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FISH ASSEMBLAGE STRUCTURE IN SHALLOW WATERS OF THE MELLAH LAGOON (ALGERIA): SEASONAL AND SPATIAL DISTRIBUTION PATTERNS AND RELATION TO ENVIRONMENTAL PARAMETERS

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Background. Southern Mediterranean lagoons are poorly studied. The Mellah Lagoon is the only coastal lagoon in Algeria. Characterized by low anthropogenic pressure it has a crucial environmental and socioeconomic role because of its fishing activities and conservation status. The spatial and temporal variations of fish assemblage structure in relation with the environmental parameters were investigated. This study contributes to a better understanding of the functioning of the Mellah Lagoon, thus providing useful data regarding its conservation and management.

Materials and methods. Sampling was carried out monthly during one year at four stations with a beach seine of 3-mm mesh. Environmental variables were measured during each sampling. Canonical correspondence analysis (CCA) and cluster analysis were used to assess environmental influences on fish spatio-temporal assemblages.

Results. A total of 11 fish species representing 8 families were collected and examined: *Aphanius fasciatus* (Valenciennes, 1821); *Atherina boyeri* Risso, 1810; *Liza saliens* (Risso, 1810); *Liza aurata* (Risso, 1810); *Mugil cephalus* Linnaeus, 1758; Mugilidae gen sp.; *Pomatoschistus marmoratus* (Risso, 1810); *Diplodus sargus sargus* (Linnaeus, 1758); *Sparus aurata* Linnaeus, 1758; *Syngnathus abaster* Risso, 1827; *Anguilla anguilla* (Linnaeus, 1758); *Hyporhamphus picarti* (Valenciennes, 1847). Resident species presented the highest abundance values, accounting for 96% of the total number of fish captured, while marine migrant species that use the lagoon as a nursery ground contributed the most to the community species richness (7 species). *Atherina boyeri* (87.59% of total catch by number) was the most abundant species. Environmental parameters measured were uniform across the whole lagoon. However, temperature and salinity showed a seasonal pattern. The CCA analysis based on species abundance indicated the absence of clear spatial and temporal patterns in fish assemblage. The majority of the species had mean values of distribution in relation to environmental variables.

Conclusion. The fish assemblage of the shallow water (<1.5 m) of the Mellah Lagoon is characterized by a small number of species dominated by resident species. The low species richness, the dominance of resident species, and the weak spatial and temporal patterns in the fish assemblage are mainly the result of a high degree of confinement because of the low freshwater inputs from the wadis and the limited tidally-driven exchanges between the lagoon and the sea. To maintain high biodiversity and a sustainable fishery in the lagoon, it is necessary to develop a management plan which would facilitate a proper water exchange between the lagoon and the sea and would promote colonization of the lagoon by marine species.

Keywords: fish fauna, abiotic factors, CCA, beach seine, coastal lagoon, Mediterranean

INTRODUCTION

Coastal lagoons are transitional waters between marine systems and continental environments. They are among the most productive aquatic ecosystems due to high levels of primary production, organic matter, and habitat diversity, offering optimal niches for numerous aquatic species (Crivelli and Ximenes 1992, Costanza et al. 1997). Although complex and fluctuating, these systems provide suitable habitats for many marine fish species. More than 199 fish species are known to be present in coastal lagoons in the Atlanto–Mediterranean region (Basset et al. 2006, Pérez-Ruzafa et al. 2011a). These habitats play important

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ecological functions such as nursery areas and feeding grounds for opportunistic marine species and also essential migration routes for diadromous fish species (Franco et al. 2008, Maci and Basset 2009, Pérez-Ruzafa and Marcos 2012). They also support important fisheries, and some of them maintain aquaculture exploitations (Pérez-Ruzafa and Marcos 2012, Cataudella et al. 2015). Coastal lagoons have raised considerable environmental concerns: land claiming, pollution, and the lack of management, among other factors, have strongly modified both the structure and the functioning of these sensitive coastal ecosystems. The lack of an adequate management of these areas has been recognized as the main cause leading to an ecological degradation of the lagoons and of their sensitive habitats (Cataudella et al. 2015). In order to understand and protect these critical habitats, it is important to document the communities they support and understand the factors that naturally influence the distribution and abundance of associated species.

In the Mediterranean Sea, the functional role of coastal lagoons in relation to fish have been extensively investigated in its northern part (Franco et al. 2012), in particular in Italy (Dumay et al. 2004, Malavasi et al. 2004, Franco et al. 2006, 2008, Maci and Basset 2009), Spain (Pérez-Ruzafa et al. 2006, Verdiell-Cubedo et al. 2013), and France (Poizat et al. 2004, Mouillot et al. 2005). In the southern part, few investigations were conducted in the Nador Lagoon, Morocco (Bouchereau et al. 2000, Jaafour et al. 2015), Mellah Lagoon, Algeria (Chaoui et al. 2006a), Ichkeul Lagoon, Tunisia (Sellami et al. 2010), Ghar El Melh and Lake Manzala lagoons, Tunisia (Kraïem et al. 2009).

There are some 400 coastal lagoons in the Mediterranean region, and they cover a total surface of over 641 000 ha and differ in their typology and use (Cataudella et al. 2015). The number of lagoons, however, in the south-western Mediterranean Sea (8) is much lower than in the north-western shores (France: 20; Italy: 198; Spain: 14) (Cataudella et al. 2015). The Mellah Lagoon is the only coastal lagoon in Algeria. Characterized by a low anthropogenic pressure it has a crucial environmental and socioeconomic role because of its fishing activities and conservation status. The above-mentioned site is classified as an integral reserve in the El Kala National Park which is itself classified as a Reserve of Biosphere of the MABUnesco and a wetland of international importance according to the Ramsar Convention. However there is no specific management plan for this lagoon today.

Although artisanal fishery is the main human activity in the Mellah Lagoon, there have been only few studies carried out on the fish fauna. The majority of the studies focused on the physicochemical parameters (Guélorget et al. 1989, Semroud unpublished*), flora (Semroud unpublished), and macrozoobenthic fauna (Drarédja et al. 2012). Regarding fish fauna, previous studies addressed the diversity and production of adult commercial catches (Kara and Chaoui 1998b, Chaoui et al. 2006a), and the biology of some species such as *Dicentrarchus labrax* (Linnaeus, 1758) (see Kara and Chaoui 1998a), *Sparus aurata* Linnaeus, 1758 (see Chaoui et al. 2005, 2006b), and *Atherina boyeri* Risso, 1810 (see Boudinar et al. 2015, 2016a, 2016b). There were three major objectives of the presently reported study:

- To describe the fish assemblages in terms of their taxonomic and functional composition;
- To describe their spatial and seasonal variations; and
- To relate these variations to environmental parameters.

