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ORIGINAL ARTICLE

Community structure of amphipods on shallow *Posidonia oceanica* meadows off Tunisian coasts

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Abstract The structure, diversity and spatial distribution of the amphipod fauna associated with *Posidonia oceanica* meadows were studied along the Tunisian coasts in 2007. Samples were collected in nine different meadows at 2 m depth. A total of 44 species belonging to 12 families were collected. The most common species in terms of abundance were *Ampithoe helleri*, *Hyale camptonyx* and *Ericthonius punctatus*. The highest values of abundance and species richness and the lowest values of diversity and equitability were found in meadows with high epiphyte biomass. Multivariate analyses of data indicated that epiphyte biomass and geographical position were major determinants of the distribution and composition of amphipod assemblages along Tunisian coasts. The presence of two lessepsian amphipod species in one of the southern *Posidonia oceanica* meadows modified the structure of assemblage.

Keywords Amphipoda · *Posidonia oceanica* · Tunisia · Epiphyte

Introduction

Posidonia oceanica, endemic magnoliophyte species in the Mediterranean Sea, is the most abundant and widely distributed seagrass species along the Tunisian coasts. *Posidonia oceanica* meadows constitute a very important ecosystem for benthic communities, providing habitat, protection and trophic resources for many species (Boudouresque et al. 2006).

Amphipod crustaceans, for example, are one of the most abundant groups associated with *Posidonia oceanica* seagrass (Chessa et al. 1983; Gambi et al. 1992; Zakhama-Sraieb et al. 2006a) where they reach a high biodiversity (Ledoyer 1966; Scipione and Fresi 1984; Gambi et al. 1992; Scipione et al. 1996; Zakhama-Sraieb et al. 2006b). They are also able to colonize different microenvironments and constitute an important link in trophic webs from producers to higher consumers (Bell and Harmelin-Vivien 1983; Virnstein 1987; Scipione and Mazzella 1992). They are highly dominant in coastal benthos and have long been known as sensitive environmental indicators (Thomas 1993). Many studies (Bellan Santini 1980, 1981; Conradi et al. 1997; Gomez Gesteira and Dauvin 2000; Guerra-Garcia and Garcia-Gomez 2001) have shown that amphipods are a very useful group in environmental studies, being good bioindicators of pollution in marine ecosystems.

The amphipod fauna of the Tunisian coast has been relatively unexplored. Following research on Tunisian amphipods conducted up to the beginning of the twentieth century (Chevreux 1910, 1911), a long interval ensued until our recent work (Zakhama-Sraieb et al. 2006a, b, 2008, 2009, 2010).

Several studies were conducted to identify the amphipod fauna inhabiting *Posidonia oceanica* meadows in the Mediterranean Sea, mainly along the northern shore (Scipione 1998; Scipione and Fresi 1984; Scipione et al. 1983, 1996; Diviacco 1988; Gambi et al. 1992; Sanchez Jerez et al. 1999). However, similar data are scarce and fragmented along the southern coasts. To rectify this lack of information, we conducted the present study which aims at: (1) analysing the composition and the structure of amphipod

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fauna in different *Posidonia oceanica* meadows distributed along Tunisian coasts; (2) investigating the potential relationships between the amphipod community composition and *Posidonia oceanica* features, and finally, (3) comparing our results with those carried along the northern shore of the Mediterranean Sea.

Materials and methods

Study sites

Sampling was carried out in July 2007 (between 15 and 23 of July) at the same depth (2 m) at 9 pm in order to avoid time and depth-related effects. A total of nine localities distributed along the Tunisian coast (Fig. 1) were selected: Tabarka, Bizerte and Rafraf in the North, Hergla, El Kantaoui, Monastir and Mahdia in the East and Zarzis Ogla and Zarzis plage Sonia in the South. In each selected locality, shallow *Posidonia oceanica* meadows covered the bottom beginning at 0.5–1 m depth.

