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Abundance and species composition of gelatinous zooplankton in Habibas Islands and Sidi Fredj (Western Mediterranean Sea)

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Abstract: Gelatinous zooplankton was studied in a series of stations coming from two different localities in the southwestern Mediterranean Sea: Habibas Islands (Alboran Sea) and Sidi Fredj (Algerian Basin). Occurrences of gelatinous zooplankton were observed to be more in spring and summer. However, the species composition varied from locations and seasons. A total 35 species were identified in the study area: 9 appendicularians, 9 siphonophores, 7 pteropods, 5 chaetognaths and five thaliaceans. The Shannon diversity index (H') values ranged from 2.44 to 3.21 bits.ind^{-1} in Sidi Fredj and 2.30 to 3.73 bits.ind^{-1} in Habibas Islands. In Sidi Fredj, minimum zooplankton diversity was recorded during autumn and maximum during spring. In Habibas Islands, the zooplankton diversity was recorded minimum during summer and maximum during spring.

Résumé : *Abondance et composition des espèces du zooplancton gélatineux des îles Habibas et Sidi Fredj (Mer Méditerranée occidentale).* Le zooplancton gélatineux a été étudié sur un ensemble de stations situées au niveau des îles Habibas (Mer d'Alboran) et au niveau de Sidi Fredj (bassin algérien). Le zooplancton gélatineux a été observé au printemps et en été. Cependant, la composition en espèces varie selon les sites et les saisons. Au total, 35 espèces ont été identifiées : 9 appendiculaires, 9 siphonophores, 7 ptéropodes, 5 chaetognathes et 5 thaliacés. Les valeurs de l'indice de diversité de Shannon (H ') varient de 2,44 à 3,21 bits.ind^{-1} à Sidi Fredj et 2,30 à 3,73 bits.ind^{-1} dans les îles Habibas. A Sidi Fredj, le mimimum de la diversité zooplanctonique a été enregistré en automne et le maximum au printemps. Dans les îles Habibas, la diversité du zooplancton gélatineux est minimum en été et maximum au printemps.

Keywords: Gelatinous zooplankton • Composition • Diversity • Southwestern Mediterranean

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Introduction

Gelatinous zooplankton is a taxonomically diverse group of mesozooplanton and macroplankton that play different and significant roles in the pelagic communities, where diversity is less explored and density of these organisms is over-or underestimated due to their fragility (Raskoff et al., 2005).

Regarding feeding ecology, gelatinous organisms belong to different trophic levels: Medusae, Ctenophora, and Siphonophora are carnivore, while Appendicularia, Doliolida, and Salpida are herbivores. Pelagic tunicates filter-feed on phytoplankton and bacteria, and, thus, are primary consumers in the food web (Sutherland et al., 2010). Tunicates often form colonies, which reach up to two meters in length, and while they cannot have direct effects, like jellyfish, their extensive blooms can have a significant impact on biochemical fluxes across the pelagic food web (Bode et al., 2013). By their capability to remove minute particles with relatively high efficiency (Sutherland et al., 2010) and by packaging them into rapidly fast-sinking fecal pellets, thaliaceans contribute to the rapid transfer of energy from the euphotic zone to the deep ocean (Deibel, 1998).

Gelatinous zooplankton is usually presumed to be a dead end in the pelagic food web because of their high water content and of their low nutritional value make them a minor food item (Sommer & Hansen, 2002). However, there is evidence disputing the dead-end function of gelatinous plankton in marine food webs and suggests that its role in fish diet may be greater than expected (Mianzan & Pajaro, 2001). In addition, Predation on gelatinous plankton can transfer supposed dead-end resources back affecting the trophic web structure (Arkhipkin & Laptikhovsky, 2013).

Despite the ecological importance of the gelatinous zooplankton in the marine food web, our knowledge of these animals such as Siphonophores, Appendicularians, Mollucs, Thaliceans and Chaetognathes in Algerian Mediterranean waters is far from complete.

The aim of this contribution was to study the diversity and to analyze the abundance of Siphonophores, Appendicularians, Mollucs, Thaliceans and Chaetognathes in two sites along the Algerian coast. This work it is not only a study of gelatinous zooplankton in Habibas Islands and Sidi Fredj, but it also contributes to new knowledge on the distribution of gelatinous zooplankton in the Western Mediterranean.

