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Influence of environmental factors on the characteristics of macrobenthic communities in soft bottoms around coral reefs of Larak Island (Persian Gulf)

Influence des facteurs environnementaux sur les caractéristiques des communautés macrobenthiques des fonds meubles autour des récifs coralliens de l'île de Larak (golfe Persique) (traduit par la rédaction)

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Abstract – The effective conservation of coastal ecosystems including soft bottoms around coral reefs of Larak Island, Persian Gulf is requiring basis data on community structure at different relevant spatial scales. In this regard, the diversity and the abundance of the macrobenthic communities in soft bottoms around coral reefs of this area were described in relation to different environmental factors. A seasonal sampling was conducted at two stations located in the east and west of Larak Island, respectively, during 4 seasons, from spring to winter 2012. A total of 20 species which belong to 20 genera and 14 families were identified. The macrobenthic density showed significant differences among seasons. The Shannon-Wiener index ranged from 2.07 to 2.89 indicating a moderate diversity in both stations. The maximum diversity of macrobenthic organisms was observed during spring. A non-metric multidimensional scaling (NMDS) analysis showed a large overlap in the macrobenthic community structure between the two stations. A principal component analysis (PCA) analysis indicated that the main environmental factors controlling macrobenthic density were phosphate, dissolved oxygen and total organic matter (TOM). Our results indicated that coral macrobenthic communities in Larak Island were characterized by low density and uniform distribution of species.

***Keywords* –** macrobenthic communities, benthos, density, diversity, environmental variables, coral reef

Résumé – Une conservation efficace des écosystèmes côtiers, y compris des fonds meubles autour des récifs coralliens de l'île de Larak, dans le golfe Persique, nécessite des données de base sur la structure des communautés à différentes échelles spatiales pertinentes. À cet égard, la diversité et l'abondance des communautés macrobenthiques dans les fonds meubles autour des récifs coralliens de cette zone ont été décrites en relation avec différents facteurs environnementaux. Un échantillonnage saisonnier a été effectué au niveau de deux stations situées respectivement à l'est et à l'ouest de l'île de Larak pendant 4 saisons, du printemps à l'hiver 2012. Au total, 20 espèces appartenant à 20 genres et 14 familles ont été identifiées. La densité macrobenthique a montré des différences significatives entre les saisons. L'indice de Shannon-Wiener a varié entre 2,07 et 2,89, indiquant une diversité modérée dans les deux stations. La diversité maximale des organismes macrobenthiques a été observée au printemps. Une analyse de positionnement multidimensionnel non métrique (NMDS) a montré un grand chevauchement dans la structure de la communauté macrobenthique entre les deux stations. Une analyse en composantes principales (ACP) a indiqué que les principaux facteurs environnementaux contrôlant la densité macrobenthique étaient le phosphate, l'oxygène dissous et la matière organique totale (MOT). Nos résultats ont indiqué que les communautés macrobenthiques coralliennes de l'île Larak étaient caractérisées par une faible densité et une répartition uniforme des espèces.

Mots clés – communautés macrobenthiques, benthos, densité, diversité, variables environnementales, récif corallien

1 Introduction

Coral ecosystems are among the most productive marine ecosystems worldwide. They support diverse communities of marine organisms and offer substantial commercial, recreational and cultural values to society (Fukunaga *et al.*, 2017). Benthic communities of coral ecosystems can vary with depth, from a community dominated by photosynthetic organisms in shallower depths to communities composed of obligate heterotrophs at greater depths (Kahng *et al.*, 2014). Nowadays, increased attention has been paid on coral habitats because of their increasing exposure to global and local disturbances which threaten their biodiversity (Lindfield *et al.*, 2016). Major threats to these ecosystems include climate change (e.g. increase in thermal stress), increase in sedimentation with reduced photosynthetically active radiation, strong wave action, nutrient enrichment, overexploitation of marine resources, and invasive species (Pyle *et al.*, 2016), which can have dramatic consequences on world's reefs (Jackson, 2010) and on the composition and structure of benthic communities (Fukunaga *et al.*, 2017). In this context of increasing human activities, there is a need and a demand to identify the responses of macrobenthic communities to environmental changes. Data on community structure (species composition and abundance) at different relevant spatial scales can provide crucial information for the effective management and the conservation of these coastal marine ecosystems (Casas Guell *et al.*, 2015).

Numerous research studies have focused on patterns of macrobenthic assemblages in relation to environmental factors including sedimentary and hydrological variables on intertidal and shallow sublittoral soft bottoms in temperate systems (Veiga *et al.*, 2016; Veiga *et al.*, 2017) or in tropical ones (Alsaffar *et al.*, 2019). Some studies have already examined the biodiversity and structure of marine macrobenthic communities in the Persian Gulf and Oman Sea including soft-bottom communities from subtropical estuaries of the Northern coasts of Oman Sea (Taherizadeh & Sharifinia, 2015). These studies suggested that temporal changes in the macrobenthic composition were related to physicochemical parameters. Similarly, Moradi *et al.* (2014) showed that the spatial and temporal distributions of scleractinian coral communities could be affected by environmental variables. The purpose of the present study is to describe, for the first time, the spatial and temporal structure of macrobenthic communities in soft-bottom around coral reefs of Larak Island from Persian Gulf (Iran) and the influence of environmental variables on these community structure.

2 Materials and methods

2.1 Studied sites

The structure of corals in the waters around Larak Island was determined using existing distribution maps of corals indicating geographical coordinates of corals as well as field diving observations for depths <5 m and the Manta tow survey (with towing a snorkel diver behind a small boat along the upper reef slope to make direct observation of corals in a broad scale) and scuba diving methods for deeper depths. Subsequently, two stations were selected: station 1 located in the east of Larak Island (26°84′ N − 56°39′ E) and station 2 located in the west of Larak Island in front of the Larak's residential area, (26°87′ N − 56°33′ E) (Fig. 1).