Sampling procedure

Shoot density was estimated in situ by counting the number of shoots present in a 40 × 40 cm quadrat with ten replicates. Concurrently, twenty *Posidonia oceanica* shoots were randomly collected. In the laboratory, the leaves of each shoot were removed and their length and the width measured. The Leaf Area Index, corresponding to the leaf surface area of *Posidonia oceanica* for 1 m² of surface (m² m^{-2}), was also calculated. After that, the epiphytic biomass was estimated by scraping epiphytes from the leaves using a razor blade and weighing it after being dried in an oven at 70°C for 48 h. Epiphytes biomass is expressed in g. m^{-2}.

In order to sample the amphipods associated to *Posidonia oceanica*, a box quadrat of 30 × 30 cm and 25 cm depth was used and placed in each *Posidonia* meadow. The shoots were pulled up and collected in a bag (net size 0.3 mm). Three replicates were done at each site. The collected *Posidonia oceanica* shoots were washed with fresh water over a 0.5-mm sieve. Retained amphipods were sorted, identified to species and counted.

A trophic-guild analysis was done attributing the identified species to trophic categories, according to the literature (Scipione 1998; Gambi et al. 1992), as follows: D, deposit feeders; DS, deposit-suspension feeders; DC, deposit feeders-carnivores; Co, commensals; He, herbivores; De, plant detritus feeders; HeD, herbivores-deposit feeders; O, omnivores; U, unknown.

Statistical analysis

Total abundance (N), number of species (S), the Shannon–Wiener diversity index (H', $\log_2$) and Pielou's evenness (J) were calculated for each locality.

The one-way ANOSIM test was used to test differences among *Posidonia oceanica* features (Density of shoot, LAI, Epiphytes biomass) of different localities with the null hypothesis that there are no significant differences.

Relationships between amphipod assemblages at the nine *Posidonia oceanica* meadows were investigated using metric multidimensional scaling (MDS) to produce the best graphical descriptions of amphipods community similarities between sites taking in account the total abundances of species at each site. Data were square-root transformed to down weight the contribution of the most abundant species and then converted to a symmetric matrix of biotic similarity between pairs of sites using the Bray–Curtis similarity index. The BIOENV procedure was used to define suites of

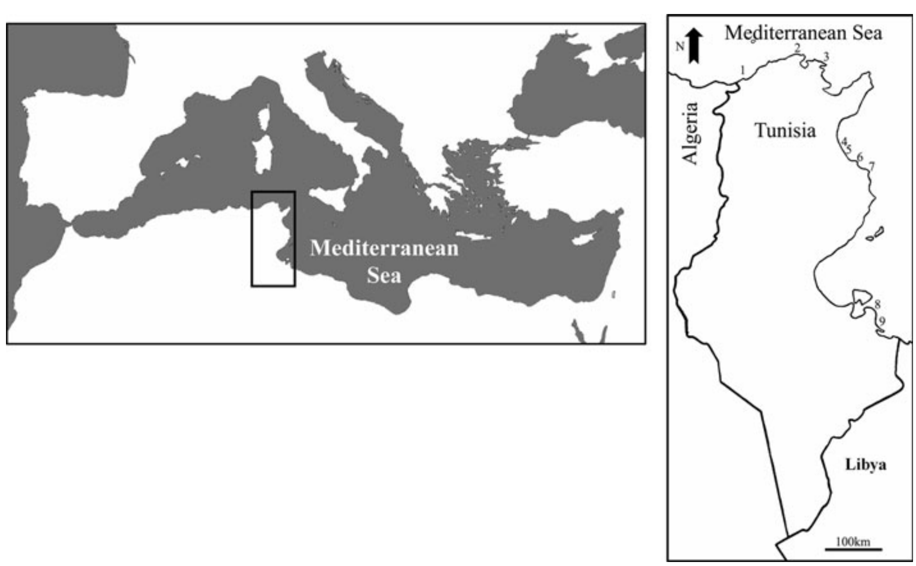

Fig. 1 Sampling localities investigated along the Tunisian coasts (*1* Tabarka; *2* Bizerte; *3* Rafraf; *4* Hergla; *5* El Kantaoui; *6* Monastir; *7* Mahdia; *8* Zarzis Ogla; *9* Zarzis plage Sonia)

five *Posidonia oceanica* meadows features (Epiphytes biomass, LAI, Density, Bottom type and Geographical position) that best explain the amphipod fauna assemblage structure. All variables were previously transformed by log $(x + 1)$.