Material and Methods

Sampling of the biological material and environmental parameters was done every three months in Sidi Fredj from November 2012 to July 2013 and in Habibas Islands (Alboran Sea) from May 2012 to July 2012 (Fig. 1 & Table 1). Zooplankton samples were collected by vertical hauls at the epipelagic layer (0-100 m) by using a Working Party II (WP2) with 200 µm mesh size (Unesco, 1968). The mean amount of water filtered in each station was 25 m³ by assuming movement at constant speed along a vertical trajectory and a constant mouth opening of 0.25 m². Each cod-end was equipped with a 7 L collection bucket in order to reduce damage to the animals in the sampling.

At each station, hydrological parameters such as temperature (°C) and salinity were obtained by using a multiparameter (HI 9828-12202/ Romania) at four depths (5, 15, 30 and 50 m).

Taxonomic identification was made under a stereomicroscope (Zeiss Stemi SV 6/ Germany) and was based on appropriate taxonomic references (e.g. Rampal, 1975; Boltovskoy, 1999; Bouillon et al., 2006).

In the laboratory, physonect siophonophores was estimated from the number of nectophores. For calycophorans, the number of colonies was determined by the number of anterior nectophores. Doliolids were identified to species level and to two life cycle stages: gonozooids and phorozooids.

The Shannon-Weaver diversity index and Pielou's evenness index were calculated in order to provide estimates of diversity and eveness (Magurran, 2003).

Hydrological parameters (temperature and salinity), three major diversity indices (species richness, Pielou's evenness, and Shannon diversity index) and gelatinous zooplankton variables were subjected to the non-parametric Mann-Whitney and Kruskal-Wallis tests.

Calculating the frequency of occurrence was also performed, and species were classified according to their frequency in three classes of occurrence: frequent ($Fr > 75\%$), common ($25\% < Fr \leq 75\%$), and rare ($Fr \leq 25\%$). Frequency of occurrence was calculated as follows:

$$Fr = \left(\frac{Pi}{P}\right) \times 100 \quad (1)$$

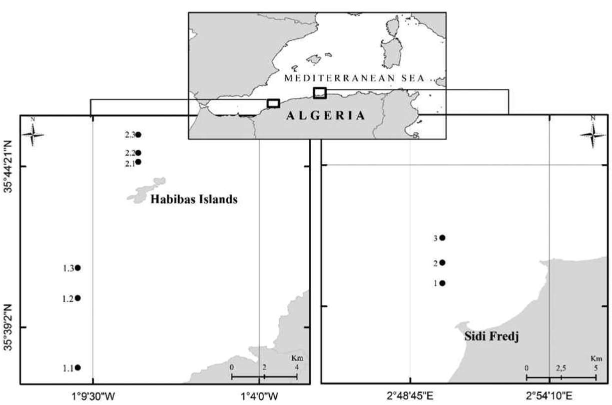

Figure 1. Sampling stations at Sidi fredj and near the Habibas Islands.

where *Fr* represents the species' frequency of occurrence, *Pi* is the total number of samples containing the species, and *P* is the total number of samples.

All analyses were carried out using the statistical software R. The following packages were used to plot graphics and calculate the statistics: ggplot2 (Wickham, 2016) and BiodiversityR (Kindt & Coe, 2005).

Results

Environmental conditions

Off Sidi Fredj, average sea surface temperature varied between 15.64 ± 0.20°C in winter and 20.01 ± 1.90°C in summer (Fig. 2). Sea surface salinity ranged from 35.72 ± 0.12 in winter to 36.89 ± 0.18 in summer. Average sea surface temperature off the Habibas Islands was 16.89 ± 1.54°C in spring and 21.55 ± 2.61°C in summer (Fig. 2). The sea surface had an average salinity of 34.53 ± 0.31 and 35 ± 0.15 in spring and summer, respectively. When Hydrological parameter were subjected to the non-parametric Mann-Whitney test, we did not find statistical difference between locations during spring and summer ($P > 0.05$, Mann-Whitney test). However, salinity did not show a significant difference between Sidi Fredj and Habibas Islands during spring and summer season ($P > 0.05$, Mann-Whitney test).

Taxonomic diversity

A total of thirty-five species were identified: 9 appendicularians, 9 siphonophores, 7 pteropods, 5 thaliaceans and 5 chaetognaths (Table 2). The most frequent species were *Oikopleura longicauda, Muggiaea atlantica, Flaccisagitta enflata, Doliolum nationalis, Limacina trochiformis, Fritillaria pellucida, Oikopleura fusiformis, Heliconoides inflatus, Abylopsis tetragona, Parasagitta friderici, Oikopleura dioica,* and *Oikopleura rufescens* (Table 2).

