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Abundance and diversity of amphipods (Crustacea: Peracarida) on shallow algae and seagrass in lagoonal ecosystem of the Mediterranean Tunisian coast

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Abstract

Background: Bizerte lagoon is a semi-enclosed marine ecosystem, where various types of human activities have been developed. To investigate the distribution and temporal variation of amphipod assemblage, monthly sampling was conducted at the Menzel Jemil site from October 2009 to September 2010.

Results: A total number of 3,620 specimens were collected from floating algae and seagrass allowing the identification of 10 amphipod species. Moreover, several indices, species richness, dominance, mean density, and diversity index were estimated to characterize the amphipode assemblage. *Gammarus aequicauda* was the most dominant species in all seasons. In addition, the minimum and maximum values of species richness of amphipod were observed in January (3 species) and April (8 species), respectively. The mean density and species richness were negatively correlated with plant biomass. Mean Shannon index (*H*′) and evenness (*J*′) were 1.62 ± 0.34 and 0.67 ± 0.16, respectively. Non-metric multidimensional scaling (MDS) analysis based on the mean species density showed three seasonal groups of samples. Therefore, canonical correspondence analysis (CCA) made it possible to summarize the overall situation for the species, monthly sampling, and environmental parameters on a single graph.

Conclusions: Thus, the temperature, turbidity, and chlorophyll *a* content are the most often reported factors for the distribution and structure of amphipods in the Bizerte lagoon.

Keywords: Coastal lagoon; Temporal distribution; Amphipod assemblage; Tunisia

Background

Wetlands are ecologically very important and extremely productive ecosystems, however very sensitive essentially in transitional locations subject to environmental and anthropogenic constraints (Mouillot et al. 2005; Rossi et al. 2006; Blanchet et al. 2008). The Tunisian lagoons, like several Mediterranean wetlands, are subject to an increasing pressure in the anthropogenic activities (urbanization, industry, pollution, aquaculture, tourism, and overfishing). The consequences can be detected on the general state of ecosystems, mainly in macrofauna that is more sensitive and more exposed (Ben Mustapha et al. 1999; Ayari and Afli 2003). In the last decades, Bizerte lagoon in the northeast of Tunisia is the best example that illustrated the disturbances that were mainly caused by the worn water rejections coming from the bordering cities (Dellali et al. 2001), the naval port and the metallurgic factory of Menzel Bourguiba, and some other industries (iron and steel plant, cement factory, refinery) established on its shoreline (Essid and Aissa 2002).

Most studies are carried out on invertebrates in the northern Mediterranean lagoon (Migné and Davoult 1997; Danesi et al. 1999; Mizzan 1999; Kevrekidis et al. 2000). In Tunisia, information on lagoonal invertebrate biodiversity is relatively scarce (Diawara et al. 2008; Tlig-Zouari and Maamouri-Mokhtar 2008; Tlig-Zouari et al. 2009; Afli et al. 2009).

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Amphipods represent one of the most important groups of invertebrates associated with algae and seagrass, playing an important link in trophic webs from producers to higher consumers such as fish populations (Sanchez-Jerez et al. 1999; Zakhama-Sraieb et al. 2006; Fernandez-Gonzalez and Sanchez-Jerez 2014). Moreover, this fauna is sensitive to environmental conditions and therefore constitutes a good bioindicator of pollution (Bellan-Santini 1980; Virnstein 1987; Conradi et al. 1997; Guerra-Garcia and Garcia-Gomez 2001). Amphipods have proven to be a difficult group to identify due to their small size and morphology; they are however scantily sampled and studied in the lagoon systems (Diviacco and Bianchi 1987; Procaccini and Scipione 1992).

The present study focuses on the dynamics during an annual cycle, with the aim to assess the influence of plant biomass and abiotic factors on the dynamics of amphipod assemblages in the Bizerte lagoon. The selected location appears suitable to analyze the temporal distribution of amphipods and the possible influence of some environmental factors on them. Results will be compared with similar studies on other Mediterranean lagoons. Our hypotheses are that algae and seagrass of the Bizerte lagoon function as a refuge for the amphipod assemblages and that they may change during the year in relation to environmental factors.

Methods

Area of study

The Bizerte lagoon is located in the northeast part of Tunisia, between latitudes: 37°8′ N and 37°14′ N, and longitudes: 9°46′ E and 9°56′ E (Figure 1). It covers an area of 130 km^2 and has a mean depth of 7 m. It is known for its geostrategic position since it is connected to the Mediterranean Sea through a 6 km long inlet and to the Ichkeul Lake through the Tinja channel, which is approximately 5 km long and a few meters in depth (3 m in the overflow period). The tide undergoes changes in the water level of the Mediterranean, while that own Bizerte lagoon is negligible (Chebbi 2010). The lagoon lies in the vicinity of several cities (Bizerte, Zarzouna, Menzel Abderrahmen, Menzel Jemil, and Menzel Bourguiba) and industrial units.