The above-mentioned analyses were performed by the PRIMER (Plymouth Routines in Multivariate Ecological Research) software package (Clarke and Warwick 1994).

Results

Localities and *Posidonia oceanica* meadows features

The physical characteristics of the nine *Posidonia oceanica* meadows are shown in Table 1. Morphological features of *P. oceanica* are reported in Fig. 2. At the same depth (−2 m), shoot density and the same period of the year, LAI and mean epiphytes biomass in the nine meadows were significantly different (ANOVA, $P < 0.05$). Shoot density and LAI were high in the localities with rocky bottoms (Bizerte, Rafraf, Mahdia and Zarzis plage Sonia). El Kantaoui meadow has the highest values of epiphyte biomass and the lowest shoot density.

Amphipods associated to *P. oceanica* meadows

A total of 12,672 individual amphipods were examined belonging to 16 families and 44 species. The following six species: *Ampelisca unidentata*, *Ampithoe helleri*, *A. ramondi*, *Hyale camptonyx*, *Ericthonius punctatus* and *Maera inaequipes* exhibited a wide distribution in the Tunisian coasts and were collected in the whole of the studied localities: However, twelve species were found in one locality only.

The most dominant species in terms of abundance were *Ampithoe helleri* with 6,811 individuals (53.75%), followed by *Hyale camptonyx* with 1,834 individuals (14.47%) and *Ericthonius punctatus* with 1,620 individuals (12.78%) (Table 2). *Ampithoe helleri* was the most abundant species in all localities except for Zarzis plage Sonia. Two lessepsian amphipods species were observed in this last locality only and represent their first record for Tunisia (Zakhama-Sraieb and Charfi-Cheikhrouha 2010).

Table 2 shows also the number of species, total abundance, diversity and eveness in the nine localities studied. The highest abundance was recorded in Hergla and El Kantaoui with, respectively 2,261 and 2,185 individuals, while the lowest values were observed in Zarzis plage Sonia (612 individuals). The number of species varied between a minimum of 12 species in Zarzis plage Sonia and 26 in Hergla; Shannon–Wiener diversity ranged between 1.29 in El Kantaoui and 3.03 in Rafaraf. Eveness showed low values in meadows exhibiting a high dominance of *Ampithoe helleri* as El Kantaoui ($J = 0.28$), Hergla ($J = 0.44$) and Monastir ($J = 0.48$).

Dominant feeding guilds in all studied sites were herbivores (73.87%) following by deposit-suspension feeders (16.94%) and omnivores (3.89%). The other feeding guilds such as herbivores-deposit feeders, deposit feeders, deposit feeders-carnivores, plant detritus feeders and commensals had an almost negligible representation (Fig. 3). Herbivores reached their highest values at El Kantaoui, Monastir and

Table 1 Summary table describing the locations and the principal characteristics of the *Posidonia oceanica* meadows

Code	Locality	Location	Bottom
TA	Tabarka	N 36° 57′ E 08° 45′	Sandy
BI	Bizerte	N 37° 12′ E 10° 12′	Rocky
RA	Rafraf	N 37° 09′ E 10° 13′	Rocky
HE	Hergla	N 36° 25′ E 10° 42′	Sandy
EK	El Kantaoui	N 35° 53′ E 10° 36′	Sandy
MO	Monastir	N 35° 47′ E 10° 49′	Sandy
MA	Mahdia	N 35° 30′ E 11° 04′	Rocky
ZO	Zarzis Ogla	N 33° 35′ E 11° 04′	Sandy
ZS	Zarzis plage Sonia	N 33° 31′ E 11° 07′	Rocky