Table 1. Gelatinous zooplankton sampling coordinates observed at the surface (0-100 m) for 3 stations in Sidi Fredj from November 2012 to July 2013 and for 6 stations in Habibas Islands from May 2012 to July 2012.

Region	Station	Geographical location		Saison	Date	Time
		Longitude	Latitude (N)			
Habibas Islands	1.1	1° 10' W	35° 37' 42"	Spring	5/13/12	9:40 AM
				Summer	7/12/12	10:10 AM
	1.2		35° 40'00"	Spring	5/13/12	10:15 AM
				Summer	7/12/12	9:30 AM
	1.3		35°41'00"	Spring	5/13/12	11:5 AM
				Summer	7/12/12	8:50 AM
	2.1	1° 8' W	35° 44' 30"	Spring	5/13/12	8:55 AM
				Summer	7/12/12	9:45 AM
	2.2		35° 44'48"	Spring	5/13/12	9:0 AM
				Summer	7/12/12	10:35 AM
	2.3		35°45'24"	Spring	5/13/12	10:40 AM
				Summer	7/12/12	11:25 AM
Sidi Fredj	1	2° 50' E	36° 47' 24"	Autumn	11/18/12	11:4 AM
				Winter	3/4/13	9:15 AM
				Spring	4/16/13	10:0 AM
				Summer	7/11/13	9:20 AM
	2		36°48' 12"	Autumn	11/18/12	12:5 PM
				Winter	3/4/13	9:50 AM
				Spring	4/16/13	10:50 AM
				Summer	7/11/13	10:10 AM
	3		36° 49' 10"	Autumn	11/18/12	13:49 pm
				Winter	3/4/13	10:20 AM
				Spring	4/16/13	11:25 AM
				Summer	7/11/13	11:0 AM