Sampling was performed in Menzel Jemil (37°13′2″ N 9°55′8″ E) in the northeast of Bizerte lagoon from October 2009 to September 2010 where algae and seagrass were developed during all the years. In this station, the bottom is sandy to sandy-mud.

Sampling procedure

The benthic macrofauna was sampled monthly during 1 year (from October 2009 to September 2010) using a metal quadrat of 25 × 25 cm with 12 replicates between 20 and 80 cm depth according to the tide. Those replicates were taken from one sampling site in Menzel Jemil and separated from a minimum of 2 m. Specimens were collected from a mix of algae *Gracilariopsis longissima* (S.G. Gmelin) M. Steentoft, L.M. Irvine & W. F. Farnham 1995, *Gracilaria bursa-pastoris* (S.G. Gmelin) P. C. Silva 1952, *Cladophora* sp., *Ulva lactuca* (Linnaeus, 1753), and seagrass *Cymodocea nodosa* (Ucria) Ascherson, 1870. Animals were removed by washing the vegetation in a big tray and recovered on a sieve of a 1 mm mesh, which retained all individuals including amphipods. Retained specimens were sorted, fixed in 70% alcohol, and then identified to species and counted. After that, the plant biomass was estimated by weighting algae and seagrass after being dried at 70°C for 48 h.

A trophic guild analysis was done attributing the identified species to trophic categories, according to the literature (Guerra-Garcia et al. 2014) as follows: S, suspension feeders; DS, deposit-suspension feeders; He, herbivores; De, plant detritus feeders; and O, omnivores.

Experimental observation

The following parameters were measured monthly *in situ*: temperature (T), salinity (S), pH, dissolved oxygen (O_2), and turbidity (Tr). Temperature, salinity, pH, and dissolved oxygen were measured at approximately 10 cm below the surface using a salinometer (WTW Cond 315i, SUNTEX, Weilheim, Germany), a pH meter (pH 330i/SET, SUNTEX, Weilheim, Germany) and oximeter (WTW Oxi315i/SET, SUNTEX, Weilheim, Germany) calibrated beforehand. The laboratory analysis of the surface water samples (at 10 cm) was performed for nitrites (NO_2^-), nitrates ($NO^-{}_3$), and phosphorous ($PO_4{}^{3-}$). The chlorophyll a (Chl a) content was determined using the spectrophotometric method of Lorenzen (1967) and following the procedure given by Parsons et al. (1984) after 24 h extractions in 90% acetone at 5°C in the dark.

Data analysis

To evaluate the importance of the different species, (i) the total abundance (over the study period) (Ni) and monthly mean abundances, (ii) the total dominances (Di%), and (iii) the frequencies (Ci) were estimated.

The mean density (individuals.m^{-2}) was calculated for each month. Collections in April to September were grouped and considered as samples from the dry season, whereas collections in December to March were considered as samples from the rainy season.

Total abundance of amphipod (N), number of species (S), Shannon-Wiener diversity index (H') (Shannon and Weaver 1963), and Pielou's evenness index (J') (Pielou 1966) were monthly calculated. Non-metric multidimensional scaling (MDS) (Kruskal and Wish 1978) were performed based on mean abundance of species at each sample.