MATERIALS AND METHODS

Study area. The Mellah Lagoon is located in the eastern coast of Algeria (36°53′56.5″N, 8°19′56.0″E; Fig.1). It is a shallow coastal lagoon of oval shape with an area of about 865 ha and a mean depth of 2.7 m (maximum depth 6.4 m). It extends from north to south for about 4 km and from east to west for 2 km (Fig. 1). The Lagoon can be classified as a micro-tidal system. It communicates with the sea via an approximately 870-m-long, 15-m-wide, and 0.5 to 2-m-deep channel and receives freshwater from three small wadis: Mellah, Bouaroug, and R'kibet. Due to the limited tidally-driven exchanges between the lagoon and the sea, the hydrology of the lagoon is strongly influenced by precipitation, evaporation, and freshwater inputs (Guélorget et al. 1989, Ounissi et al. 2002). Rainfall is generally concentrated in autumn–winter and the annual precipitation amounts to about 910 mm. The main evaporation rate is about 889 mm $\cdot$ year^{-1} (Cataudella et al. 2015). The Mellah Lagoon is characterized by the existence of extremely reduced banks. The bottom of the shallow zones of the lagoon is made up of fine sand with more or less shell debris. In the central part of the lagoon the sediment is enriched with fine particles (carbonates and organic matter) while the whole central zone below 3 m depth is covered with mud (Guélorget et al. 1989). The seagrass *Ruppia* sp. covers the bed of a large part of the shallow area of the lagoon but is more important on the west side of the lagoon. Fishing activities are practised only in the peripheral belt of the lagoon down to the depth of 4 m, because captures are rare in the central part (Guélorget et al. 1989). This is probably due to the lack of oxygen in these central zones. The Mellah Lagoon is subject to a southern Mediterranean climate with hot dry summers and wet cold winters.

The presently reported study has been carried out in accordance with the Algerian regulations concerning fish sampling and conservation.

Sampling protocol. The fishes were caught in the shallow waters (<1.5 m) at four stations (Fig. 1), covering almost all the lagoon and representing different habitats (e.g., distance from the inlet, bottom sediment characteristics, habitat-associated vegetation). The sampling was done during daylight hours using a beach seine net (length = 14 m, height = 2 m, mesh size = 3 mm). The seine net was considered appropriate for catching small (<100 mm total length) fishes, which abound in shallow transitional waters

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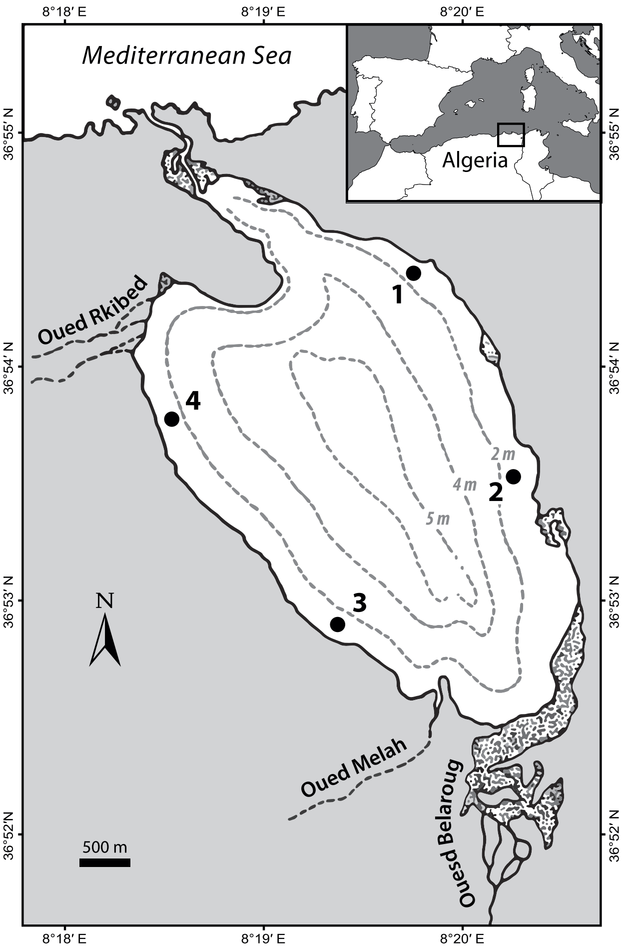

Fig. 1. Mellah Lagoon, Algeria, and location of the four sampling stations

(Pierce et al. 1990, Franco et al. 2012). Hauls were taken parallel to the shoreline at a standardized distance of about 15 m. Each seine covered an area of approximately 240 m^2. At each station, two replicate collections were made. Sampling was carried out in a monthly basis between October 2012 and September 2013.

After each sampling, fishes were preserved in plastic bags and transported in a cooler with ice to the laboratory. Each individual caught was identified to species level, measured (TL) to the nearest mm, and weighed (total weight) with a precision of 0.01 g. Juveniles and larvae were handled carefully to avoid damage which could complicate the identification of the species. Mugilids of less than 60 mm, where identification is problematic (Laffaille et al. 2000), were not identified to the species level. For each species, catches were standardised to numbers of individuals per 100 m^2. Environmental variables were measured on each sampling occasion immediately before the fishing procedure. Temperature, salinity, dissolved oxygen (mg · L^{-1}), and pH were measured using a multiparameter probe. Visual estimates of substrate type (sandy or muddy based on visual texture of the sediment), habitat-associated vegetation (percentage of margin cover by the vegetation) and hydrographic characteristics (level of exposure to freshwater according to the proximity of freshwater input such as wadi or proximity to the channel) were recorded to characterize the habitat structure of the four stations.

Data analysis. Species richness (the total number of species caught in each month or during each season or each station) and Shannon–Wiener index (*H*′) were used to quantify species diversity. Fish species were also assigned to functional groups according to their habitat use, following the classification of Franco et al. (2008) and information from FishBase (Froese and Pauly 2017).