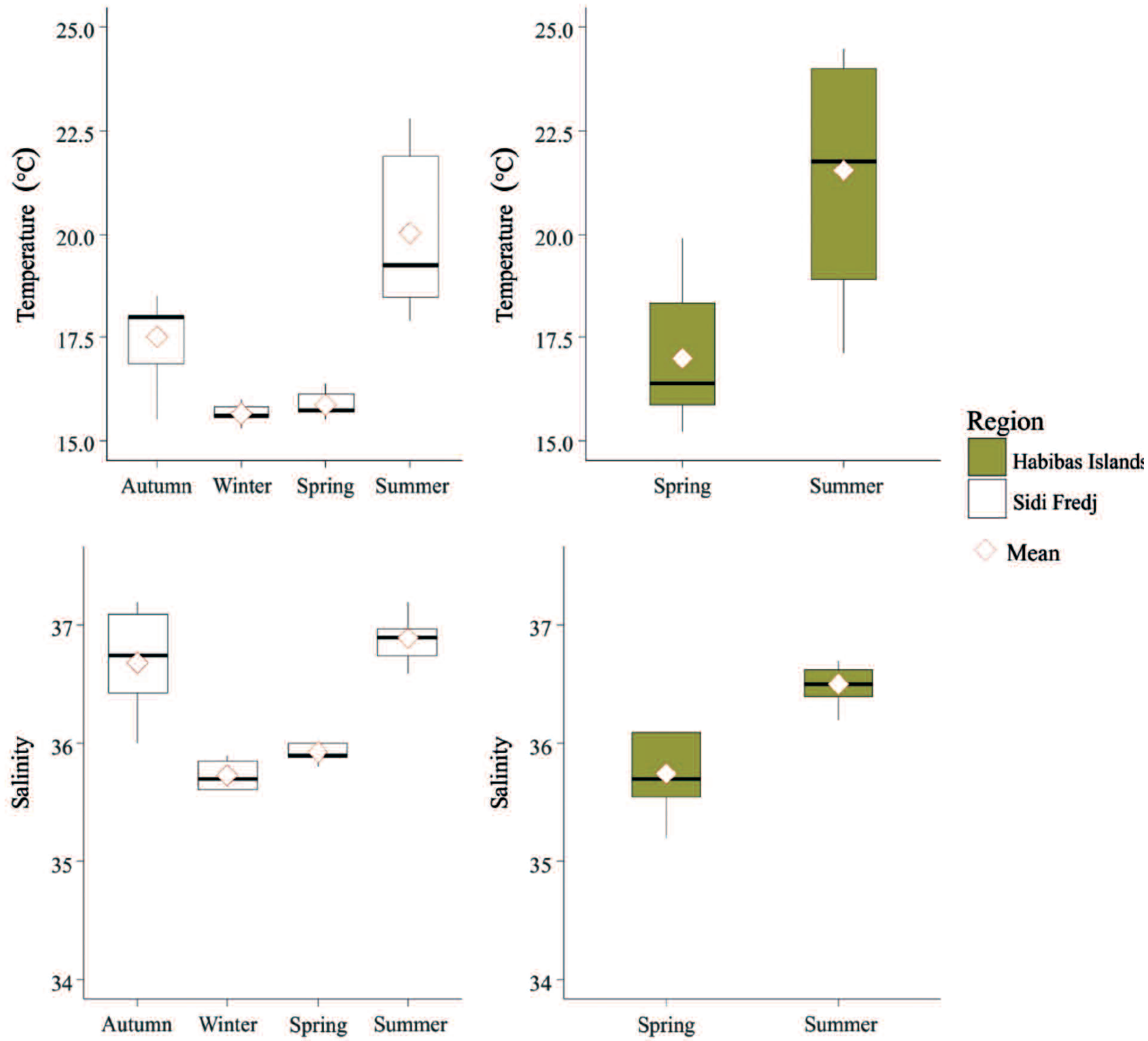

Figure 2. Boxplot of temperature and salinity in the layer (0-50 m) in Sidi Fredj (from November 2012 to July 2013) and in Habibas Islands (from May 2012 to July 2012).

The Shannon diversity index (H') values were ranged from 2.44 to 3.21 bits.ind^{-1} in Sidi Fredj and 2.30 to 3.73 bits.ind^{-1} in Habibas Islands. In Sidi Fredj, minimum zooplankton diversity was recorded during autumn and maximum during spring. In Habibas Islands, the zooplankton diversity was recorded minimum during summer and maximum during spring (Fig. 3). The gelatinous zooplankton diversity did not show significant difference between locations during spring and summer ($P > 0.05$, Mann-Whitney test).

The Pielou's evenness (E) was ranged from 0.62 to 0.80 in Sidi Fredj and 0.64 to 0.86 in Habibas Islands. In Sidi Fredj, minimum and maximum species evenness was recorded during autumn. In Habibas Islands, species evenness was recorded minimum during summer and maximum during spring (Fig. 3). The species evenness did not show significant difference between locations during spring and summer ($P > 0.05$, Mann-Whitney test).

The species richness (S) ranged from 15 to 21 in Sidi Fredj and 11 to 23 in Habibas Islands. The minimum species was recorded during autumn and the maximum species was recorded during spring. In Habibs Islands, the minimum species was recorded during summer and the maximum was recorded during spring (Fig. 3). We find statistical difference of species richness between locations during summer ($P < 0.05$, Mann-Whitney test).

Table 2. Frequencies of occurrence of species observed at the surface (0-100 m) for 3 stations in Sidi Fredj from November 2012 to July 2013 and for 6 stations in Habibas Islands from May 2012 to July 2012.

Taxon	Species	Frequency of occurrence (%)	
		Habibas Islands	Sidi Fredj
Appendicularia	*Fritillaria formica tuberculata* Lohmann in Lohmann & Buckmann, 1926	75	16.67
	Fritillaria fraudax Lohmann, 1896	0	8.33
	Fritillaria pellucida (Busch, 1851)	100	83.33
	Kowalevskia oceanica Lohmann, 1899	0	8.33
	Oikopleura dioica Fol, 1872	91.67	83.33
	Oikopleura fusiformis Fol, 1872	100	83.33
	Oikopleura intermedia Lohmann, 1896	0	33.33
	Oikopleura longicauda (Vogt, 1854)	100	100
	Oikopleura rufescens Fol, 1872	83.33	75
Pteropoda	*Cavolinia inflex*a (Lesueur, 1813)	8.33	0
	Clio polita Pelseneer, 1888	25	0
	Creseis virgula (Rang, 1828)	16.67	25
	Heliconoides inflatus (d'Orbigny, 1834)	91.67	91.67
	Hyalocylis striata (Rang, 1828)	8.33	0
	Limacina bulimoides(d'Orbigny, 1834)	0	16.67
	Limacina trochiformis (d'Orbigny, 1834)	100	91.67
Siphonophorae	*Abylopsis tetragona* (Otto, 1823)	91.67	100
	Agalma elegans (Sars, 1846)	0	16.67
	Chelophyes appendiculata (Eschscholtz, 1829)	0	25
	Lensia subtilis (Chun, 1886)	41.67	100
	Lensia subtiloides (Lens and van Riemsdijk, 1908)	50	50
	Muggiaea atlantica Cunningham, 1892	100	100
	Muggiaea kochii (Will, 1844)	33.33	25
	Nanomia bijuga (Delle Chiaje, 1844)	0	25
	Sphaeronectes irregularis (Claus, 1873)	50	75
Chaetognatha	*Flaccisagitta enflata* (Grassi, 1881)	100	100
	Mesosagitta minima (Grassi, 1881)	0	8.33
	Parasagitta friderici (Ritter-Záhony, 1911)	83.33	100
	Pterosagitta draco (Krohn, 1853)	0	8.33
	Pseudosagitta lyra (Krohn, 1853)	0	8.33
Thaliacea	*Cyclosalpa affinis* (Chamisso, 1819)	8.33	0
	Doliolina krohni Herdman, 1888	50	91.67
	Doliolum nationalis Borgert, 1893	100	100
	Salpa fusiformis Cuvier, 1804	50	25
	Thalia democratica (Forskål, 1775)	50	50