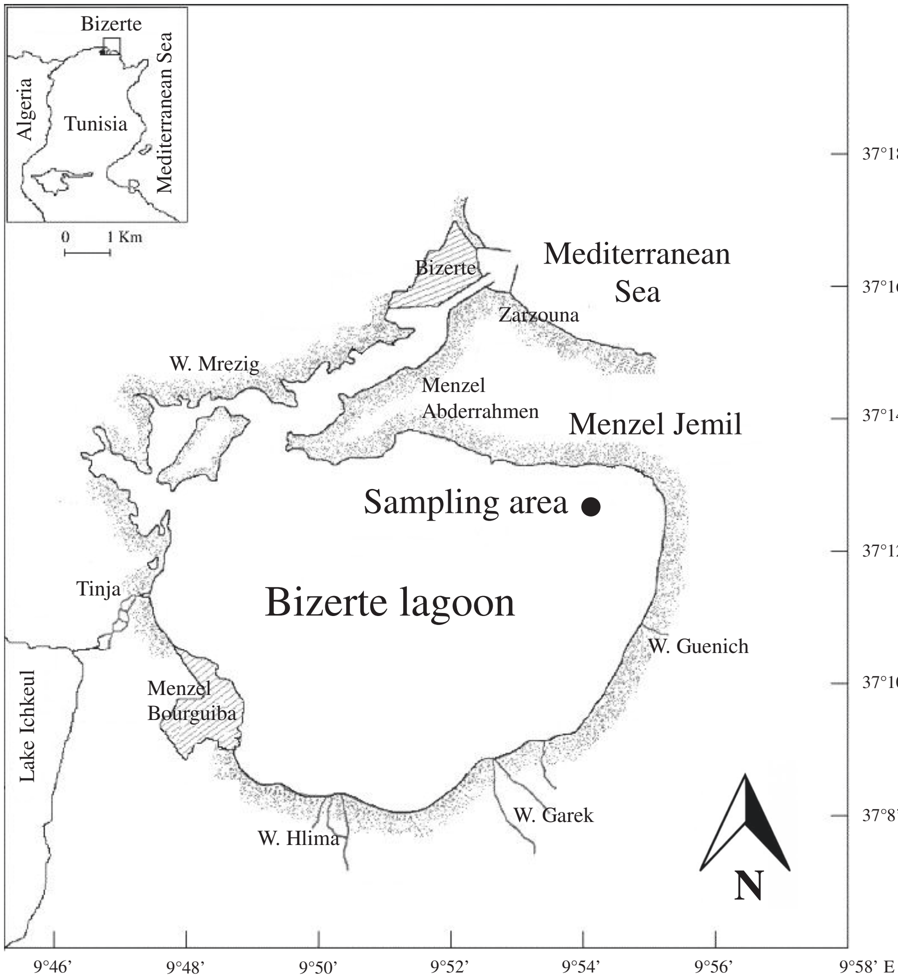

Figure 1 Map of the Bizerte lagoon area showing the location of the study site (Menzel Jemil) and wadis (W).

To investigate the relationship between the environmental variables and the species abundance data, the canonical correlation analysis (CCA) (Anderson and Willis 2003), extremely informative, was applied to the data to show which was the most contributed parameter in the differences reported among samples. The analysis was performed using PRIMER v5.2 (Plymouth Routines of the Multivariate Ecological Research software package) (Clarke and Warwick 1994) and XLSTAT 2013.

Results

Vegetal composition

The biomass of each plant species (Table 1) collected during an annual cycle shows a seasonal variation. In fact, the biomass of *G. bursa-pastoris* is maximized in the spring while that of *U. lactuca* peaked in summer (68.6 g.m^{-2} in August). Regarding *Cladophora* sp., it appears in winter, when the three algae biomass decreases and reappears in summer with the proliferation of *U. lactuca*. The seagrass *C. nodosa* is present all year, and its biomass reaches a maximum in autumn (38.48 g.m^{-2} in November).

The highest total plant biomass was recorded in early summer reaching 127.12 g.m^{-2} in June, followed by spring and autumn, whereas the lowest one was reported in winter (23.11 g.m^{-2} in January), showing a clear seasonal trend (Table 1).

Abiotic factors

Due to the connection of the Bizerte lagoon to the Mediterranean Sea from the north and to the Ichkeul Lake from the south, the exchange of seawater and the freshwater impact from wadi runoff defines the brackish characteristics and the presence of seasonal spatial gradients in the distribution of the abiotic and biotic variables inside the lagoon. In the present study, the term *wadi* means a temporary or permanent watercourse, whose flow depends on rains. The principal *wadis* which feed the Bizerte lagoon with freshwater are the *wadis* of Mrezig, Hlima, Garek, Guenich, and the channel of

Table 1 Monthly variation of total plant biomass (gDW.m^{-2}) and amphipod abundance and values of Shannon-Wiener (*H*′) and evenness indexes (*J*′)