2.2 Sampling procedure and measurements

At each station, the sampling of corals was performed through diving and the usage of 50×50 cm quadrate. A “Petersen” grab with an opening of 0.4 m^2 was used for sediment sampling. At each station, three grab samples were collected at each season (from spring to winter 2012). Immediately after collection, sediment samples were sieved on a 0.5 mm mesh sieve and the macrobenthic organisms were preserved with diluted alcohol (70%) before being identified to the lowest possible taxonomic level, in general the species level, counted and weighed with an accuracy of 0.001 g. The following references were used for species identification: Tagliapietra & Sigovini (2010), and Castelli *et al.* (2004). Physical and chemical properties of water (i.e. temperature, salinity, oxygen and turbidity) were measured by a multiparametric CTD SBE25 probe in near-bottom waters (Ostrovskii & Zatsepin, 2011).

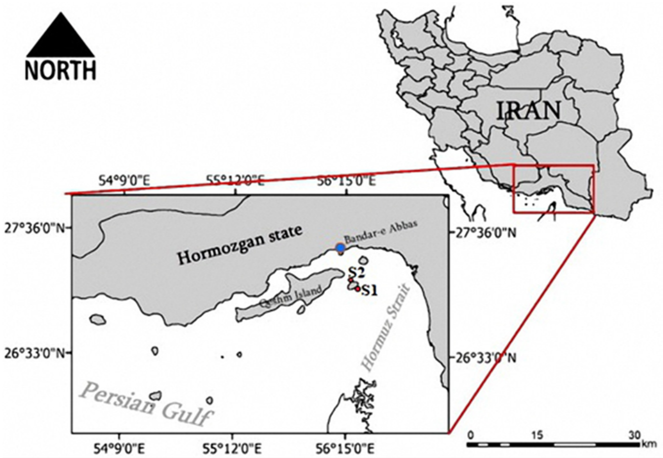

Fig. 1. Sampling locations showing station 1 (S1) in the east of Larak Island and station 2 (S2) in the west of Larak Island, Persian Gulf.

Fig. 1. Lieux d'échantillonnage montrant la station 1 (S1) à l'est de l'île Larak et la station 2 (S2) à l'ouest de l'île Larak, golfe Persique.

Species number and abundance were expressed as the number of species and the number of individuals per m^2 respectively. Particle size distribution of sediment was analyzed by sieving dry sediment through a stack of Wentworth grade sieves according to the technique described by Buchanan (1984). The sediment was characterized by the percentage of fine particles $<63\,\mu$m, the percentage of particles between 500 μm and 2 mm, and the percentage of particles >2 mm. The total organic matter (TOM) was determined using the loss on ignition method at 525 °C for 4 h (Caeiro *et al.*, 2005). The measurements of nitrate, nitrite, silicate, and phosphate from near bottom waters were performed following international standards (APHA, 2002) using a spectrophotometer according to the recommendations of the manufacturer's manual book.

2.3 Data analyses

The species diversity was calculated using the Shannon-Wiener diversity index (H'; Shannon, 1948), the Simpson index of diversity (D; Simpson, 1949) and the species richness (M; Margalef 1958). The evenness was estimated by Pielou's evenness index (J'; Pielou, 1966). These indices were used to evaluate the ecological quality status. Shannon-Wiener diversity index (H'), Simpson index of diversity (D), species richness (Margalef: M) and Pielou's evenness index (J) were tested for normality using the Kolmogorov-Smirnov (Lilliefors) (D) test and showed normality. We have also tested homogeneity of variance for four indices (Levene's test). Subsequently, they were subjected to parametric methods. We used 2-way analyses of variance (ANOVAs) to assess the effects of both seasons and stations on the abundance of macrobenthos and diversity indices. The physico-chemical variables (mean ± standard deviation) were calculated for each sampling site during the sampling period. The Kolmogorov-Smirnov test was used to assess the normality of data distribution. The physico-chemical variables and total abundance of macrobenthos showed normal distributions ($P > 0.05$), subsequently parametric tests were used. The physico-chemical variables were compared between two stations and among four seasons through 2-way ANOVAs. The correlation between the physico-chemical variables and total abundance of macrobenthos was tested through a Pearson's correlation.

The structure of the macrobenthic communities was analysed by a cluster analysis and a non-metric multidimensional scaling (NMDS) based on Bray–Curtis similarities on the relative abundances of the macrobenthic species. Similarity analyses (ANOSIM) were used for the detection of any significant differences in community structure between the two stations. A SIMPER (similarity of percentages) procedure was used to examine the contribution of taxa to the similarities (or dissimilarities) among seasons. The statistical package PRIMER version 5.0 was used for these analyses.

The association between the densities of the dominant species (Including *Cirratulus cirratus*, *Solen dactylus*, and *Hediste diversicolor*) with environmental variables (including salinity, dissolved oxygen, phosphate, silicate, turbidity, nitrate, nitrite, and pH) and sedimentary parameters (including TOM, silt, clay and sand) were investigated by a principal component analysis (PCA). For this purpose, environmental variables were standardized and log-transformed before running PCA. In PCA, the KMO and Bartlett's tests were used for suitability and validity level of data (Zhou *et al.*, 2006). In order to identify hidden component and variables, the rotation method was used.