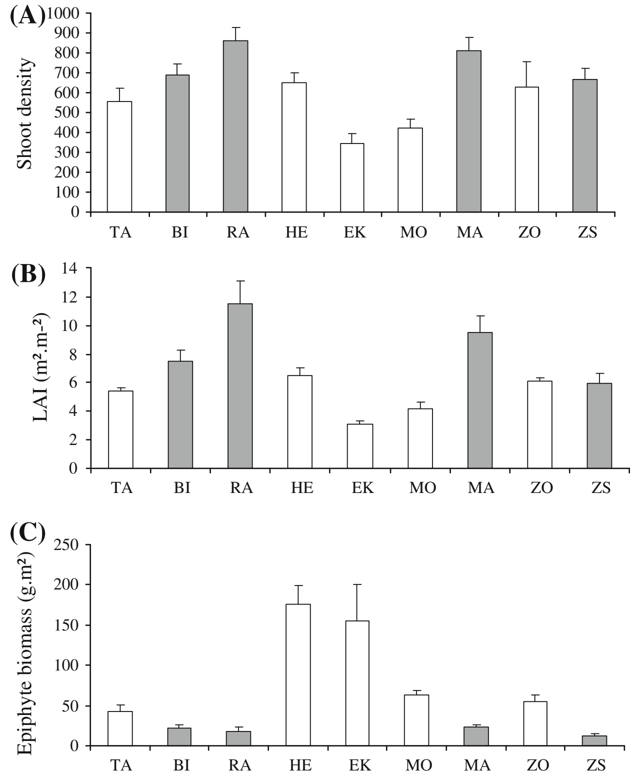

Fig. 2 Variation of mean shoot density (**a**), LAI (**b**) and epiphyte biomass (**c**) in the nine studied *Posidonia oceanica* meadows (rocky bottom in *grey*, sandy bottom in *white*)

Table 2 Abundance of each species (number of individuals per 0.27 m² of *Posidonia oceanica* meadow) of the different amphipod species