	October	November	December	January	February	March	April	May	June	July	August	September	Ni	Di	Ci	Ci × Di	TG
Macroalgae and seagrass																	
Ulva lactuca	4	7	5.15	2.11	3	3	8	10.73	60	66.10	68.60	30					
Cladophora sp.	0	0	7	2	3	3.73	0	0	8	11	0	0					
Gracilariopsis longissima	1	4	0	3	14	20	27	30	20.10	11.01	8	9.08					
Gracilaria bursa-pastoris	1	4	0	4	15	20	30.18	32	23	11.10	8.01	9					
Cymodocea nodosa	38	38.48	30	12	8	7	8	8	16.2	17	17	37.08					
Monthly total biomass	44	61.48	41.15	23.11	44	53.73	73.18	80.73	127.12	116.21	96.7	85.16					
Amphipods																	
Gammarus aequicauda (Martynov, 1931)	99	199	87	111	128	132	320	165	172	116	41	233	1,803	49.80	1	49.80	De
Gammarus insensibilis Stock, 1966	89	19	38	113	92	11	89	12	18	13	6	94	594	16.40	1	16.40	De
Gammarella fucicola (Laech, 1814)					15		49	32	18	34	87	81	325	8.97	0.66	5.92	He
Elasmopus rapax Costa, 1853	9	1				5							15	0.41	0.25	0.10	S
Monocorophium acherusicum (Costa, 1853)	7	3					1					4	15	0.41	0.33	0.13	Ds
Ericthonius difformis (Milne-Edwards, 1830)	21	20	28	67	11	48	8	14	8	32	29		286	7.90	0.91	7.18	Ds
Cymadusa filosa Savigny, 1816	13	19	12	6		15	5	14		153	159	84	480	13.26	0.66	8.75	He
Microdeutopus gryllotalpa Costa, 1853							5	10	1	9		9	34	0.94	0.41	0.38	He
Dexamine spinosa (Montagu, 1813)							11	10	4	42			67	1.85	0.33	0.61	De
Caprella sp. (Laech, 1814)		1											1	0.02	0.08	0.00	O
N	238	262	165	297	246	220	488	257	221	399	322	505	3,620	100			
H′	2.19	1.53	1.70	1.54	1.37	1.05	1.74	1.74	1.03	1.92	1.68	1.98					
J′	0.78	0.54	0.85	0.97	0.68	0.45	0.58	0.62	0.4	0.74	0.72	0.76					

Tinja (Figure 1). In rainy seasons, autumn, winter, and early spring, the winds induce a vertical mixture of the water column, the rains are strong, and the freshwater flow coming from the Ichkeul Lake is important. On the other hand, in summer, the dry season, the influence of seawater is important and the water column warming can induce its stratification.

Physical properties, temperature, and salinity of the Bizerte lagoon varied, depending on rainy season and atmospheric forcing (Table 2). Water temperature and salinity ranged from 9°C in January to 30.86°C in August and from 30.8 psu in February to 39.2 psu in August, respectively, indicating a seasonal gradient of temperature and salinity in this lagoon. However, dissolved oxygen content showed an obvious seasonal variation from 4.8 mg.l^{-1} in October (autumn) to 7.3 mg.l^{-1} in May (spring). The turbidity varied from 2.1 NTU in April (spring) to 15.44 NTU in October (autumn). The high nitrogen anion content (NO_3^- and NO_2^-), measured during the sampling period, was about 3.7 μmol.l^{-1} in winter. The maximum phosphorous content was about 0.38 μmol.l^{-1} in August. The Chl *a* content ranged between 3.3 μg.l^{-1} in April and 6.3 μg.l^{-1} in August.

Except for the pH, homogeneous during the sampling period, the temperature, salinity, dissolved oxygen, and turbidity fluctuated with season (Table 2). In fact, the winter cold and wet conditions decrease the water temperature and salinity at 9°C and 30.86 psu, respectively. In summer, the hot and dry conditions lead to the opposite situation because of evaporation (30.86°C and 39.2 psu).

Amphipod assemblages and species affinities

Results of the frequencies (Ci) are divided into several categories in ascending order of constant according to the Lopez De La Rosa et al. (2006) classification. Therefore, *Caprella* sp. (Ci <12%) is considered as a scarce species; *Elasmopus rapax* (13% ≤ Ci ≤ 25%) a restricted species; *Monocorophium acherusicum*, *Dexamine spinosa*, and *Microdeutopus gryllotalpa* (26% ≤ Ci ≤ 50%) are common species; and *Gammarus aequicauda*, *Gammarus insensibilis*, *Gammarella fucicola*, *Cymadusa filosa*, and *Ericthonius difformis* are constant species (51% ≤ Ci ≤ 100%). According to the Ci% × Di% values (>5), the most important species in the amphipod assemblage are *G. aequicauda*, *G. insensibilis*, *G. fucicola*, *E. difformis*, and *C. filosa*, representing 88.074% of the total number of specimens.

Our results showed that seasons have a noticeable effect on the amphipod assemblage structure, at the Menzel Jemil station, affecting species richness, mean density, and diversity. *Caprella* sp. was absent in the samples except in November, where the presence of one specimen was probably due to the frequent tides in autumn. Although they are typical lagoon species, *M. acherusicum* and *E. rapax* were rarely observed in Menzel Jemil. In fact, the presence of the two species *D. spinosa* and *M. gryllotalpa* is limited to the spring period during which the *Gracilaria* are dominant. However, *E. difformis*, *C. filosa*, *G. insensibilis*, and *G. aequicauda* were collected throughout the sampling period and whatever the season, with varied abundance. The presence of these species coincides with that of the seagrass *C. nodosa* and the macrophyte *U. lactuca*.

The monthly species richness fluctuated between 3 and 8 in January and April, respectively (Figure 2). The lowest species richness was recorded in winter.