Distribution of total abundances

As shown in figure 4, comparison between total gelatinous zooplankton densities in summer and in spring did not show a significant difference between Habibas Islands and Sidi Fredj ($P > 0.05$, Mann-Whitney test).

In Sidi Fredj, high concentrations (up to 500 ind.m^{-3}) of gelatinous zooplankton were sampled in spring at all stations with a maximum at station 3 (686. 98 ind.m^{-3}), while the lowest values (below 80 ind.m^{-3}) were observed in autumn. On the other hand, values varied between 150

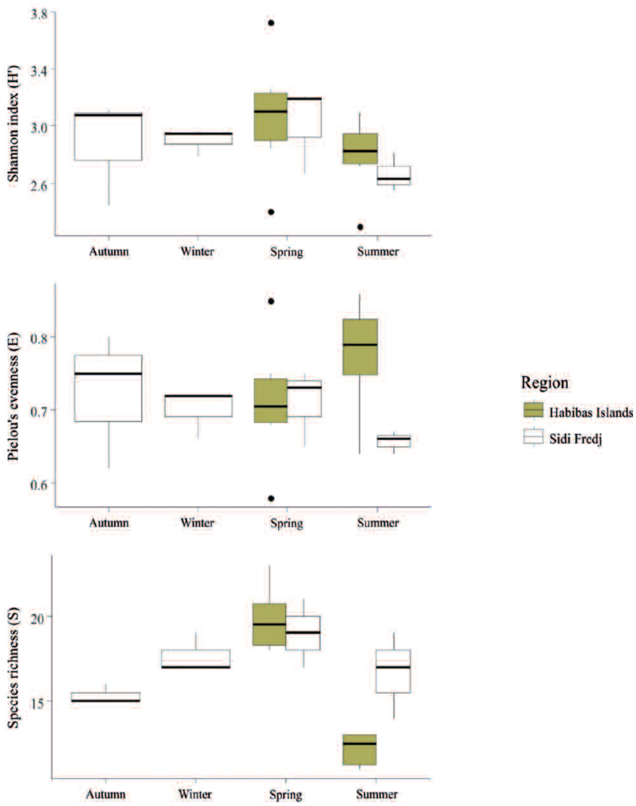

Figure 3. Boxplots of the diversity indices of gelatinous zooplankton in Sidi Fredj (from November 2012 to July 2013) and Habibas Islands (from May 2012 to July 2012).

ind.m-3 at station 3 and 250 ind.m-3 at station 1 in winter. maximum densities were observed in summer at station 1 (410.6 ind.m-3) and 3 (400 ind.m-3). We find statistical difference between autumn and spring ($P < 0.05$, Kruskal-Wallis test).

In Habibas Islands, gelatinous zooplankton showed a significant difference between seasons ($P < 0.01$, Mann-Whitney test) (Fig. 4). High values were recorded in spring. Abundances fluctuated between 550 ind.m-3 at station 2.1 and 120 ind.m-3 at station 2.3. Low abundances were observed in summer. Abundances varied between 80 ind.m-3 at station 2.1 and 165 ind.m-3 at station 2.3.

Distribution of the main species

Doliolum nationalis was the most abundant and frequent species; In Sidi Fredj (Fig. 5), high density was recorded in spring and summer: 175.44 ± 25 ind.m-3 and 117.35 ± 50 ind.m-3, respectively.

Oikopleura longicauda, F. pellucida, O. fusiformis and *O. dioica* were the most dominant and frequent appendicularians (Table 2). *Oikopleura longicauda* had higher abundance in spring especially in Habibas Islands with 76.08 ± 40 ind.m-3 (Fig. 5). The maximum values of *F. pellucida* were found in spring and winter (98.61 ± 25 ind.m-3, 23.66 ± 15 ind.m-3, respectively) in Sidi Fredj. While values less than 23 ind.m-3 were found during other seasons.