3 Results

3.1 Main species of coral reef

Manta tow survey showed that the main scleratinian corals present in the study area included the families Poritidae (*Porites compressa*), Faviidae (*Dipsastraea matthaii*, *Favites pentagona*, *Cyphastrea microphthalma*, *Platygyra daedalea*, *Leptastrea transversa*) and Siderastreidae (*Siderastrea savignyana*, *Coscinaraea columna*). The highest coverage rate was observed for *Porites compressa* and *Leptastrea transversa*. Conversely, stone corals *Cyphastrea microphthalma and Coscinaraea columna* had the lowest coverage rate.

3.2 Species composition on soft bottom around coral reefs

Based on morphological characteristics, a total of 20 species (including 6 Mollusca, 6 Arthropoda, 6 Annelida, and 2 Echinodermata) were identified (Tab. 1). They belong to 14 families and 20 genera. Additionally, one ostracod was identified at the genus level. The total abundances of the different species have also shown in Table 1. The minimum of total abundance was observed for *Metaprotella macoranicus* and *Glyphocuma dentatum* at station 1 and for *Metacytheropteron* at station 2. We observed the maximum of total abundance for *Murex echinodes* and *Aphelochaeta monilaris* at station 1 and *Solen dactylus* at station 2 (Tab. 1). The total abundance of *Murex echinodes*, *Metacytheropteron*, *Hediste diversicolor*, and *Aphelochaeta monilaris* showed significant differences between stations (2-way ANOVAs; $P < 0.05$). Moreover, the total abundance of *Neverita didyma*, *Murex echinodes*, *Solen dactylus*, *Gnathia maxillaris*, *Carcinus maenas*, *Cirratulus cirratus*, and *Echinometra mathaei* showed significant differences between four seasons (2-way ANOVAs; $P < 0.05$) (Tab. 1).

Among the three dominant species, *Cirratulus cirratus and Solen dactylus* showed the significant differences in the total abundances between seasons (2-way ANOVAs; df = 3; F = 7.91; $P < 0.01$ for *C. cirratus*, F = 33.30; $P < 0.01$ for *S. dactylus*) (Fig. 2). In contrast, the total abundances of *Hediste diversicolor* did not vary significantly with seasons (2-way ANOVAs; $P > 0.05$) (Fig. 2). The species richness showed the highest and lowest numbers in spring at station 1 and in summer at station 2, respectively (Fig. 3). There was no significant difference in species richness between stations (2-way ANOVAs; $P > 0.05$), and among seasons (2-way ANOVAs; $P > 0.05$).

3.3 Physico-chemical parameters

The environmental data obtained at each station during four seasons are given in Table 2. Temperature showed a significant difference among the four seasons (2-way ANOVAs; F = 7.42, $P < 0.01$) and significant differences between stations were detected depending on the season (2-way ANOVAs F = 5.97; $P < 0.01$). Other parameters (except pH) showed significant differences between different seasons ($P < 0.05$), stations ($P < 0.05$) and in terms of interaction ($P < 0.05$). The Pearson's correlation coefficients calculated between the physico-chemical parameters and the total abundance of macrobenthos showed that water temperature and salinity were the most significant factors influencing the total abundance (N = 24; r = 0.55; $P < 0.05$ for temperature and N = 24; r = 0.57; $P < 0.01$ for salinity), while other parameters showed no significant correlation with total abundance of macrofauna.

The percentage of sediment fractions and organic matter contents for 2 stations during the four seasons are shown in Table 3. There was no significant difference in the percentage of sand particles, silt and clay between the two stations ($P > 0.05$), four seasons ($P > 0.05$) and in terms of interaction ($P > 0.05$) (Tab. 3), whereas TOM showed significant differences between stations (2-way ANOVAs; F = 32.67; $P < 0.01$), among seasons (F = 36.89, P = 0.00) and differences between stations depended on season (2-way ANOVAs; F = 4.43; $P < 0.05$). The results of the Pearson's correlation showed high and significant correlations between the total abundance of macrofauna and the TOM in sediments (N = 24; r = 0.62; $P < 0.01$) and the percentage of silt particles (N = 24;

Table 1. Lists of identified taxa from bottoms around coral reefs, Larak Island, Persian Gulf along with the mean total abundance of each species ± SE at both stations.

Tableau 1. Listes des taxons identifiés des fonds autour des récifs coralliens, île de Larak, golfe Persique ainsi que l'abondance totale moyenne de chaque espèce ± SE aux deux stations.