In fact, during the most part of the study period, the mean density according to the four depths (20, 40, 60, and 80 cm) exhibited a similar evolution to the species richness (Figure 2). In December, the mean density showed the lowest value and then increased from spring to summer. Shannon-Wiener diversity ranged between

Table 2 Monthly variation of physicochemical parameters of water in Menzel Jemil during the sampling period

Months	*T* (°C)	*S* (psu)	pH	O_2 (mg.l^{-1})	Tr (NTU)	NO_2^- (μM.l^{-1})	NO^-_3 (μM.l^{-1})	PO^3_4 (μM.l^{-1})	Chl *a* (μg.l^{-1})
October	19.73	35.40	7.90	*(4.80)*	*(15.44)*	0.50	1.60	0.13	5.00
November	13.25	34.60	8.30	4.90	14.06	0.69	1.80	0.14	4.40
December	10.00	31.80	8.39	5.90	4.70	0.49	2.00	0.16	4.20
January	*(9.00)*	32.00	8.62	6.70	4.17	0.43	2.10	0.2	4.00
February	11.20	*(30.80)*	8.65	6.50	3.01	0.50	*(3.20)*	0.18	*(3.80)*
March	15.10	31.10	8.62	6.00	2.45	0.57	3.00	0.24	4.50
April	26.13	36.80	8.20	5.50	*(2.10)*	0.30	1.80	0.23	*5.30*
May	25.63	37.20	8.30	*(7.30)*	5.12	0.28	1.70	0.26	4.70
June	27.73	37.90	8.10	6.70	4.76	*(0.10)*	1.00	0.27	5.00
July	28.46	39.00	8.20	5.70	6.42	0.70	0.81	0.28	*5.70*
August	*(30.86)*	*(39.20)*	8.10	5.90	3.20	*(1.00)*	(0.73)	0.38	*(6.30)*
September	26.70	38.60	8.38	5.60	6.18	0.49	1.40	0.12	5.40

For each parameter, maximum and minimum values were indicated in italic and in parentheses.

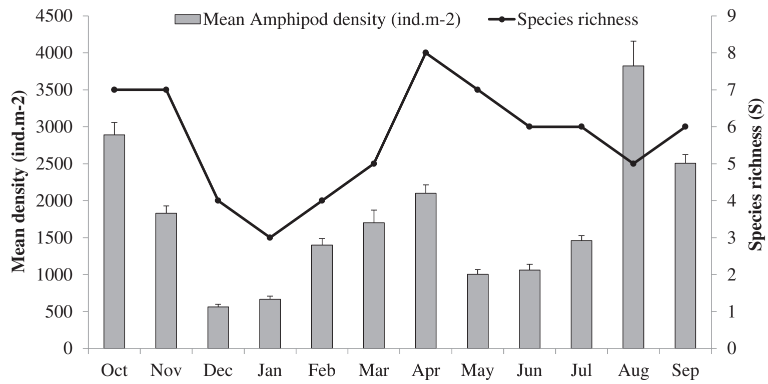

Figure 2 Monthly mean density and species richness of amphipods between October 2009 and September 2010.

1.03 bits in June and 2.19 bits in October. However, eveness index (J') showed low values in June (0.4) and peaked in January (0.97) (Table 1).

Relationships between amphipod fauna and environmental variables

MDS ordination plot based on the mean species density revealed three distinct groups of samples corresponding to different periods of the year (Figure 3). Group I included the samples of October and November (autumn), in which species richness and Shannon index were higher. *G. aequicauda* and *G. insensibilis* exhibited the most important mean density in this group. Group II was made up of months from December to March (winter) in which greater mean densities of *G. aequicauda* and *E. difformis* were found with decrease of species richness and increase of mean evenness index (J'). Group III, composed of months from April to September (spring and summer), has a greater mean density of *C. filosa*. The number of species increased and peaked in April.

According to the results of canonical correspondence analysis between amphipods species and environmental variables, the first two axes accounted for 77.95% of the variance of species-environment relation (Figure 4). Forward selection in this analysis selected water chlorophyll *a* content, turbidity, and temperature as the variables explaining most of the variance in the species data ($p < 0.01$). Nitrate concentration, pH, and salinity had less influence on the system, while nitrite and phosphate concentrations and dissolved oxygen had a minimal influence. The ordination showed that temperature, dissolved oxygen, and nitrite concentration were related to axis F1 and that pH, salinity, and chlorophyll *a* content, phosphate and nitrate concentrations, and turbidity were related to axis F2 (Table 3).

G. fucicola and *M. gryllotalpa* were associated with chlorophyll *a* content and pH. *C. filosa* was related to high values of temperature and salinity. *G. aequicauda* was associated with turbidity and nitrate concentration.