To analyse the seasonal variations of species and environmental variables, seasons were aggregated into three-month groups: winter comprising December, January, and February; spring: March, April, and May; summer: June and August, and autumn: September, October, and November. A one-way analysis of variance was used to compare fish density, number of species, and environmental variables among seasons and among stations. An a-posteriori Tukey HSD test followed ANOVA procedures every time (that) the null hypothesis was rejected at $\alpha < 0.05$. All data were previously log transformed using $\log_{10}(x + 1)$, where x is the raw value, to address the assumptions of normality and homogeneity of variance of the parametric analyses. Total length (TL) data for the dominant species were analysed with the nonparametric Kruskal–Wallis test to investigate possible seasonal and spatial variations in the size of individuals. Whenever differences were detected, the Mann–Whitney test was applied to the data to quantify and establish those differences.

Fish assemblage and composition were compared between stations and sampling months. Species composition on a presence/absence basis was analysed using Jaccard index (Krebs 1999), which measures the number of species in common between two samples and ranges from zero to one. Similarities in species abundances between stations were graphically represented by a dendrogram using the Bray–Curtis similarity coefficient. Canonical correspondence analysis (CCA) performed with R software (Venables et al. 2005) was used to assess environmental influences on fish spatio-temporal assemblages. Logarithmic transformations ($\log_{10}(x + 1)$) of species abundance were performed and only the most commonly occurring species (>0.1% of abundance) were included in the analysis in order to reduce effects of rare species. The CCA is a robust method that directly relates community data to environmental variables by constraining species ordination to a pattern that correlates with environmental variables (Ter Braak 1986).

RESULTS

Environmental variables. During the study period, the water temperature varied from 10.8°C in January to 28.9°C in August (mean ± SD = 20.4 ± 6.3°C) (Fig. 2). Salinity ranged from 20.1‰ in February to 29.8‰ in August (mean ± SD = 25.3 ± 3.4‰). A clear seasonal pattern was observed for both parameters, with minimum values during the winter months and maximum values during the summer months (Fig. 2). During the cold period, there was a decrease of 11.5°C during the period September–

January followed by a period of increasing temperature of about 14.3°C from February to July. The temperature difference between the hottest month (August) and the coldest month (January) was 18.1°C. The dissolved oxygen and the pH showed no clear seasonal trend. The oxygen concentrations ranged from 4.39 mg · L^{-1} in October to 8.63 mg · L^{-1} in February (mean = 6.95 ± 1.21 mg · L^{-1}). The pH ranged from 8.48 in August to 9.55 in January (mean ± SD = 8.92 ± 0.38) (Fig. 2).

The environmental parameters measured were uniform across the whole lagoon. There were no significant spatial differences (between stations) (P > 0.001). The sandy sediments dominated at the four stations. In the western part of the lagoon, stations 3 and 4 were characterized by the fresh water supply due to the proximity of wadis (R'kibet and El Mellah) and the presence of seagrass *Ruppia* sp. which covers the bed of a large part of the shallow area (>70%) whereas stations 1 and 2 located on the eastern side of the lagoon covered less than 30%. Station 1 was located near the channel.

Fish species composition. We sampled a total of 22 852 fish specimens of 11 species, representing 8 families: *Aphanius fasciatus* (Valenciennes, 1821); *Atherina boyeri* Risso, 1810; *Liza saliens* (Risso, 1810); *Liza aurata* (Risso, 1810); *Mugil cephalus* Linnaeus, 1758; Mugilidae gen sp.; *Pomatoschistus marmoratus* (Risso, 1810); *Diplodus sargus sargus* (Linnaeus, 1758); *Sparus aurata* Linnaeus, 1758; *Syngnathus abaster* Risso, 1827; *Anguilla anguilla* (Linnaeus, 1758); *Hyporhamphus picarti* (Valenciennes, 1847) (Table 1). Two functional groups were identified according to species' habitat use: residents, included those species spawning in the lagoon, where they maintain stable populations; marine migrants, included marine euhaline species (i.e., spawning at sea) entering the lagoon on a regular basis mainly for feeding and shelter. Seven marine migrants and four resident species were captured. However, in terms of density, the fish assemblage was largely dominated by resident species (mean density: 150 individuals · 100 m^{-2}) representing 96% of the total catches (Table 1).

The majority of the specimens caught were juveniles, with the exception of *Atherina boyeri*, *Aphanius fasciatus*, *Pomatoschistus marmoratus*, and *Syngnathus abaster* which were mainly adult individuals. Mugilidae was the most representative family comprising in the presently reported study three species. Six species were present throughout the year in the lagoon and comprised almost 99.65% of the total catch, while three of them (*A. boyeri*: 87.59%, 20 015 individuals; *A. fasciatus*: 7.44%, and *Liza aurata*, 2.30%) made up the majority of the fish assemblage.

The most abundant species had a mean length under 6 cm. For the four most abundant species (*A. boyeri*, *A. fasciatus*, *L. saliens*, and *L. aurata*) there was a significant difference in fish size among the four stations sampled (Kruskal–Wallis, P < 0.05) (Table 2).

The mean sizes of *Atherina boyeri*, *Aphanius fasciatus*, and *Liza aurata*, from stations 1 and 2 were different from stations 3 and 4. The fish lengths of *A. boyeri* and *A. fasciatus* at stations 1 and 2 were significantly higher than at station 3 and 4 (Table 2). The inverse was observed for *L. aurata*, with higher sizes at stations 3

