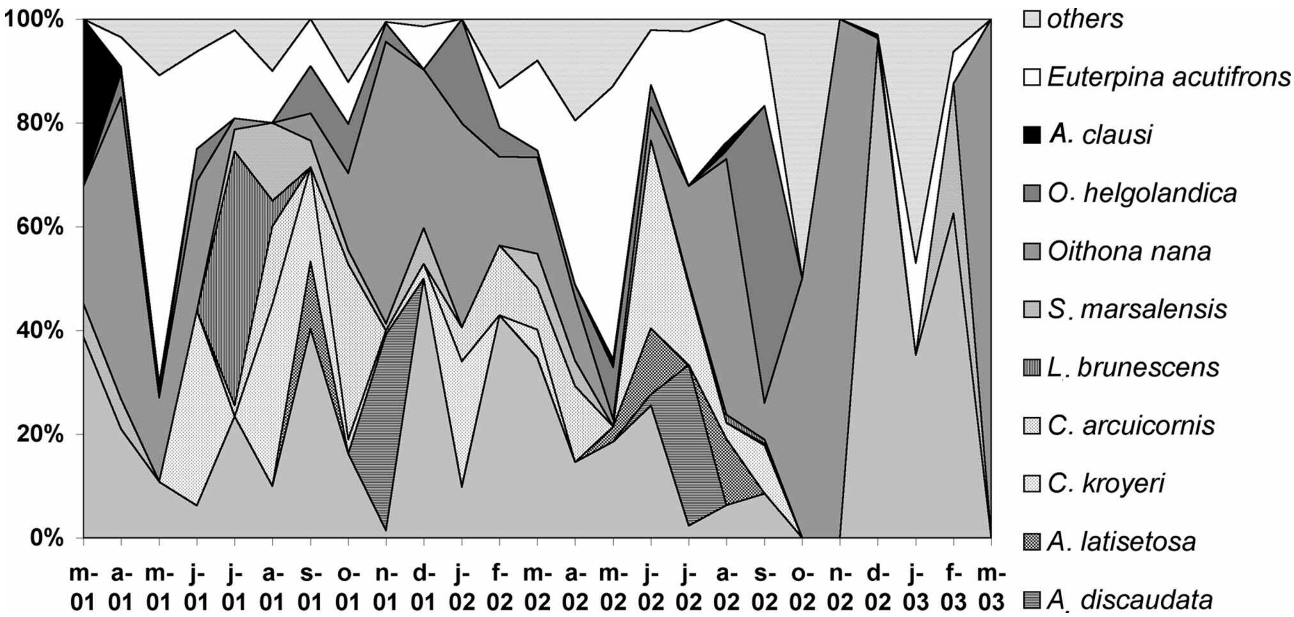

Figure 4. Average monthly contribution of the main taxa in total planktonic copepod abundance.
Figure 4. Contribution moyenne mensuelle des espèces principales par rapport à l'abondance totale des copépodes planctoniques.

= 0.44) and *Oithona plumifera* (r = 0.42). *Centropages kroyeri* and *Euterpina acutifrons* showed correlations with SPM (r = 0.44 and 0.43, $p < 0.05$). Only nauplii (r = 0.42, $p < 0.05$), *Clausocalanus arcuicornis* (r = 0.57, $p < 0.05$) and *Corycaeus speciosus* (r = 0.46, $p < 0.05$) showed positive correlations with chlorophyll-*a*.

Discussion

Mesozooplankton of the North Tunis lagoon was dominated by copepoda, which made up nearly 70% of total abundance. The dominance of copepoda in Tunisian lagoons has already been described in Tunisian (Daly-Yahia & Romdhane, 1994) and other Mediterranean lagoons (Lam Hoai & Amanieu, 1989).

Planktonic copepod densities in the North lagoon of Tunis showed two characteristics: low values (except the four peaks) and strong temporal and seasonal fluctuations. Densities of Copepod populations in the North lagoon of Tunis seem to be controlled by predators and by the low chlorophyll-a stock. The rich macrophyte communities in the North lagoon of Tunis allow proliferation of hydrarians of *Obelia* spp (Daly-Yahia et al., 2003; Annabi-Trabelsi et al., 2004). During the study period hydromedusea (*Obelia* spp) represented a controlling factor in copepod population dynamics (Fig. 5). Total copepods densities were negatively correlated ($P < 0.001$, r = -0.62) with these predators, despite their small size.