Abylopsis tetragona and M. atlantica were the dominant calycophorans. There was a marked increase in the

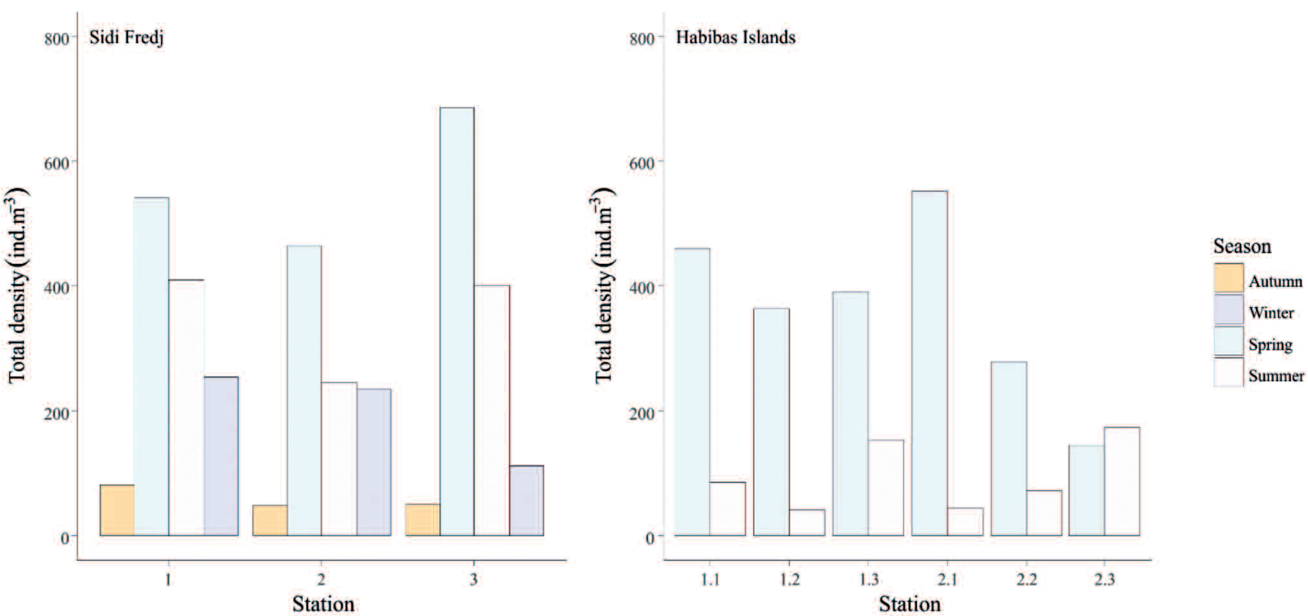

Figure 4. Seasonal distribution of total density in Sidi Fredj (from November 2012 to July 2013) and Habibas Islands (from May 2012 to July 2012).