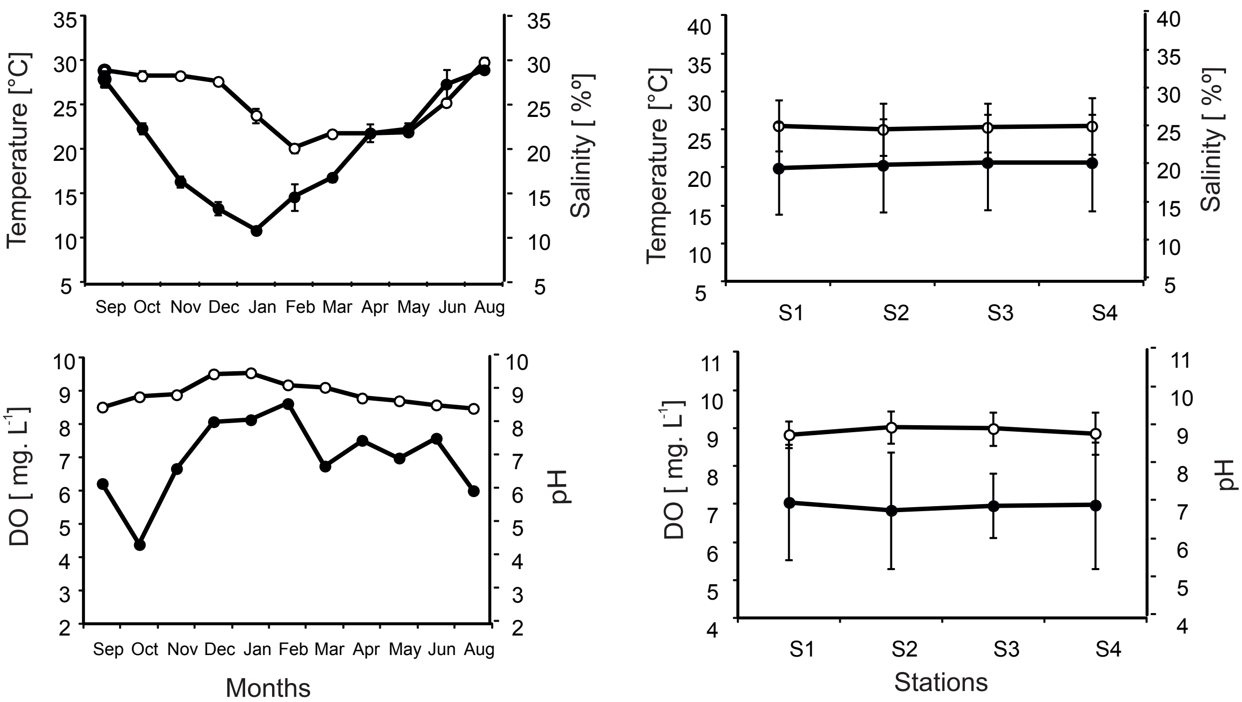

Fig. 2. Temporal and spatial fluctuations in environmental parameters (mean ± SD) between October 2012 and September 2013 in the waters of the Mellah Lagoon, Algeria: black dots = dissolved oxygen (DO) and temperature, white dots = pH and salinity

Table 1

Principal occurrence and ecological data of the fish species of the Mellah Lagoon, Algeria

Species	Family	Mean density of fish species [individuals · 100 m^{-2}]											%FO	EG
		Autumn			Winter			Spring			Summer			
		Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Aug		
Aphanius fasciatus	CY	28.98	3.46	2.06	1.34	0.52	7.84	0.05	20.17	30.42	18.86	7.58	100	R
Atherina boyeri	AT	21.20	385.96	107.79	58.63	96.92	242.09	25.64	195.51	226.04	121.47	43.41	100	R
Liza saliens	MU	4.28	7.23	1.56	0.00	0.00	0.10	0.00	0.83	0.46	0.36	3.43	72.72	MM
Liza aurata	MU	0.05	0.00	1.92	0.75	4.48	5.10	4.11	2.18	6.75	6.40	0.00	81.81	MM
Mugil cephalus	MU	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.73	0.05	0.00	18.18	MM
Mugilidae gen sp.	MU	0.00	5.10	1.35	0.00	0.26	1.17	0.48	0.05	0.00	0.00	0.00	54.54	MM
Pomatoschistus marmoratus	GO	0.54	0.00	1.00	3.95	0.65	0.33	0.36	0.05	0.00	0.00	0.20	72.72	R
Diplodus sargus sargus	SP	0.00	0.00	0.00	0.00	0.41	0.20	1.45	3.12	0.00	0.00	0.00	36.36	MM
Sparus aurata	SP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.00	9.09	MM
Syngnathus abaster	SY	0.78	0.11	0.05	0.05	0.00	0.05	0.21	0.05	0.00	0.10	0.00	72.72	R
Anguilla anguilla	AN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	9.09	MM
Hyporhamphus picarti	HE	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.10	27.72	MM

%FO = frequency of occurrence of the fish, EG = ecological guild (based on the habitat use); CY = Cyprinodontidae; AT = Atherinidae; MU = Mugilidae; GO = Gobiidae; SP = Sparidae; SY = Syngnathidae; AN = Anguillidae; HE = Hemiramphidae; R = resident, MM = marine seasonal migrant.

Table 2

Mean total length of the four most abundant fish species at the four sampling stations at the Mellah Lagoon, Algeria

Fish species	Sampling station			
	S1	S2	S3	S4
Atherina boyeri	4.88 ± 0.79	4.86 ± 0.68	4.51 ± 0.77	4.72 ± 1.06
Aphanius fasciatus	3.91 ± 0.72	3.79 ± 0.52	3.38 ± 0.57	2.77 ± 0.61
Liza aurata	3.83 ± 1.29	4.07 ± 1.01	4.60 ± 1.46	5.44 ± 0.93
Liza saliens	3.98 ± 2.96	4.93 ± 1.60	4.90 ± 1.73	2.91 ± 0.96

Values are mean ± standard deviation.

and 4. A different pattern was observed for *Liza saliens*, with significantly lower sizes at stations 4 and 1. The temporal evolution of the length-frequency distribution showed that the mean size of the four species increased from September to June (Fig. 3). This pattern in growth was particularly evident for marine species (*L. saliens* and *L. aurata*) with smallest mean sizes during August and September/October suggesting colonization of the lagoon by young juveniles mainly in late summer-early autumn.

Spatial and temporal variations of the fish assemblage structure. A spatial pattern of fish species richness was identified with higher number of fish species recorded at stations 3 and 4 (10 and 9 species respectively) (Fig. 4). Although fish density was lower at station 1 (54.8 individuals · 100 m^{-2}) (Fig. 4), there was no significant variation in fish density among the four stations ($P > 0.05$). Cluster analysis based on species abundances showed a spatial grouping of the samples. Two groups were identified at approximately 5% level of dissimilarity (Fig. 5). The first cluster group was mainly represented by stations 3 and 4 located on the western part of the lagoon. This group was characterized by high abundance of the resident species *A. fasciatus* and high species richness in which the species *Mugil cephalus*, *Anguilla anguilla*, and *Sparus aurata* are exclusive. The second cluster group is composed by stations 1 and 2 and also includes station 3 in summer and station 4 in winter.