Phylum	Class	Order	Family	Genus	Species	S1	S2	P-value St	P-value Se
Mollusca	Scaphopoda		Dentaliidae	*Antalis*	*Antalis vulgaris*	6.95 ± 0.54	4.57 ± 0.30		
	Gastropoda	Neotaenioglossa	Naticidae	*Neverita*	*Neverita didyma*	5.42 ± 0.34	5.55 ± 0.54		*
		Neogastropoda	Muricidae	*Murex*	*Murex echinodes*	11.25 ± 0.76	6.67 ± 0.50	*	*
	Bivalvia	Arcoida	Arcidae	*Anadara*	*Anadara transversa*	5 ± 0.30	6.67 ± 0.33		
				Trisidos	*Trisidos tortuosa*	3.90 ± 0.24	3.75 ± 0.22		
		Euhetrodonta	Solenidae	*Solen*	*Solen dactylus*	8.60 ± 0.72	8.60 ± 0.62		*
Arthropoda	Malacostraca	Amphipoda	Caperellidae	*Caprella*	*Caprella circur*	5 ± 0.36	3.32 ± 0.33		
				Metaprotella	*Metaprotella macoranicus*	3.32 ± 0.33	2.92 ± 0.16		
		Comacea	Bodotriidae	*Glyphocuma*	*Glyphocuma dentatum*	3.32 ± 0.21	4.45 ± 0.22		
				Eocuma	*Eocuma carinocurvum*	3.60 ± 0.24	3.90 ± 0.24		
		Isopoda	Gnathiidae	*Gnathia*	*Gnathia maxillaris*	6.40 ± 0.62	3.95 ± 0.19		*
		Decapoda	Portunidae	*Carcinus*	*Carcinus maenas*	8.32 ± 0.37	5.82 ± 0.33		*
	Ostracoda			*Metacytheropteron*	-(fossil)	4.57 ± 0.20	2.77 ± 0.11	*	
Annelida	Polychaeta	Phyllodocida	Nereididae	*Hediste*	*Hediste diversicolor*	8.32 ± 0.37	5.62 ± 0.35	*	
			Sigalionidae	*Sigalion*	*Sigalion edwardsi*	6.45 ± 0.46	0		
			Capitellidae	*Capitella*	*Capitella capitata*	4.72 ± 0.30	4.57 ± 0.30		
				Notomastus	*Notomastus tenuis*	5 ± 0.81	5 ± 0.37		
				Cirratulus	*Cirratulus cirratus*	6.05 ± 0.39	7.70 ± 0.46		*
				Aphelochaeta	*Aphelochaeta monilaris*	11.25 ± 1.47	3.05 ± 0.14	*	
Echinodermata	Echinoidea	Comarodonta	Echinometridae	*Echinometra*	*Echinometra mathaei*	7.5 ± 0.78	3.75 ± 0.22		*
		Ophiurida	Ophiocomidae	*Ophiocoma*	*Ophiocoma scolopendrina*	6.05 ± 0.33	4.72 ± 0.35		

S1: station 1; S2: station 2; St: station; Se: season.

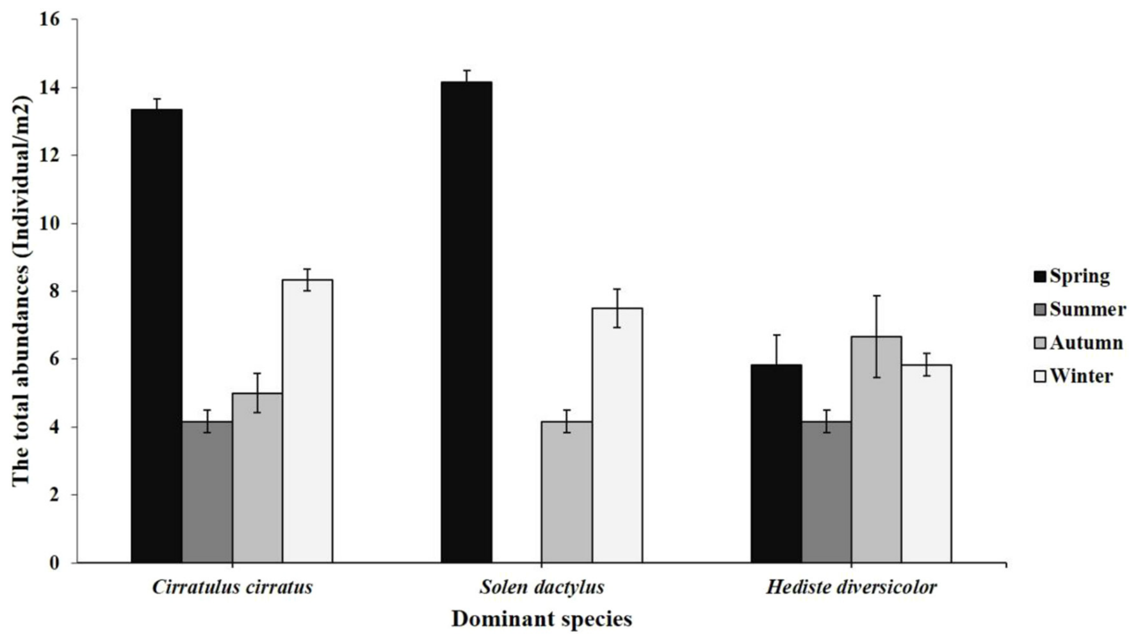

Fig. 2. The total abundances of dominant species (mean ± SE) during four seasons, Larak Island, Persian Gulf.
Fig. 2. L'abondance totale des espèces dominantes (moyenne ± SE) pendant quatre saisons, île Larak, golfe Persique.