Dominant feeding guilds in all studied period were herbivores and plant detritus feeders (three species) followed by deposit-suspension feeders (two species), but suspensivores and omnivores were only represented with one species each (Table 1). Herbivores reached their highest values in summer, represented by *G. fucicola* and *C. filosa*; however, plant detritus feeders were abundant in autumn and represented by the genus *Gammarus*.

Discussion

The vegetation in Menzel Jemil consists essentially of five species with a seasonal variation in their distribution. Indeed, *G. longissima* and *G. bursa-pastoris* dominate other species in the spring, *U. lactuca* whose biomass increases from the spring peaked in summer, *Cladophora* sp. appears in the winter, while *C. nodosa*, all year round, dominates in autumn. The temporal distribution of *G. bursa-pastoris* and *U. lacuta* in Menzel Jemil station is similar to that described by Sahli-Hazami (2004). In the lagoon of Venice, Italy, Fava et al. (1992) describe another seasonal succession of vegetation cover which consists mainly of *Ulva rigida*; the *G. bursa-pastoris* is present during the cold season, *Cladophora* sp. is occasional, and marine phanerogam *Zostera noltii* is found in limited fields.

Plant species richness in the Menzel Jemil station is lower than that described by Zaouali (1980) and Frisoni et al. (1986) in the lagoon of Bizerte; this could be due to eutrophication resulting in the presence of *Ulva lacuta* (Anonyme 2000), or the increase in salinity caused a decrease in species diversity (Zaouali 1980).

Monthly plant biomass fluctuates with an increase in early spring, peaking in June, and a decrease in summer. Indeed, the rise in water temperature in the spring causes the increase in plant biomass, but when the temperature reaches its maximum in August, plant biomass starts to decrease to reach the lowest values in winter. Highlighting the close relationship between temperature and plant biomass confirms the work of Antit-Ben Rejeb (2012) which showed the same effect of

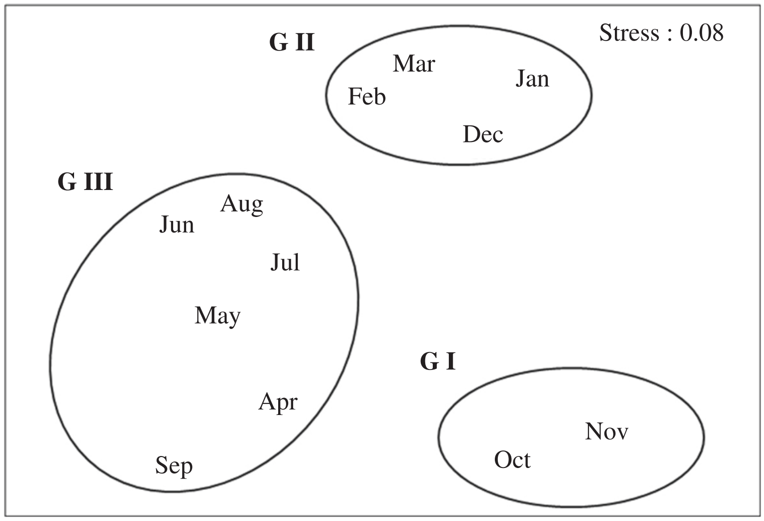

Figure 3 MDS ordination plots based on amphipod abundance of monthly sample.

temperature on the variation of biomass photophilic algae in the bay of Tunis.

In the Bizerte lagoon, water temperature ranges between 9°C in January to 30.86°C in August. Harzallah (2002) and Béjaoui et al. (2008) reported however a seasonal cycle in the lagoons, ranging between 10°C in winter and 28°C in summer, and from 11.5°C in January to 29.5°C in August, respectively. The water salinity ranges from 30.8 in February to 39.2 in August, which is higher than the values reported by ANPE (1990), 30 in winter to 38 in summer (Béjaoui et al. 2005). Thus, seasonal gradients of temperature and water salinity in the Bizerte lagoon are relatively large. Moreover, during the last decade, the temperature and salinity have increased. The evaporation in the lagoon is very important particularly in summer with 166 million $m^3.year^{-1}$. Precipitation does not exceed 146 million $m^3.year^{-1}$ in winter while it is weak and scarce in summer (74 million $m^3.year^{-1}$). The water input from the Ichkeul Lake has dramatically decreased during the last decades as an effect of the construction of dams discharging into this lake (MAERH 2003). This has led to a significant alteration of the water characteristics of the lagoon, particularly a dramatic increase in salinity (Béjaoui et al. 2005).