Species richness and Shannon–Wiener diversity index (H') fluctuated between seasons (Fig. 4). Species richness ranged from 4 species in December to 8 in April and showed a seasonal pattern similar to H', with lowest values reported in autumn–winter and highest in spring–summer. Mean monthly fish abundance ranged from 32 individuals · 100 m^{-2} (March) to 401 individuals · 100 m^{-2} (October) (Fig. 4). The abundance peaked in autumn (October), winter (February) and spring (April–May) thus revealing no clear seasonal pattern. Variations in fish abundance were mainly due to the variations in abundance of *Atherina boyeri* (Table 1). The comparison of the species composition among seasons by presence-absence methods showed high Jaccard index values of 0.57 to 0.80 suggesting low differences in community structure between seasons.

The CCA analysis based on species abundance confirmed the absence of clear spatial and temporal patterns in fish assemblage (Fig. 6). Although four axes were determined within the analysis, only the first and second axes were plotted as they accounted for 81.8% of variance of the species–environment relation modelled by CCA (48% and 33.8% for axis 1 and 2, respectively) (Table 3). Station-samples from the same season were mostly grouped in the same region of the CCA plot indicating a weak spatial separation. Salinity was highly correlated with axis 1 ($r = -0.78$) and distinguished the autumn from the other seasons. Temperature and pH were best correlated with axis 2 but were opposite to each other ($r = -0.66$ and 0.65, respectively). Higher

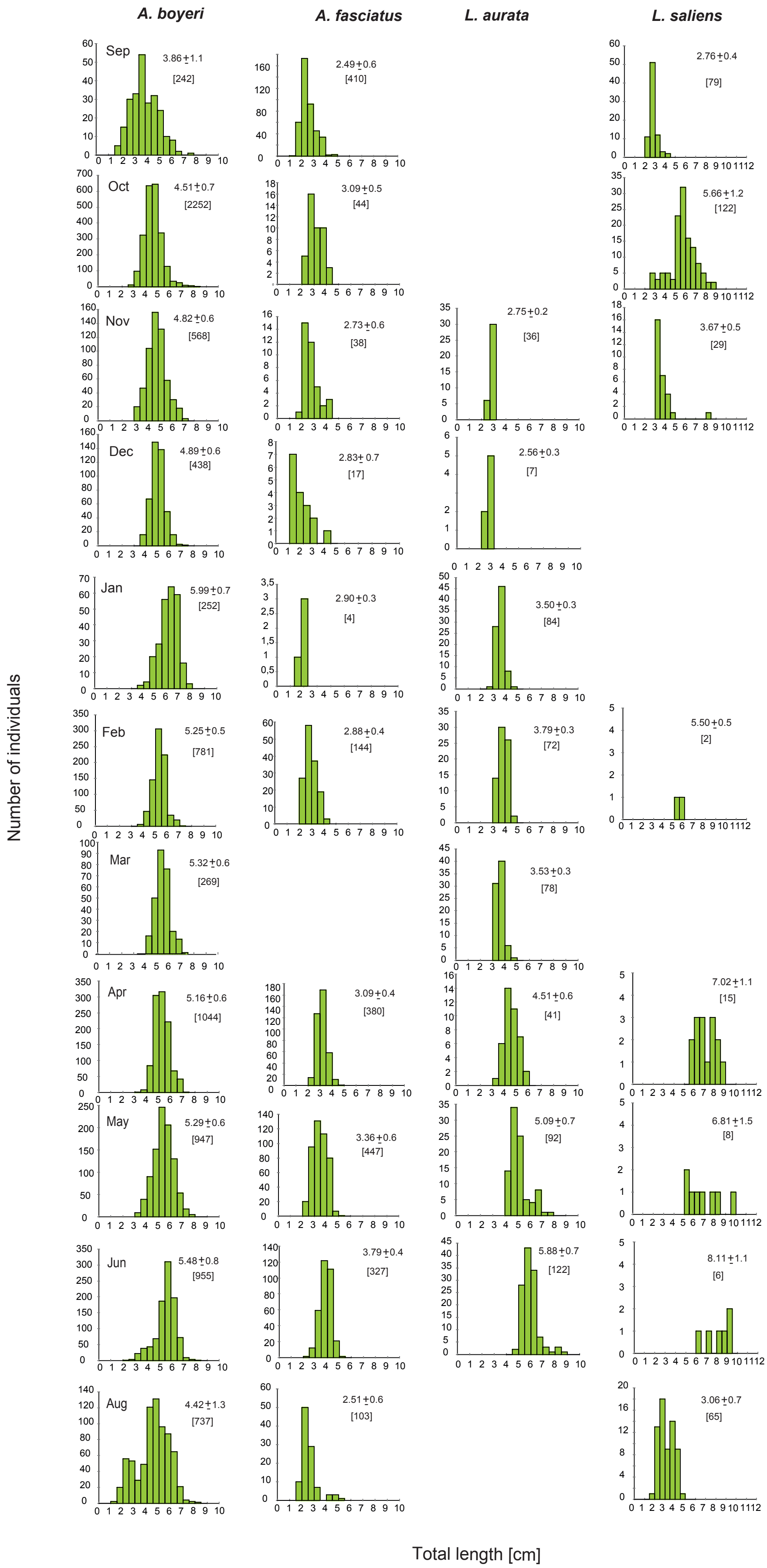

Fig. 3. Monthly length-frequency distribution of the four main species caught in the Mellah Lagoon, Algeria; Mean fish length ± SD [cm] and number of individuals measured are indicated