	t. g.	TA	BI	RA	HE	EK	MO	MA	ZO	ZS	DI
Ampelisca rubella A. Costa, 1864	DS	24	3	30			4	13			0.58
Ampelisca spinipes Boeck, 1861	DS	9	2	3		1	2	1			0.14
Ampelisca unidentata (Schellenberg, 1936)	DS	5	2	7	15	1	8	13	35	3	0.70
Amphilochus neapolitanus Della Valle, 1893	U	15	8	5	6	3	4	18	9		0.54
Dexamine spiniventris (A. Costa, 1853)	HeD							2			0.02
Dexamine spinosa (Montagu, 1813)	HeD	16	9	14	7		59	27	5		1.08
Tritaeta gibbosa (Bate, 1862)	U	1	1	8	3	1		4	2		0.16
Hyale camptonyx (Heller, 1866)	He	83	75	245	244	272	200	373	211	131	14.47
Parhyale aquilina (A. Costa, 1857)	He					4					0.03
Leucothoe venetiarum Giordani-Soika, 1950	Co							2			0.02
Leucothoe spinicarpa (Abildgaard, 1789)	Co				1	3					0.03
Lysianassa costae (Milne-Edwards, 1830)	DC	1	11		2	2	1	6	2	9	0.27
Lepidepecreum longicorne (Bate & Westwood, 1861)	DC					4					0.03
Orchomene humilis (A. Costa, 1853)	DC				6	7	3				0.13
Socarnes filicornis (Heller, 1866)	DC							12			0.09
Elasmopus brasiliensis (Dana, 1855)	He	2	14	23	11			36		10	0.76
Elasmopus pectenicrus (Bate, 1862)	He									84	0.66
Elasmopus pocillimanus (Bate, 1862)	He				2	3	9	4			0.14
Gammarella fucicola (Leach, 1814)	De				10						0.08
Maera hirondellei Chevreux, 1900	U			7	7	4	2	10	20	3	0.42
Maera inaequipes A. Costa, 1857	U	24	31	97	13	13	59	24	67	18	2.73
Pereionotus testudo (Montagu, 1808)	He	3		3	3						0.07
Metaphoxus simplex (Bate, 1857)	U				2	4					0.05
Stenothoe gallensis Walker, 1904	O									125	0.99
Stenothoe monoculoides (Montagu, 1813)	O		3	5	7	1		9	3	6	0.27
Aora gracilis (Bate, 1857)	DS				4	5	3	6			0.14
Aora spinicornis Afonso, 1976	DS				9						0.07
Lembos websteri Bate, 1857	D	15		30							0.36
Lembos sp	D					2	25	11	7		0.36
Leptocheirus guttatus (Grube, 1864)	DS				14	11	49	32			0.84
Microdeutopus chelifer (Bate, 1862)	D		34	2	13						0.39
Ampithoe helleri G. Karaman, 1975	He	373	430	335	1,190	1,700	1,615	631	477	60	53.75
Ampithoe ramondi Audouin, 1826	He	42	106	88	91	60	39	17	30	32	3.99
Apocorophium acutum (Chevreux, 1908)	DS					6					0.05
Caprella acanthifera Leach, 1814	O				10	2	42				0.43
Caprella grandimana Mayer, 1882	O			4	3						0.06
Caprella liparotensis Leach, 1814	O				3						0.02
Deutella schieckei Cavedini, 1982	O	9	6	12							0.21
Pseudoprotella phasma (Montagu, 1804)	O					7	32	22			0.48
Ericthonius punctatus (Bate, 1857)	DS	121	335	101	585	68	55	203	21	131	12.78
Ericthonius difformis Milne-Edwards, 1830	DS			3		1		3			0.06
Ischyrocerus inexpectatus Ruffo, 1959	DS	18	9					2			0.23
Gammaropsis dentata Chevreux, 1900	DS	24	64	36							0.98
Gammaropsis ostroumoui (Sowinsky, 1898)	DS						47				0.37
	S	18	18	21	26	25	20	25	13	12	
	N(0.27 m²)	785	1,143	1,058	2,261	2,185	2,258	1,481	889	612	
	H'(log 2)	2.69	2.58	3.03	2.06	1.29	2.08	2.61	2.09	2.84	
	J'	0.64	0.62	0.69	0.44	0.28	0.48	0.56	0.56	0.79	

In the table are given the trophic guild (t. g.), *D*, deposit feeders; *De*, plant detritus feeders; *DC*, deposit feeders-carnivores; *DS*, deposit-suspension feeders; *He*, herbivores; *HeD*, herbivores-deposit feeders; *Co*, commensals; *O*, omnivores; *U*, unknown Number of species (*S*), total abundance (*N*), the Shannon–Wiener diversity index (H', log 2) and Pielou's evenness (J') in the nine studied localities

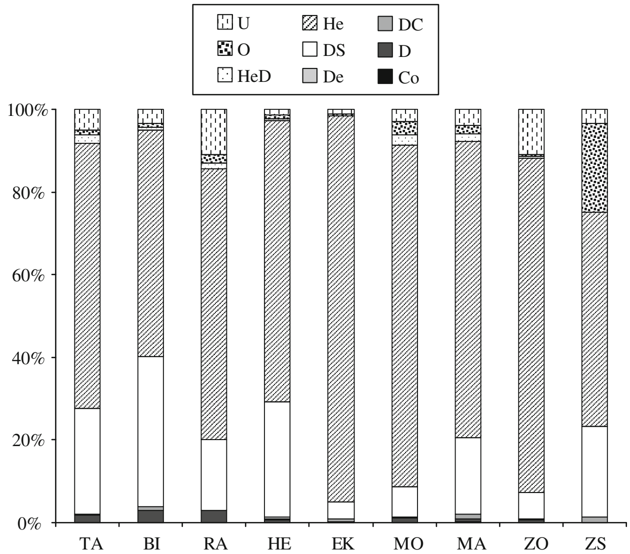

Fig. 3 Percentage of the trophic guilds at the studied *P. oceanica* meadows. *D*, deposit feeders; *DS*, deposit-suspension feeders; *DC*, deposit feeders-carnivores; *Co*, commensals; *He*, herbivores; *De*, plant detritus feeders; *HeD*, herbivores-deposit feeders; *O*, omnivores; *U*, unknown