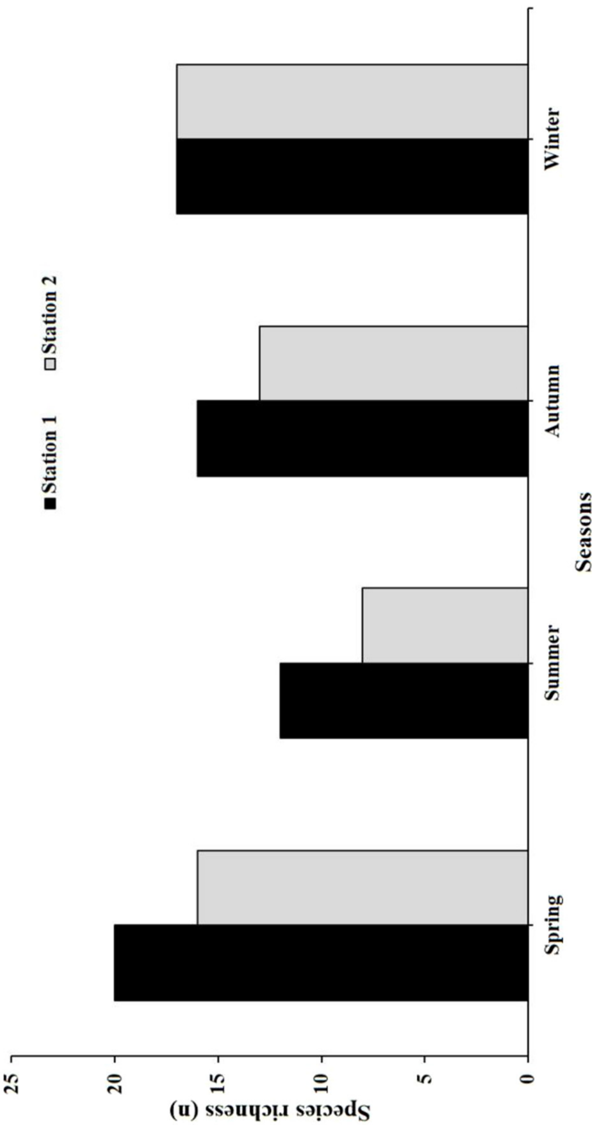

Fig. 3. The changes in species richness of macrobenthic community during four seasons.

Fig. 3. L'évolution de la richesse spécifique de la communauté macrobenthique pendant quatre saisons.

Table 2. Mean values of (±SE) the environmental variables measured at each station.
Tableau 2. Valeurs moyennes (± SE) des variables environnementales mesurées à chaque station.

Station	Season	Temperature (°C)	pH	Salinity (PSU)	DO (mg/L)	Turbidity (FTU)	Nitrate (μM/L)	Nitrite (μM/L)	Phosphate (μM/L)	Silicate (μM/L)
Station 1	Spring	25.35	8.45	38.22	4.44	1.76	26.00	4.63	22.02	119.83
	Summer	33.43	8.27	37.62	3.97	2.22	21.10	3.85	20.51	141.99
	Autumn	23.95	8.08	38.17	4.13	1.73	18.24	4.79	17	50.38
	Winter	20.55	8.25	38.46	5.17	1.60	26.63	6.64	54.99	52.43
	Min	20.15	7.75	37.62	3.81	1.58	15.82	3.45	16.54	48.32
	Max	33.70	8.50	38.47	5.21	2.40	28.40	6.90	58.14	143.65
	SD	4.95	0.18	0.32	0.49	0.27	3.93	1.12	16.10	42.36
	SE	1.43	0.05	0.09	0.14	0.08	1.14	0.32	4.65	12.23
Station 2	Spring	24.87	8.27	38.09	4.2	1.94	27.20	14.28	22.55	97.20
	Summer	34.17	8.30	37.67	3.95	2.87	20.91	9.31	21.85	93.24
	Autumn	24.22	8.00	38.94	4.15	1.86	36.55	4.02	23.53	73.25
	Winter	20.20	7.27	38.51	4.89	1.75	27.87	17.12	27.37	77.67
	Min	20.10	5.23	37.65	3.86	1.72	19.30	3.56	15.20	70.23
	Max	34.20	8.45	39.00	5.00	2.90	38.10	19.20	32.00	100.20
	SD	5.34	0.88	0.50	0.38	0.47	5.93	5.31	4.91	11.10
	SE	1.54	0.25	0.14	0.11	0.13	1.71	1.53	1.42	3.20

Table 3. Mean values (±SE) of the sedimentary parameters measured at station 1 (S1) and 2 (S2) in Larak Island.

Tableau 3. Valeurs moyennes (± SE) des paramètres sédimentaires mesurés aux stations 1 (S1) et 2 (S2) de l'île Larak.

Station	Season		Sand (%)	Silt (%)	Clay (%)	TOM (%)
S1	Spring	Mean	92	5.33	8	0.65
		SE	0.58	0.33	0.58	0.03
	Summer	Mean	91.83	4	8.17	0.33
		SE	0.44	0.58	0.44	0.02
	Autumn	Mean	92.67	5.50	7.33	0.51
		SE	0.88	1.04	0.88	0.01
	Winter	Mean	92.17	4.50	7.83	0.53
		SE	1.30	1.04	1.30	0.02
S2	Spring	Mean	90.33	4.33	9.67	0.65
		SE	0.88	0.88	0.88	0.03
	Summer	Mean	91.33	3.67	8.67	0.48
		SE	0.88	0.67	0.88	0.04
	Autumn	Mean	92.33	2.33	7.67	0.65
		SE	1.45	0.33	1.45	0.02
	Winter	Mean	93.50	5.00	6.50	0.62
		SE	1.04	0.58	1.04	0.01

Table 4. Formed groups based on *a priori* sampling design using data set of station 1 and 2, with indication each group similarity (%) and the most representative species (%) contributing for the similarity within each group, determined with SIMPER analysis.

Tableau 4. Groupes formés sur la base d'un plan d'échantillonnage a priori utilisant l'ensemble de données des stations 1 et 2, avec indication de la similitude de chaque groupe (%) et des espèces les plus représentatives (%) contribuant à la similitude au sein de chaque groupe, déterminée par une analyse SIMPER.

Group	Main species	% contribution
Spring sampling period	*Cirratulus cirratus*	21.38
Average similarity 84%	*Solen dactylus*	30.76
	Hediste diversicolor	18.76
Summer sampling period	*Cirratulus cirratus*	6.55
Average similarity 63.2%	*Solen dactylus*	8.72
	Hediste diversicolor	10.91
Autumn sampling period	*Cirratulus cirratus*	12.65
Average similarity 82.76%	*Solen dactylus*	6.55
	Hediste diversicolor	15.05
Winter sampling period	*Cirratulus cirratus*	15.27
Average similarity 88.24%	*Solen dactylus*	15.71
	Hediste diversicolor	16.58

$r = 0.45$; $P < 0.05$). Moreover, a positive and significant relationship was found between the total abundance of macrofauna and the proportion of sand and clay particles ($N = 24$; $r = 0.99$; $P < 0.01$).