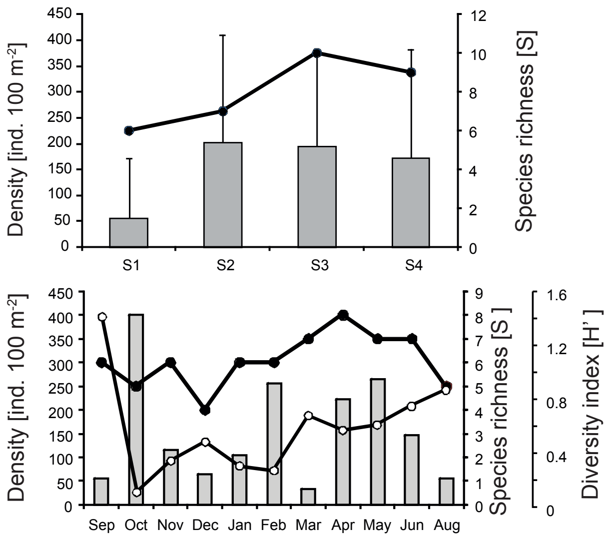

Fig. 4. Spatial and temporal variations of species richness (white dot), Shannon–Wiener diversity H' (black dot) and abundance (individuals · 100 m^{-2}) (bars) in Mellah Lagoon, Algeria; Error bars = SD

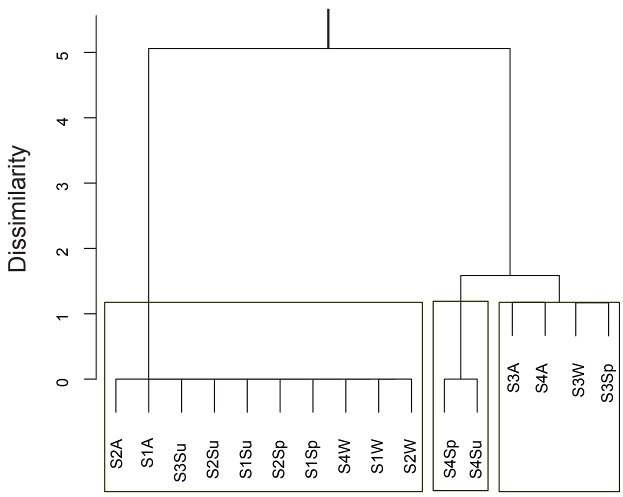

Fig. 5. Cluster analysis dendrograms (Bray–Curtis dissimilarity index) based on $\log_{10}(x + 1)$ transformed mean monthly abundances of the species sampled at four stations between October 2012 and September 2013; Stations and seasons code: the two first letters indicate the station and the other letters the season; A = autumn, W = winter, Sp = spring, Su = summer)

temperature characterized the summer period while higher pH values characterized the winter period. Dissolved oxygen was correlated with both axes 1 and 2. In the CCA, associations between environmental parameters and the most abundant species indicated that species plotted closer to the vector, or other species have stronger relations with them. Species located near the origin either do not show a strong relation to any of the variables or are found at mean values of environmental variables. The majority of species and particularly the two numerically dominant ones (*Aphanius fasciatus* and *Atherina boyeri*) had average values in relation to environmental variables except *Pomatoschistus marmoratus* which was strongly correlated with pH and DO and negatively correlated with temperature (Fig. 5). With the exception of *Liza saliens*, strongly correlated with salinity, marine juvenile species were not correlated with the salinity gradient.

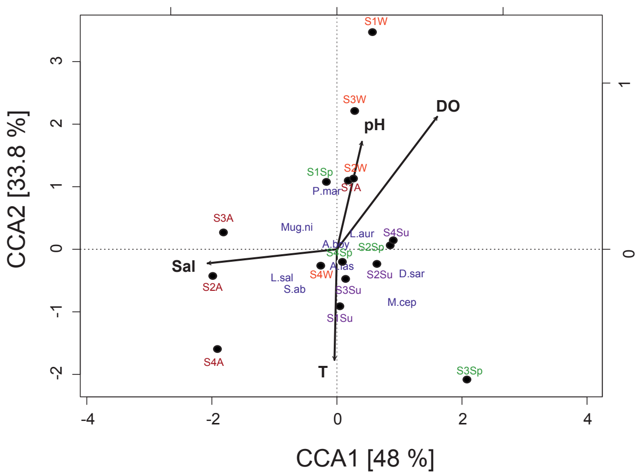

Fig. 6. Triplot of canonical correspondence analysis relating site score, fish taxa abundance and environmental variables correlated with axes; Objects (sampling sites) are represented by circles (station and season), response variables (species densities) are plotted by species abbreviation names (in blue), arrows represent quantitative explanatory variables (environmental variables: T = temperature, Sal = salinity, DO = dissolved oxygen, pH = potential of hydrogen) with arrowheads indicating their direction of increase; Environmental variables coordinates are placed on the upper X axis and the right Y axis; Green sites = spring, red sites = winter, purple sites = summer, brown sites = autumn; W = winter, Sp = spring, Su = summer, A = autumn; Species name abbreviations: P.mar = *Pomatoschistus marmoratus*; L.aur = *Liza aurata*; A.boy = *Atherina boyeri*; A.fas = *Aphanius fasciatus*; D.sar = *Diplodus sargus*; M.cep = *Mugil cephalus*; S.ab = *Syngnathus abaster*; L.sal = *Liza aurata*; Mug.ni = Mugilidae gen sp.

Table 3

Statistics associated with the first two canonical axes from canonical correlation analysis of environmental influences on fish spatio-temporal assemblages

Parameter	Axis	
	CCA1	CCA2
Canonical correlation	0.53	0.30
Percent of variance explained	48%	33.8%
Standardized correlation with environmental axis		
Temperature	–0.01	–0.67
Salinity	–0.78	–0.08
Dissolved oxygen	0.60	0.80
pH	0.15	0.65