Table 2. Pearson correlations coefficients between copepods taxa abundance and environmental factors (temperature, salinity, SPM and chl-*a* concentrations). *: $P < 0.05$.

Tableau 2. Coefficients de corrélation de Pearson entre l'abondance des espèces copépodes et les paramètres environnementaux (température, salinité, MES et concentrations en chl-*a*). *: $P <$ 0,05.

	temperature	Salinity	SPM	Chl-a
temperature				
Salinity	0.89*			
SPM	0.44*	0.17		
Chl-*a*	0.17	0.25	-0.3	
Nauplii	0.1	0.17	-0.3	0.42*
A. clausi	-0.34	-0.19	-0.01	-0.3
A. discaudata	-0.1	-0.01	-0.2	0.1
A. latisetosa	0.43*	0.34	0.37	-0.12
C. kroyeri	0.4	0.33	0.44*	-0.08
C. arcuicornis	0.11	0.16	-0.1	0.57*
L. brunescens	0.35	0.44*	0.02	0.09
O. nana	-0.14	-0.02	-0.2	0.1
O. plumifera	0.43*	0.42*	0.15	0.40
O. helgolandica	0.15	0.16	0.28	-0.11
C. speciosus	0.21	0.26	-0.1	0.46*
E. acutifrons	0.34	0.17	0.43*	-0.14
total copepods	0.04	0.14	-0.3	0.37

The water column is inhabited by fish that may feed on zooplankton, principally copepods, their preferred food

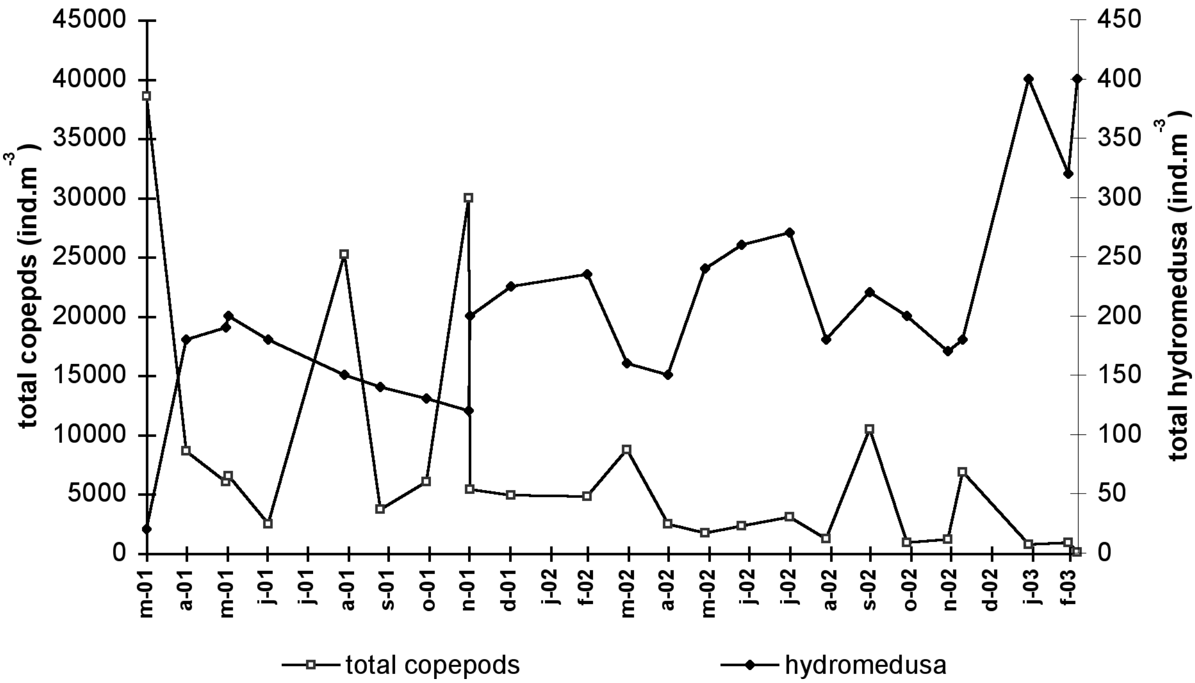

Figure 5. Average monthly densities of total planktonic and hydromedusa in the North Lagoon of Tunis.
Figure 5. Densités moyennes mensuelles des copépodes totaux et des hydroméduses dans la Lagune nord de Tunis.