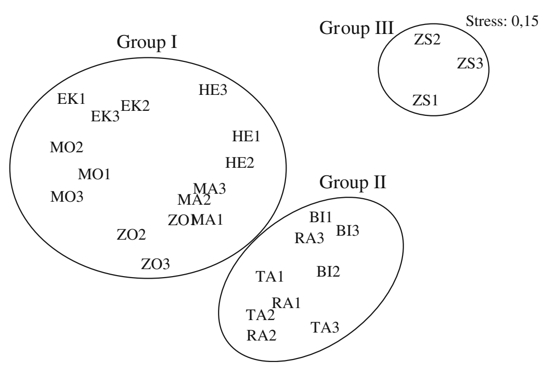

Fig. 4 Multidimensional scaling plot according to species abundance (3 replicates). Stress: 0.16. Legend: *TA*, Tabarka; *BI*, Bizerte; *RA*: Rafraf; *HE*, Hergla; *EK*, El Kantaoui; *MO*, Monastir; *MA*, Mahdia; *ZO*, Zarzis Ogla; *ZS*, Zarzis plage Sonia

Zarzis El Ogla, mainly represented by the genus *Ampithoe* and the species *Hyale camptonyx*.

Relation between species and *Posidonia oceanica* features

The MDS analysis in Fig. 4 based on the abundance of species performed by pooling the three replicates of each locality, suggests that the amphipod communities could be grouped into three categories: Group I containing the eastern (HE, EK, MO and MA) and a southern locality (ZO), Group II containing the northern localities (TA, BI and RA) and Group III is composed of the three replicates of Zarzis plage Sonia.

The BIOENV procedure revealed most accurately the relationship between the spatial distribution of the amphipods and the *Posidonia oceanica* meadows features. Analysis showed that the combinations of the Epiphyte biomass and Geographical position (north, east or south) produced the highest degree of correlation between the biotic and environmental data matrices (Table 3).

Table 3 Results of BIOENV analyses

No. variable	Correlation	Selections
2	0.604	Epiphyte biomass, geographical position
3	0.593	Epiphyte biomass, geographical position, shoot density
3	0.586	Epiphyte biomass, geographical position, bottom type
2	0.585	Geographical position, density
3	0.581	Epiphyte biomass, LAI, geographical position
4	0.575	Epiphyte biomass, geographical position, bottom type, shoot density
4	0.558	Epiphyte biomass, LAI, geographical position, bottom type
3	0.534	Geographical position, bottom type, shoot density
4	0.508	Epiphyte biomass, LAI, geographical position, shoot density
5	0.501	Epiphyte biomass, LAI, geographical position, bottom type, shoot density

Discussion

During this study, a relatively high number of amphipod species have been recorded in Tunisian shallow *Posidonia oceanica* meadows. A total of 44 species were reported in July 2007, whereas the number of species in each site ranges from 12 to 26 species. This result is similar to other areas of the Mediterranean Sea at the same depth and in the same period of year. For example, Scipione (1998) studied the amphipod fauna of the foliar stratum of *Posidonia oceanica* from nine stations distributed along the Spanish, Italian and Maltese coasts in July, collecting a total of 45 species. Number of species per site ranged from 9 to 25; the highest number (25 species) was collected in Porto Conte in Sardinia. Katagan et al. (2001) collected 40 species of amphipods in the shallow *Posidonia oceanica* meadows off the Aegean Turkey coasts in June and July 1995. Number of species per site ranged from 9 to 15 species.