3.4 Spatial and seasonal variation of macrobenthic diversity indices

The spatial and seasonal variations of Shannon-Wiener diversity index (H), Simpson index of diversity (D), species

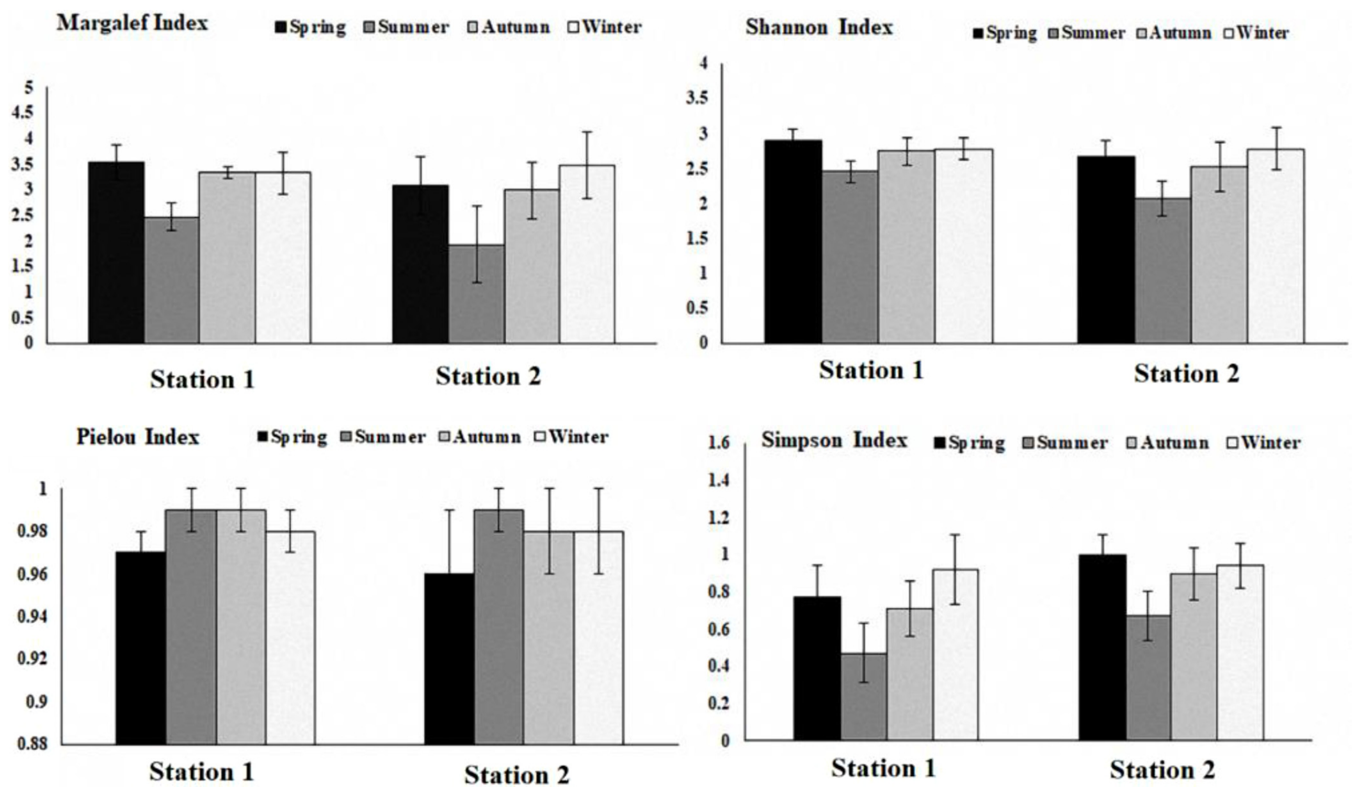

Fig. 4. The average of species richness ± SE (Margalef), Shannon-Wiener diversity index, Pielou's evenness index and Simpson index of diversity across sampling stations during four seasons.

Fig. 4. La moyenne de la richesse spécifique ± SE (Margalef), l'indice de diversité de Shannon-Wiener, l'indice de régularité de Pielou et l'indice de diversité Simpson à travers les stations d'échantillonnage pendant quatre saisons.

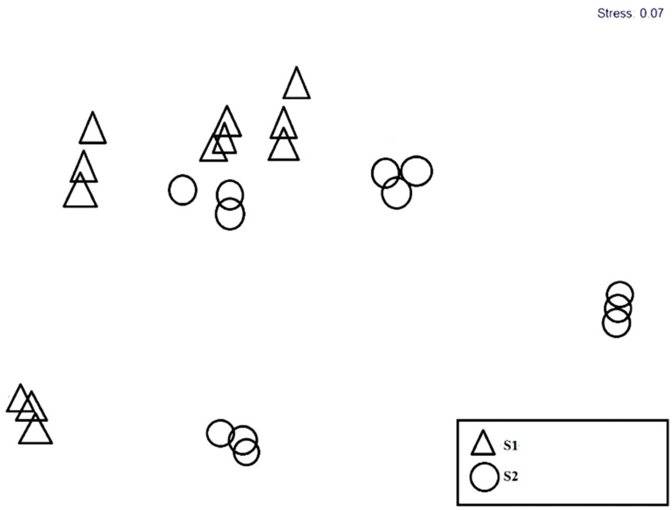

Fig. 5. The comparison of macrobenthic assemblage structure using the non-parametric multi-dimensional scaling (NMDS).