DISCUSSION

The presently reported study was the first to analyse quantitatively the fish-fauna composition of the Mellah Lagoon, and to relate this to environmental parameters using statistical methods. The fish assemblage of the shallow water (<1.5 m) of the Mellah Lagoon showed a low species richness of only 11 species. The majority had mean length values of less than 6 cm, represented by juveniles or adults of small fish species. The beach seine net used is considered to be a very effective technique for sampling small fish (<10 cm) in shallow waters, especially in lagoon ecosystems (Franco et al. 2012). The fish species diversity was lower than those described in other Mediterranean lagoons. For example, the fish species richness listed in 40 Atlanto–Mediterranean lagoons ranged from 6 to 48, with a mean of 23.4 species (Pérez-Ruzafa et al. 2007, 2011a). The Mellah Lagoon supported fewer fish species than the majority of the southern Mediterranean lagoons (Table 4) including Ghar El Melh in Tunisia (26 species), Lake Manzala in Egypt (17) (Kraïem et al. 2009), Ichkeul Lagoon in Tunisia (13) (Sellami et al. 2010), Nador Lagoon in Morocco (15–18) (Bouchereau et al. 2000, Jaafour et al. 2015). Caution is needed when comparing fish diversity or assemblage structure in different ecosystems. Variations in observed fish diversity between lagoons might depend on the lagoon characteristics (surface area, depth, connection with the sea), hydrological parameters (e.g., tidal range, temperature, salinity), the sampling effort, as well as the fishing gear type (Akin et al. 2005, Franco et al. 2008, Maci and Basset 2009). For example, in the Mellah Lagoon, Chaoui et al. (2006a) recorded 38 fish species, mainly adult individuals, using commercial catches. This difference is due to the diversity of the fishing gear used (fish trap, gill net, beach seine), sampling location (in deeper water >1.5 m), and sampling effort (several years).

Marine migrant species that use the lagoon as a nursery ground were the most represented in terms of number of species, with Mugilidae as the dominant family. Nevertheless, resident species were numerically prevalent accounting for 96% of the total fish captured. Neither marine stragglers nor freshwater species were caught. The dominance of resident species has been observed in other southern Mediterranean lagoons such as Nador Lagoon in Morocco (Jaafour et al. 2015), Ichkeul Lagoon in Tunisia (Sellami et al. 2010), and some northern Mediterranean lagoons (Manzo et al. 2016). These results contrast with many other studies conducted in European lagoons. Franco et al. (2008) showed that fish assemblages from 19 northern Mediterranean lagoons were dominated in general by marine species.

As in many others lagoons, a small number of species dominated the assemblage (Franco et al. 2008, Maci and Basset 2009). The shallow water fish assemblages in the Mellah Lagoon were dominated, in terms of fish abundance by two species *Atherina boyeri* (87.59% of the total catches) and *Aphanius fasciatus* (7.44%). The dominance of these two opportunistic species is a common feature of the fish assemblages of several Mediterranean lagoons (Bouchereau et al. 2000, Koutrakis et al. 2005, Franco et al. 2008, Manzo et al. 2016).

Environmental parameters measured were uniform across the lagoon. Due to the limited freshwater inputs from wadis and tidally-driven exchanges between the lagoon and the sea, the hydrology of the lagoon is strongly influenced by precipitation and evaporation, which explains the homogeneous spatial distributions of several environmental variables. The annual precipitation approximates 910 mm and is of the same order of magnitude as evaporation which is about 889 $mm \cdot year^{-1}$ (Cataudella et al. 2015). The lagoon communicates with the sea by a small channel which is approximately 870-m long and 15-m wide. However, the process of water exchange with the sea is weak because of the very important silting which gradually reduces the free section of the channel (Ounissi et al. 2002, Messerer unpublished*). Guélorget et al. (1989) suggested that the confinement of the Mellah Lagoon is due to the hydrological isolation (long and narrow channel), and to the relatively high depth (6 m) with regard to the surface area (800 ha) on the other hand. Pérez-Ruzafa et al. (2011b) suggested that the main factor that contributes to the structuring lagoon assemblages and which, to a certain extent, integrates all the others is related to the degree of isolation from the sea. Therefore, such confinement may explain the weak spatial pattern of variation in the fish assemblage and the prevalence of opportunistic species such as residents and Mugilidae which are known to have broad ecological tolerance. The same conclusion was suggested to explain the weak spatial pattern of variation in benthic macrofauna (diversity and abundance) in the Mellah Lagoon (Guélorget et al. 1989, Draredja et al. 2012). A more detailed spatial studies of the fish assemblages with more sampling stations covering the entire lagoon are necessary to confirm such hypothesis.

Salinity has been usually considered as the major driving factor of spatial patterns of fish fauna in many lagoon systems (Akin et al. 2005, Pérez-Ruzafa et al. 2007, Maci and Basset 2009). In the Mellah Lagoon, despite homogeneous hydrological parameters, we found a higher species richness at stations 3 and 4 located on the western part of the lagoon but no significant variations in abundance between stations. This highest fish diversity observed on the western part of the lagoon may be associated with the higher presence of the seagrass *Ruppia* sp. which covers the bed of a large part of the shallow area of the lagoon. Generally, vegetated habitat supports more diverse fauna due to the higher complexity of this habitat providing higher food availability and refuge from predators (Malavasi et al. 2004, Franco et al. 2006).

There was no clear temporal pattern of variation in the fish assemblage. The CCA analysis based on abundance data showed a relatively poor monthly separation of samples. Temporal variations in total abundance reflect fluctuations in the most dominant species, which in this case were *Atherina boyeri* and *Aphanius fasciatus*.

* Messerer Y. 1999. Etude morphométrique et hydrologique du complexe lacustre d'El-Kala (Cas du lac Mellah et du lac Oubéira). Thèse de magister en Ecologie et Environnement, Université de Annaba, Algeria.