Dissolved oxygen content shows an obvious seasonal variation. Therefore, low water oxygenation logically

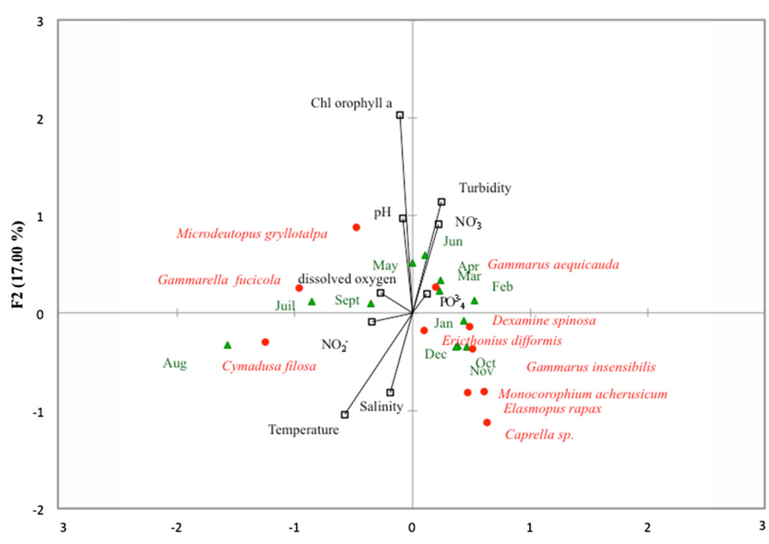

Figure 4 Canonical correspondence analysis ordination of environmental variables and sampled time. Red spot: species; green triangle: month; black square: physicochemical parameter.

Table 3 CCA: correlation matrix of environmental variables with the first two axes

	F1	F2
Temperature (°C)	−0.344	−0.096
Salinity (psu)	−0.188	−0.816
Dissolved oxygen (mg.l^{-1})	−0.273	0.209
pH	−0.079	0.964
Turbidity (NTU)	0.244	1.140
NO^{-}_{2} (μmol.l^{-1})	−0.574	−1.038
NO^{-}_{3} (μmol.l^{-1})	0.223	0.905
PO^{3-}_{4} (μmol.l^{-1})	0.119	0.195
Chl *a* (μg.l^{-1})	−0.106	2.022

characterizes the dry period. These results agree with those of Béjaoui et al. (2008). Nutrient variability appears to be related to two factors, by seawater coming from the ship canal and also by freshwater coming from the Ichkeul Lake and its large catchment area. The high nitrogen anion concentrations (NO^{-}_{3} and NO^{-}_{2}) and phosphorous content can be related to the domestic sewage input from towns around the lagoon and specially Menzel Abderrahmen city or to the freshwater from Oued Guenich located on the eastern side of the Bizerte lagoon which is widely open to an agricultural zone where fertilizers are constantly applied. These factors may provide the explanation of the various content of chlorophyll *a* during the sampling period. However, the turbidity appears to be related to two factors, (i) hydrodynamic conditions and (ii) rainy season, which create water movements. Indeed, studies performed by Harzallah (2003) on the currents of the Bizerte lagoon reveal that the flow of water in both the surface and the bottom follows the wind direction, which is often northwest with low amplitude. Nevertheless, the interpretation of these results must take into account the special conditions of the Bizerte lagoon, which is a transitional area currently affected by many environmental variables (Afli et al. 2008). Moreover, nutrients and chlorophyll *a* concentrations recorded during the sampling period are lower than those observed before the connection of the urban and industrial waste to the ONAS network (National Sanitation Utility) (MAERH 2003; Béjaoui et al. 2008). Besides, coastal lagoons are considered to be highly productive ecosystems but they are vulnerable to human disturbance as a result of their semi-enclosed situation and their proximity to the sources of terrestrial effluents (Bazairi et al. 2005).

In Menzel Jemil (Bizerte lagoon, Tunisia), 3,620 specimens of amphipods were collected from October 2009 to September 2010 belonging to 8 families and 9 genera; the species are common in Tunisian lagoons (Diawara et al. 2008; Zakhama-Sraieb et al. 2009). Differences in the abundance of the ten species were observed. While *G. aequicauda* was the most abundant, *G. fucicola*, *C. filosa*, and *Caprella* sp. were recorded for the first time in the Bizerte lagoon. *M. gryllotalpa* was typically a lagoonal species. Compared to Diawara et al. (2008), the number of amphipod species herein recorded is lower than that found in the Tunis north lagoon; however, a relatively high number of amphipod species are found in the coastal lagoon of Smir (northwest of Morocco) by Chaouti and Bayed (2011), by Cherkoui et al. (2003) in the Bou Regreg estuary Moroccan Atlantic coast, and by Mogias and Kevrekidis (2005) in the Laki lagoon (Northern Aegean).