(Thiel, 1996). Calanoid copepods constitute a high quality food source for fish (Hop et al., 1997) and their maximum abundance recorded during summer and autumn (Fig. 3B) were corresponding respectively to the period of recruitment of anchovies and the period of migration of Mugilidae (Tudela & Palomera, 1997). For cyclopoids including poecilostomatoids, the maximum abundance was observed in October 2001 and August 2002 (Fig. 3B) and is associated with the abundance of macrozooplankton like microphageous scyphomedusa that occurred at density of 0.5 ind.m^{-3} and rapidly controlled and reduced these peaks (Annabi-Trabelsi et al., 2004).

Most of the copepod species reported in this study are common in the coastal waters of Tunisia and have been mentioned in previous investigations in Tunis Bay (Daly-Yahia et al., 2004) showing a feed-back phenomenon between the North lagoon of Tunis and Tunis Bay.

The southwestern polluted part of the bay of Tunis that communicates directly with the North lagoon of Tunis is characterized by neritic r-strategy-type species dominated by *Oithona nana, Centropages kroyeri, Acartia clausi* and *Euterpina acutifrons* (Daly–Yahia et al., 2004). Cyclopoid copepods are genrally able to survive in a wider range of habitats, and to maintain populations under more adverse conditions because they are morphologically less specialized than calanoids (Paffenhöfer, 1993). The genus *Oithona* that is numerically well represented in the lagoon was characterized by an autumnal maximum abundance (*Oithona nana* and *Oithona helgolandica*). Many studies in the Mediterranean reported a maximum of this genus in the winter and beginning of spring (Mazzocchi & Ribera d'Alcalà, 1995; Siokou-Frangou, 1996). *Oithona* spp dominated especially in summer in the Bay of Blanes (coastal NW Mediterranean) (Calbet et al., 2001). These differences in copepod seasonal successions between coastal Mediterranean areas may be explained by the particular conditions of each one. *Acartia clausi* has been reported in Mediterranean (Lakkis, 1976; Gucu, 1987). *Acartia clausi* is confined to nearshore environments because of its inability to feed on the phytoplankton below a certain cell concentration (Thor, 2000). *Euterpina acutifrons* is a highly eurythermic and euryhaline species, as has been demonstrated by laboratory experiments (Moreira et al., 1982) that colonizes virtually all coastal marine environments (Delia Vinas & Gaudy, 1996). The occurrence of deep water or oceanic species such as *Paracalanus aculeatus, Centropages chirchiae, Labidocera brunescens, Oithona plumifera, Sapphirina angusta* gives an indication of the importance of water exchanges between the lagoon and Tunis Bay. This input and the hydrological conditions in the lagoon especially controlled by laevogyrate circulation and exchange frequency of 25 days that is greater than the average of development time of a copepod generation (approximately 20 days) influenced copepod community structure.

The distribution and succession of copepods are influenced by environmental factors, especially in estuaries, bays and lagoons (Ferrari et al. 1985). According to Calbet et al. (2001), the fact that the abundance of a given species is well correlated with an environmental factor, such as temperature, does not imply causality. For instance, in our study we did not find any correlation between environmental factors and the dominant species *Acartia clausi* and *Oithona nana* that appeared in all the study period and probably presenting omnivorous copepods adapted to low chlorophyll-*a* concentrations in the lagoon. In fact, *Acartia* has been categorized as an omnivorous, and non-opportunistic feeder (Cotonnec et al., 2001). *Euterpina acutifrons* and *Centropages kroyeri* showed positive correlation with SPM. The ability of *Euterpina acutifrons* to feed on detritus could explain its dominance in many shallow coastal areas (Moraitou-Apostolopoulou, 1978). *Clausocalanus arcuicornis* and *Corycaeus speciosus* are probably herbivores because their abundance pattern correlates to chlorophyll-*a* concentrations. *Acartia latisetosa*, *Oithona plumifera* and *Labidocera brunescens* are typically summer copepods that appeared with the increase of water temperature and salinity in the North lagoon of Tunis.

The total species composition and distribution of copepods in the North lagoon of Tunis were not mostly and directly affected by physical environmental factors (i.e., temperature, salinity, chl-*a* and SPM), but were rather influenced by hydrodynamic (the exchanges with Tunis bay) and predators.

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