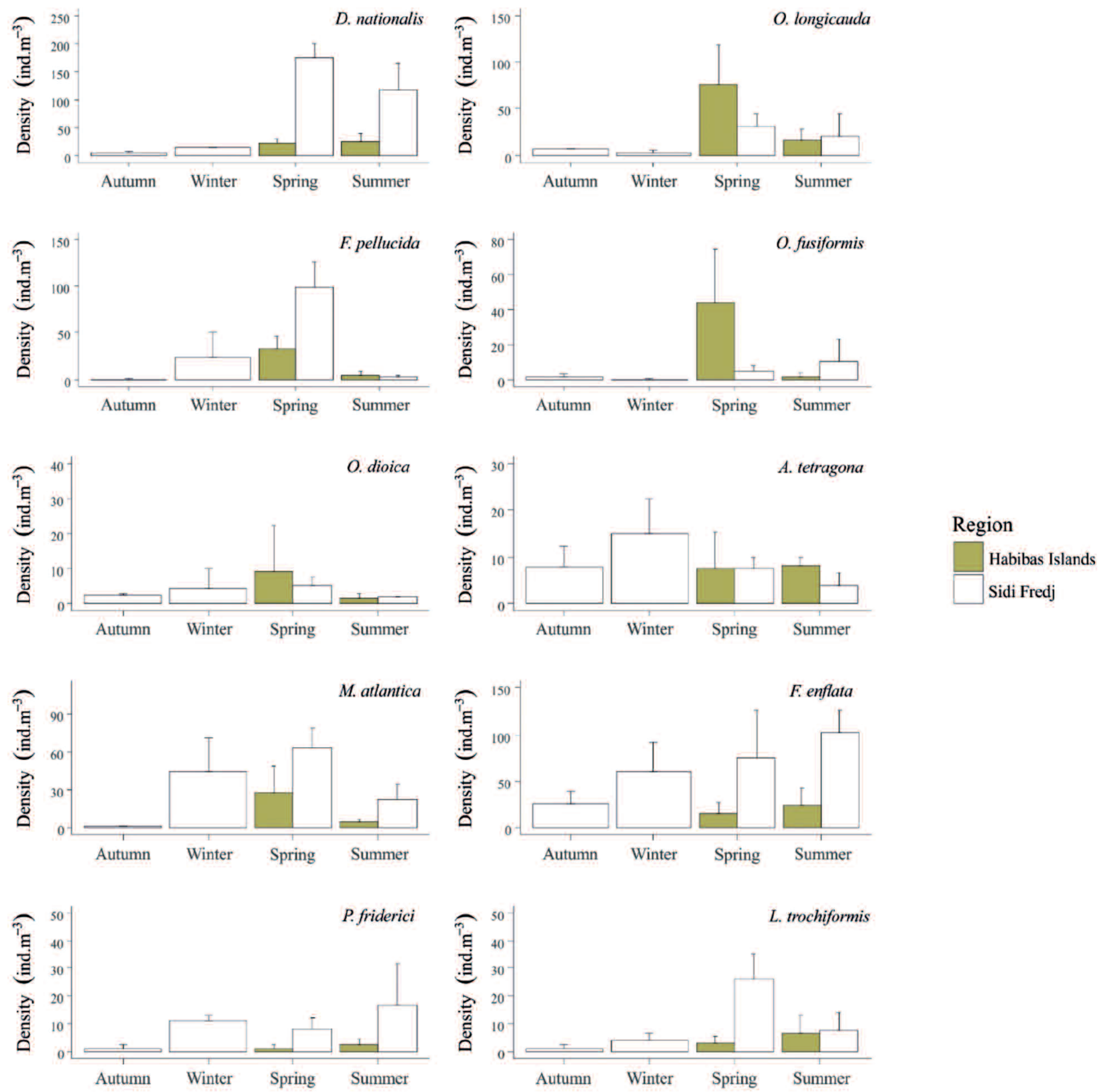

Figure 5. Distribution of most abundant gelatinous species in Sidi Fredj (from November 2012 to July 2013) and in Habibas Islands (from May 2012 to July 2012).

abundance of *A. tetragona* in Sidi Fredj, with a maximum of 15.08 ± 7 ind.m^{-3} in winter. Abundances of *M. atlantica* had maximum in spring (63.51 ± 24 ind.m^{-3}) and winter (44.18 ± 26 ind.m^{-3}).

Flaccisagitta enflata and *P. friderici* were the frequent and dominant chaetognaths. Higher abundance of *F. enflata* was found in summer and spring in both regions, with a maximum of 102.56 ± 24 ind.m^{-3} and 24.75 ± 18 ind.m^{-3}, respectively, in Sidi Fredj and Habibas Islands. *Parasagitta friderici* occurred during the year in Sidi Fredj having densities not higher than 20 ind.m^{-3}. Maximum abundance of *L. trochiformis* was found in spring (26.23 ± 07 ind.m^{-3}) in Sidi Fredj.

Discussion

The study of the composition of gelatinous zooplankton collected near the Habibas archipelago and Algerian central coast (Sidi Fredj) allowed us to identify different zoological groups, such as the appendicularians, chaetognaths, thaliaceans, siphonophores, and pteropods.

Oikopleura langicauda was numerically abundant in Habibas Islands, with maximum abundance in the spring and summer. The same was reported by Fenaux et al. (1998). *Oikopleura fusiformis* was found with high densities in summer in Sidi Fredj. The same result was observed by Tomita et al. (2003) in Toyama Bay. In addition, these species are commonly regarded as warm water species and tend to be among the most abundant appendicularians wherever they occur (Fenaux et al., 1998).

Significant densities of *F. pellucida* were observed during spring and winter. High densities of this species observed in spring were reported in the Mediterranean Sea (Fenaux, 1976). *Fritillaria pellucida* was previously noted as more abundant in winter in the Balearic Sea (Fernandez de Puelles et al., 2003), as this species seems to have a large capacity to develop large populations very quickly under favorable conditions (Siokou-Frangou et al., 1998).