Fig. 5. La comparaison de la structure d'assemblage macrobenthique en utilisant la mise à l'échelle multidimensionnelle non paramétrique (NMDS).

richness (Margalef: M) and Pielou's evenness index (J) are displayed on Figure 4. The species richness (Margalef Index) showed a significant difference among the four seasons (2-way ANOVAs; $F = 4.31$; $P < 0.05$) and seasonal differences depended on studied station (2-way ANOVAs; $F = 5.83$; $P < 0.01$). There was no significant difference for the three other indices between stations ($P > 0.05$) and among four seasons ($P > 0.05$).

The comparison of the community structure of macrobenthos between the two stations using the NMDS indicated a partial overlap between the communities collected in the two stations (Fig. 5). ANOSIM indicated a significant difference in the structure of the communities between the two stations (ANOSIM, $P < 0.05$). SIMPER analysis showed that most of the similarity in the community structure among samples at each station was mainly due *Solen dactylus*, *Hediste diversicolor*, *Cirratulus cirratus* and *Sigalion edwardsi* (Tab. 4). The comparison of the similarity index (Mean ± SE) between the two stations showed that the similarity index was 79.5 ± 11.5% in general, and the highest value was observed in winter (88.24%) (Tab. 4).

A first PCA analysis based on physico-chemical parameters showed that salinity, dissolved oxygen, turbidity, nitrite, phosphate, and silicate were the most significant factors on the factorial axis 1 which explained 62.07% of the total variance while pH and nitrate were the most significant factors on factorial axis 2 which explained 24.56% of the total variance (Fig. 6). The densities of the most abundant species were strongly correlated with the axis 2. The second PCA analysis included sediment parameters

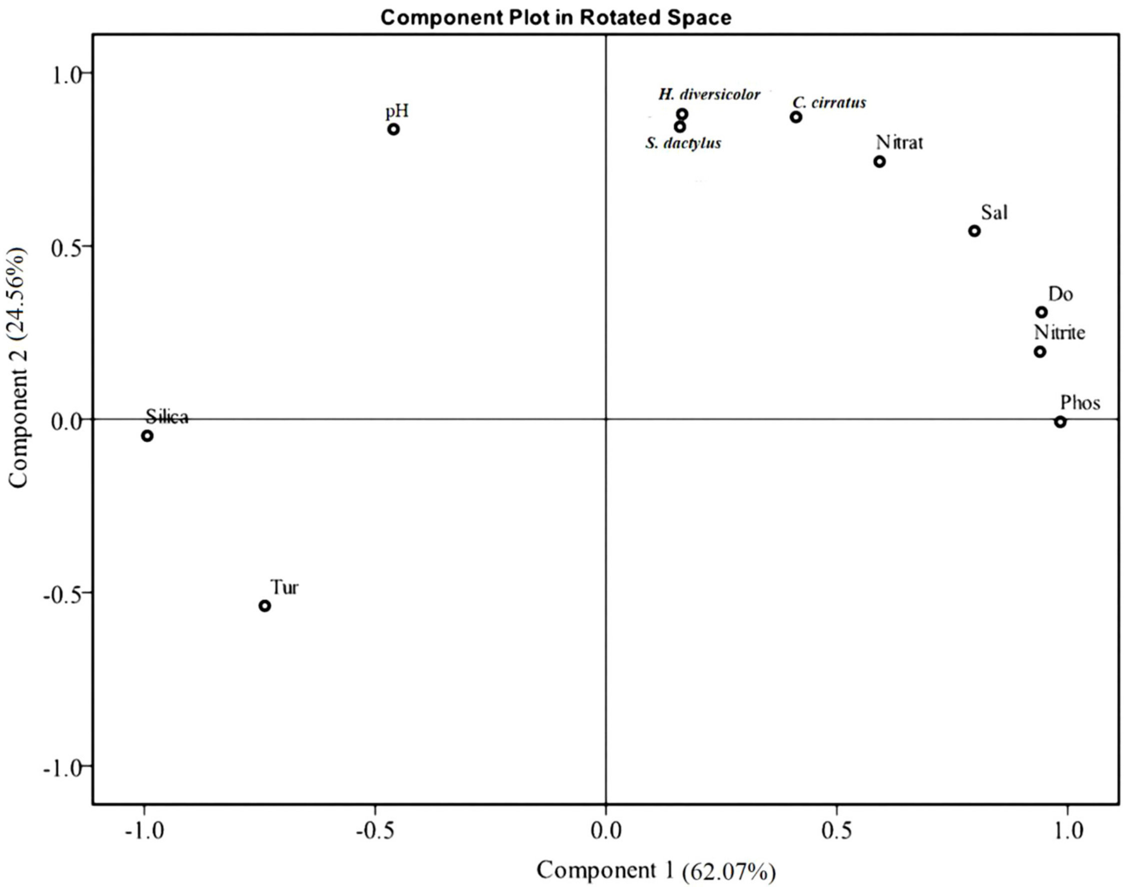

Fig. 6. Changes in the component scores of PCA related to the first and second components highlight the effect of physicochemical parameters on the density of dominant macrobenthos species. Sal: salinity; Do: dissolved oxygen; Phos: phosphate; Silica: silicate; Tur: turbidity.

Fig. 6. Les changements dans les scores des composants de l'ACP liés aux premier et second composants mettent en évidence l'effet des paramètres physico-chimiques sur la densité des espèces de macrobenthos dominantes. Sal: salinité; Do: oxygène dissous; Phos: phosphate; Silice: silicate; Tur: turbidité.