Our results show that the distribution of the amphipod fauna in the Bizerte lagoon is primarily linked to temperature and salinity. Oscillations in these environmental variables are related to the climatic season. An increase in temperature and salinity is characteristic of the dry season (summer), when the seawater penetrates the lagoon in a greater volume as a result of reduced rainfall, whereas in the wet season (winter), freshwater comes from rivers and the Ichkeul Lake and thereby reduces salinity. These results agree with studies on distribution patterns for other crustaceans in relation to the temperature and salinity of the water, which are considered extremely important for a better understanding of the dynamics of these species (Pinheiro 1991). Variations in temperature and salinity have been cited by a number of authors as important factors for the occurrence of particular amphipod species (Nevis et al. 2009; Mogias and Kevrekidis 2005). In fact, many ecological studies have shown salinity to be the main factor controlling zonation in the structure of the benthic communities (Cacabelos et al. 2010). However, Bazairi et al. (2003) have emphasized that this is not the main factor in brackish environments. Some other authors have demonstrated that modification in habitat complexity affects crustacean assemblages (Sanchez-Jerez et al. 1999; Ayala and Martin 2003; Vazquez-Luis et al. 2008). Indeed, the importance of temperature should be interpreted carefully, since Ysebaert and Herman (2002) pointed out that long-term averages of environmental variables are more important than values obtained during samplings (Cacabelos et al. 2010). Nevertheless, the difference in mean density between months can be explained by the ecological preferences of each species. Amphipod assemblages at the Bizerte lagoon are dominated in terms of density and species richness by the genus *Gammarus*. The temporal variability of the total density is mainly due to the numerically dominant species, such as *G. aequicauda*, *G. insensibilis,* and *C. filosa*. The seasonal variation in mean density recorded from our study area was similar to that described in other Mediterranean lagoons (Mogias and Kevrekidis 2005; Procaccini and

Scipione 1992). With respect to changes in algae and seagrass, which create refuge and food resource to diverse amphipods, an important reduction in species richness was recorded in January in our study contrary to Mogias and Kevrekidis (2005) in July.

Concerning the diversity of the communities, the diversity index (H') and evenness (J') values are low in the different seasons. Moreover, abundance and species richness values showed a sharp decrease during December, January, and February when both temperature and salinity diminish, whereas equitability and Shannon-Wiener indexes in the studied amphipod assemblage are more stable over time than those found in other areas.

The temporal distribution of amphipod assemblage studied by analyses of similarity between the samples, based on the abundance of species, exhibited three major assemblages whose distribution is strongly dependent on the water temperature and shows a seasonal pattern. Similar distribution patterns for amphipods and other crustaceans have been reported in several studies (Bazairi et al. 2003; Mogias and Kevrekidis 2005; Lopez De La Rosa et al. 2006; Vazquez-Luis et al. 2008; Nevis et al. 2009; Cacabelos et al. 2010; Zakhama-Sraieb et al. 2010). In fact, canonical correspondence analysis (CCA) made it possible to summarize the overall situation for the species, sampling months, and environmental parameters on a single graph. In accordance with our results, the temperature, turbidity, and chlorophyll *a* content are the most often reported factors in determining the distribution and composition of amphipods in Menzel Jemil. However, phosphate and nitrite concentrations do not show large variability. Thus, amphipod assemblages are probably not very influenced by their modest variations. On the other hand, these changes in environmental factors in this study may affect algae and seagrass which are support of the amphipod assemblages.

Amphipods play an important role in structuring benthic assemblages (Duffy and Hay 2000) as secondary and tertiary producers in marine communities (Beare and Moore 1996). Amphipods are important source of food for benthic fauna of commercial interest and also very ecologically sensitive organisms and good indicators of natural or disturbed environmental conditions (Conradi et al. 1997). Moreover, benthic databases are essential for comparisons valuable for impact studies or monitoring programs, in order to preserve the environment and the species of commercial importance that they support (Desroy et al. 2002).

Conclusions

A total of 3,620 amphipod individuals were collected in Menzel Jemil (Bizerte lagoon, Tunisia) belonging to ten species. *G. aequicauda* was the most abundant species, and *G. fucicola*, *C. filosa*, and *Caprella* sp. were recorded for the first time in the Bizerte lagoon. The diversity index (H') and evenness (J') values are low in the different seasons, while abundance and species richness values showed a sharp decrease during December, January, and February when both temperature and salinity diminish. According to canonical correspondence analysis, the temperature, turbidity, and chlorophyll *a* content are the most often reported factors in determining the distribution and composition of amphipods in Menzel Jemil.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

All the authors performed the field sampling, participated and coordinated in the design and analysis of the study, and drafted the manuscript. All authors read and approved the final manuscript.

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