Doliolidae have a cosmopolitan distribution, preferring warm, continental shelf waters (Deibel, 1998). In the bay of Villefranche-sur-Mer, doliolids appear to be characteristic organisms of the second half of the year, maximum abundance values being observed in the warm months (Menard et al., 1997). According to Braconnot & Dallot (1995), doliolids begin to be numerous from May to June, with high abundances in summer and autumn. Gibson & Paffenhöfer (2002) proposed that the blooming of Doliolidae was related to high rates of sexual or asexual reproduction. In the present study, two peaks of *D. nationalis* were recorded: in spring, related to phytoplankton blooms (Deibel, 1998), and in summer, when the environment was most oligotrophic (Menard et al., 1997); this species was also most dominant in early summer in the neritic area of the Balearic Sea (Fernandez de Puelles et al., 2003).

Pteropod abundance can occasionally occur in large numbers, then disappear completely from the plankton (Rampal, 1975). *Limacina trochiformis* was recorded in the present study with maximums during spring and summer. A similar situation was observed in the Boka Kotorska Bay Sea in the southern Adriatic, where *L. trochiformis* prevailed from February to September (Pestoric et al., 2016). *Limacina trochiformis* had high abundances in spring and summer (Pestoric, 2013).

Abylopsis tetragona and *M. atlantica* constituted the main part of the calycophoran community in the study area. They became dominant calycophoran in winter for *A. tetaragona* and winter–spring for *M. atlantica*. In the Bay of Villefranche (from March 1993 to March 1996), higher abundances of *A. tetragona* were recorded in period of mixed and cold water (May to June), while a less numerous occur when the seasonal thermocline develops (Buecher, 1999). Molinero et al. (2008) in their research found higher values of *A. tetragona* in the northwestern Mediterranean in Spring.

Muggiaea atlantica is widespread in the western and eastern Mediterranean (Batistić et al., 2007 & 2014). The progressive expansion of the distribution of *M. atlantica* into some regions of the Mediterranean (Batistić et al., 2014) suggests that this species is able to exploit favourable environmental conditions more efficiently than other siphonophores. In Catalan coast, spring corresponds to a state of maximum development and abundance of *M. atlantica* with fewer species and individuals in autumn (Gili et al., 1988). Along the Ligurian coast *M. atlantica* population become established and dominate siphonophore community during spring (Licandro & Ibanez, 2000).

Flaccisagitta enflata is a cosmopolitan species in temperate and warm waters and occurs mainly in the upper 200 m (Pierrot-Bults & Nair, 1991). It is the dominant chaetognath species by number in the Alboran Sea (Dallot et al., 1988). In the present investigation the most dominant species in the chaetognatha is also *F. enflata*.

Higher numbers of *S. friderici* were found in winter and summer. This species was also recorded with two peaks in South Atlantic waters, one in the fall-winter period and a greater one in the summer (Daponte et al., 2004).

The species richness of the Algerian coast was high compared to that recorded in Bizerte Bay (24 species, Touzri et al., 2012) and almost similar in the Adriatic Sea (32 species, Batistić et al., 2007). Some of them can be considered characteristics of Atlantic water such as *M. atlantica* and *L. subtiloides* (Gamulin & Kršinic, 1993), *P. friderici, P.draco, C. affinis,* and *K. oceanica* (Ghirardelli & Gamulin, 2004).

In fact, the lowest abundance recorded in autumn and winter seems to be related to poverty of phytoplankton which does not promote the development of zooplankton communities (Hafferssas & Seridji, 2010). In addition, circulation of Modified Atlantic Water (MAW) which affects both the richness and variety of communities as well as its composition and its seasonal distribution. This influence is exercised more along the Algerian coast (Taupier-Letage et al., 2003). Moreover, during the winter months, the transport by the Strait of Gibraltar is the most massive (Béranger et al., 2004), which enriches Mediterranean ecosystem with plankton at this time of the year (Hassen et al., 2009). It appears that the variation in the diversity index is in conjunction with the hydrological structure. This is translated in summer and autumn by a decrease in the species number with a high density of the dominant species and, thus, a lower diversity.

In summary, the epipelagic ecosystem along the

Algerian coast contains a variety of zooplankton groups. Further research with many spatiotemporal data inputs are necessary to complete the taxonomic compostion of these hitherto poorly studied faunas; understand the role of gelatinous zooplankton in the local ecosystem, and investigate the impact of gelatinous zooplankton on fisheries and tourism in this area.

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