Table 4

List of the fish species recorded in the Maghreb lagoons

Family	Species	Bouchereau et al. 2000	Jaafour et al. 2015	Sellami et al. 2010	Chaoui et al. 2006a	Presently reported study
		Nador Lagoon, Morocco	Nador Lagoon, Morocco	Ichkeul Lagoon Tunisia	Mellah Lagoon, Algeria	Mellah Lagoon, Algeria
Atherinidae	*Atherina presbyter* Cuvier, 1829		+			
	Atherina boyeri Risso, 1810	+		+	+	+
Blenniidae	*Salaria pavo* (Risso, 1810)	+	+		+	
	Parablennius sp.	+				
Callionymidae	*Callionymus risso* Lesueur, 1814	+	+			
Gobiidae	*Pomatoschistus marmoratus* (Risso, 1810)	+	+			+
	Pomatoschistus microps (Krøyer, 1838)	+		+		
	Gobius paganellus Linnaeus, 1758	+			+	
	Gobius cobitis Pallas, 1814	+			+	
	Gobius bucchichi Steindachner, 1870	+			+	
	Gobius niger Linnaeus, 1758	+	+	+	+	
Hemirhamphidae	*Hyporhamphus picarti* (Valenciennes, 1847)		+			+
Moronidae	*Dicentrarchus punctatus* (Bloch, 1792)		+			
	Dicentrarchus labrax (Linnaeus, 1758)	+		+	+	
Mugilidae	*Liza aurata* (Risso, 1810)		+	+	+	+
	Liza saliens (Risso, 1810)			+	+	+
	Liza ramada (Risso, 1810)			+	+	
	Chelon labrosus (Risso, 1827)				+	
	Mugil cephalus Linnaeus, 1758		+	+	+	+
Mullidae	*Mullus barbatus* Linnaeus, 1758		+			
	Mullus surmuletus Linnaeus, 1758				+	
Soleidae	*Solea solea* (Linnaeus, 1758)		+			
	Solea senegalensis Kaup, 1858				+	
	Pegusa lascaris (Risso, 1810)	+				
Cyprinodontidae	*Aphanius fasciatus* (Valenciennes, 1821)			+	+	+
Cyprinidae	*Luciobarbus callensis* (Valenciennes, 1842)			+		
Belonidae	*Belone belone* (Linnaeus, 1761)				+	
	Parablennius pilicornis (Cuvier, 1829)				+	
Apogonidae	*Apogon imberbis* (Linnaeus, 1758)				+	
Scorpaenidae	*Scorpaena scrofa* Linnaeus, 1758				+	
Congridae	*Conger conger* (Linnaeus, 1758)				+	
Labridae	*Thalassoma pavo* (Linnaeus, 1758)				+	
	Symphodus tinca (Linnaeus, 1758)		+		+	
	Coris julis (Linnaeus, 1758)				+	
	Symphodus cinereus (Bonnaterre, 1788)	+	+			
Muraenidae	*Muraena helena* Linnaeus, 1758				+	
Carangidae	*Lichia amia* (Linnaeus, 1758)				+	
Poeciliidae	*Gambusia holbrooki* Girard, 1859				+	
Serranidae	*Serranus hepatus* (Linnaeus, 1758)				+	
Anguillidae	*Anguilla anguilla* (Linnaeus, 1758)	+		+	+	+
Syngnathidae	*Syngnathus typhle* Linnaeus, 1758	+	+			
	Syngnathus abaster Risso, 1827	+		+	+	+
	Hippocampus guttulatus Cuvier, 1829				+	
Sparidae	*Diplodus puntazzo* (Walbaum, 1792)				+	
	Diplodus vulgaris (Geoffroy Saint-Hilaire, 1817)				+	
	Diplodus sargus sargus (Linnaeus, 1758)	+			+	+
	Lithognathus mormyrus (Linnaeus, 1758)				+	
	Sparus aurata Linnaeus, 1758		+	+	+	+
	Boops boops (Linnaeus, 1758)				+	
	Sarpa salpa (Linnaeus, 1758)				+	
	Oblada melanura (Linnaeus, 1758)				+	
Engraulidae	*Engraulis encrasicolus* (Linnaeus, 1758)	+				

We found seasonal patterns in species richness with higher diversity from March to June. The seasonal variation in fish community structure is well documented, with the arrival of many juveniles of marine species during the spring and summer, resulting in an assemblage dominated by a larger number of species (Pérez-Ruzafa et al. 2007, Maci and Basset 2009). This supports the idea that fish species richness in coastal lagoons is mostly determined by colonization rates from the adjacent coastal zone and depends on the rate of water exchange between the sea and the lagoon (Mariani 2001, Perez-Ruzafa et al. 2006). Generally, Mediterranean lagoons, which show significant spatial and temporal patterns of the fish assemblage structure, contain large numbers of marine stragglers (Mariani 2001, Franco et al. 2008, Maci and Basset 2009). This is the case of the Nador Lagoon (Morocco) which was sampled using the same protocol as in the presently reported study and where many marine stragglers were caught, such as: *Mullus barbatus* Linnaeus, 1758; *Callionymus lyra* Linnaeus, 1758; *Diplodus puntazzo* (Walbaum, 1792); *Symphodus tinca* (Linnaeus, 1758); *Symphodus cinereus* (Bonnaterre, 1788) (see Jaafour et al. 2015). This lagoon is little confined because it communicates extensively with the sea (Guélorget et al. 1989) and the salinity of its waters is much higher than those of the Nador Lagoon (Iouzzi et al. unpublished[*]). As described for the Lesina Lagoon in the Adriatic Sea (Manzo et al. 2016), the low species richness in the Mellah Lagoon is mainly due to limited colonization by marine species, reflected especially in the failure to find marine stragglers.

The results of CCA and cluster analysis indicate that the fish assemblage of Mellah Lagoon exhibited weak spatial and temporal patterns. Most species and particularly the two numerically dominant species (*Aphanius fasciatus* and *Atherina boyeri*) do not show a strong relation to any of the variables or are found at average values of environmental variable. Such weak temporal and spatial patterns variation of the fish assemblage is characteristic of confined lagoons i.e., with limited connectivity between the lagoon and sea (Guélorget and Perthuisot 1983, Manzo et al. 2016). The species diversity in these lagoons is low and constituted almost exclusively by resident and marine migrants which are opportunistic species with a broad tolerance for the extreme changes in abiotic parameters, which make them capable of exploring the entire lagoon basin (Pérez-Ruzafa et al. 2007, Manzo et al. 2016).

In conclusion, the fish assemblage of the shallow water (<1.5 m) of Mellah Lagoon is characterized by a small number of species dominated by resident species, the most abundant of them being the big-scale sand smelt *Atherina boyeri*. The low species richness and the weak spatial and temporal patterns in the fish assemblage is mainly the result of a high degree of confinement because of the limited freshwater inputs from wadis and tidally-driven exchanges between the lagoon and the sea. In addition to the small size of the channel, water exchanges with the sea are weakened because of the very important silting which gradually reduces the free section of the channel. Lagoon management is recognized as the main instrument to preserve the ecological features of lagoons and prevent the depletion of the valuable aquatic resources and degradation of sensitive habitats. At this time, there is no specific management plan for the Mellah Lagoon. For maintaining high biodiversity and a sustainable fishery in the lagoon, it is necessary to develop a management plan which would allow a proper water exchange between the lagoon and the sea and would promote colonization of the lagoon by marine species. Understanding the influence of connections and fluxes on lagoon fauna is important for prediction of the ecological impacts of future management plans.

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