A group of species (*Ampithoe helleri*, *Hyale camptonyx*, *Ericthonius punctatus*, *Ampithoe ramondi*, *Maera inaequipes*, *Ampelisca unidentata*, *Dexamine spinosa, Amphilocus neapolitanus, Maera hirondellei, Lysianassa costae, Stenothoe monoculoides* and *Tritaeta gibbosa*) are common in the studied meadows of *Posidonia oceanica* in Tunisia.

The same group of species has often found in *P. oceanica* meadows elsewhere in the Mediterranean (Scipione and Fresi 1984, Gambi et al. 1992; Scipione et al. 1996, Scipione 1998; Katagan et al. 2001; Mazzella et al. 1989). These species seem to be strongly related to seagrass ecosystems in the Mediterranean Sea. Some of them belong to the "biocoenotic stock of *P. oceanica*" as mentioned by Ledoyer (1962).

Amphipod assemblages differ seasonally at different stations, both in terms of number of species and density in the same depth of water. The abundance and diversity of amphipods is higher in meadows with high epiphyte loading. El Kantaoui and Hergla meadows showed the highest values of epiphyte biomass (EK: 155 g.m^{-2}; HE: 175.50 g.m^{-2}) accompanied by high values of amphipod number species and density when compared with the other localities. However, the lowest diversity values indices in El Kanatoui and Hergla were attributed to the dominance of few herbivorous species such as *A. helleri*, *A. ramondi* and *H. camptonyx* due to the availability of food. In fact, the presence of epiphytes on host seagrass meadows raised habitat complexity, creating new attachment sites and shelter as well as increasing food supply for the associated fauna (Hall and Bell 1988; Martin-Smith 1993). Epiphytes also favour detritus accumulation and amplify surface area for the colonization of bacteria and microalgae (Hacker and Steneck 1990; James and Heck 1994; Leber 1985; Russo 1990), thus benefiting species that consume these food resources (Edgar 1990). In several seagrass ecosystems, algal epiphytes are found to be more attractive food for herbivores than the leaves themselves (Kitting et al. 1984; Orth and Van Montfrans 1984, Van Montfrans et al. 1984). In this study, epiphyte biomass was the factor that had the most direct bearing on diversity and species distribution, either acting alone or in conjunction with other variables like geographical position.

The dominant feeding category observed across all Tunisian seagrass meadows was herbivores mainly represented by *A. helleri*, *A. ramondi* and *H. camptonyx*. The dominance of herbivores was already observed at shallow water in summer (Gambi et al. 1992).

Analyses of similarity between the sampling stations based on the abundance of species showed three major assemblages whose distribution agreed mostly with that of gradient south/north. The first includes eastern and one of the southern meadows, the second group is composed by the northern localities and the last one is composed by the three replicates collected in Zarzis plage Sonia. Analysis of each assemblage revealed three species collected only in the northern meadows, seventeen species exclusively collected in the eastern meadows and two observed just in southern meadows. A previous study has shown that some species have a limited geographical distribution along the Tunisian coasts (Zakhama-Sraieb et al. 2009).

The structure of the third assemblage seems to be influenced by the presence of two lessepsian amphipods species *Elasmopus pectinicrus* and *Stenothoe gallensis,* recorded since 2006 in Zarzis Sonia plage meadow (Zakhama-Sraieb and Charfi-Cheikhrouha 2010). The presence of the lessepsian species seems to change the community structure of amphipod fauna. The decrease of abundance of *A. helleri* in Zarzis plage Sonia suggests the substitution of these species by the lessepsian ones.

In conclusion, it is evident that the *Posidonia* system is characterized by higher species richness and abundance. The architecture of *Posidonia* creates many microhabitats especially for epiphytic algae, therefore creating refuge and food resource for diverse forms of invertebrates. A group of amphipods, collected routinely from several *Posidonia oceanica* meadows around the Mediterranean coasts, could be considered as characteristic of this ecosystem. However, the characteristics of some *Posidonia oceanica* meadows and the presence of alien species can modify that community structure. Further studies in other seasons of the year should be conducted to survey the dynamics of the amphipod community in the south of Tunisia meadows.

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