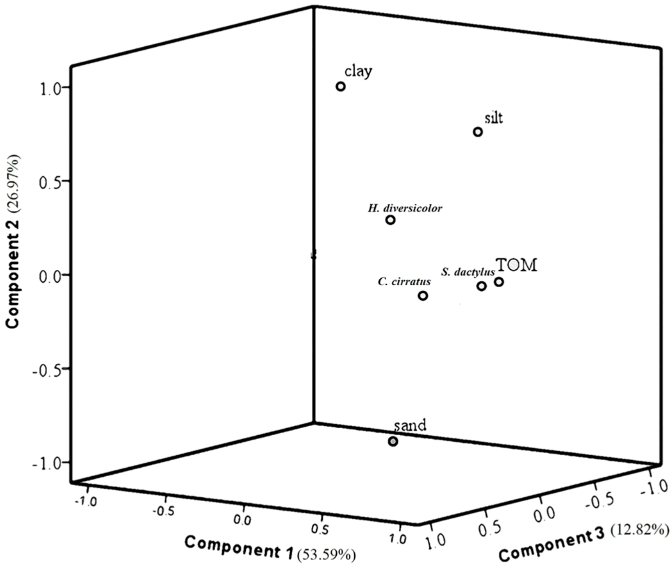

Fig. 7. Changes in the component scores of PCA related to the first, second, and third components to highlight the effect of sedimentary parameters on the density of dominant macrobenthos species.

Fig. 7. Changements dans les scores des composants de l'ACP liés aux premier, deuxième et troisième composants pour mettre en évidence l'effet des paramètres sédimentaires sur la densité des espèces de macrobenthos dominantes.

and the density of the dominant species showed that the TOM was the most significant factor on the density of *Cirratulus cirratus*, and *Solen dactylus* with the proportions of variance explained by the first three factorial components of 53.59, 26.97 and 12.82% respectively (Fig. 7).

4 Discussion

In this study, we have highlighted that the two habitats studied consisted of 20 species, mainly polychaetes, belonging to 14 families. An inventory of the macrobenthic fauna from the coast of the Arabian Sea reported 165 species belonging to 32 families with the dominance of polychaetes (Joydes & Damodaran, 2008). Our finding showed lower richness and abundance in comparison with the Arabian Sea study (Joydes & Damodaran, 2008), which could probably be due to lower sampling effort and locations as well as lower ecological quality because of heavy-metal concentration (Taherizadeh & Sharifinia, 2015).

The dominance of species such as *C. cirratus* may be due to its reproductive traits (e.g. continuous spawning and potential for asexual reproduction) (Petersen, 1999). On the other hand, it was also reported that the increasing of abundance in species such as *H. diversicolor* is probably related to small patches of dead seaweed at the sediment surface (Bolam *et al.*, 2000).

The small scale heterogeneity reported in the measured environmental parameters was already observed in tropical soft-sediment habitats around coral reefs from the Indian Ocean (Alsaffar *et al.*, 2019). The environmental dissimilarity associated with seafloor high heterogeneity generates high differences in species distribution and promotes species composition and abundance even at relatively small spatial scales of tropical regions (Loiseau *et al.*, 2017).

The total macrobenthic abundance recorded in the present study was quite low, ranging from zero to 12.5 ± 0.58 ind./m^2 depending on the seasons. While higher abundance of benthic macrofauna are commonly reported in coastal areas in temperate regions (see Dolbeth *et al.*, 2007) and sometimes in tropical latitudes (Alsaffar *et al.*, 2019), Mackie *et al.* (2005) reported low abundance of molluscs and polychaetes in the Indian Ocean. The oligotrophy, low level of organic matter, and high temperature were reported as the main reasons for the low abundance of macrobenthic communities of tropical areas such as the Red Sea (Alsaffar *et al.*, 2019).

The results of this study indicated a seasonal cycle in abundance with the highest and the lowest values reported in spring and summer, respectively for two dominant species. The increasing of temperature can be one of the reasons for the decreasing of the abundance of macrobenthos in summer. It was reported that the reducing of spawning and the increasing of energy consumption in the metabolic process can be related to environmental stress including temperature, dissolved oxygen concentration, and nutrient concentrations (Karakassis & Eleftheriou, 1997). Our results showed that the water temperature was the most significant factor in the abundance of macrobenthos where the lowest total abundances of dominant species and species richness were observed in summer with the average temperature above 30°C. In parallel, the biotic interactions are commonly considered as more important factors determining abundance patterns than environmental factors at small scales (Jungerstam *et al.*, 2014).

Shannon-Wiener diversity index, which is the most commonly used diversity index in ecological studies varied between 2.07 to 2.89 during summer and spring respectively, indicating a moderate diversity in both stations (≥5, high diversity). According to Taherizadeh & Sharifinia (2015), Margalef and Shannon-Wiener indices are able to detect ecological situations of stations through time. They reported high ecological status of stations at value between 4.12 and 4.15 of Margalef index and 2.09 and 2.18 of Shannon–Wiener index in the assessment of benthic community structure from subtropical estuaries of the Iranian coastal waters (Taherizadeh & Sharifinia, 2015). No significant difference in diversity was reported between the two stations. The diversity index followed the same pattern of seasonal variation as the organic matter content with a maximum and a minimum during spring and summer respectively. The organic matter content has generally a strong impact on the local environment characteristics and the structure of benthic communities (Tomassetti *et al.*, 2016). Evenness values of our study (0.98) indicated no dominance patterns in the soft-bottom sediments around coral habitats as already mentioned by Alsaffar *et al.* (2019) from the open water of the Red Sea. The lack of dominance can be related to low densities of all species in sandy sediment (Alsaffar *et al.*, 2019). These results are in agreement with previous observations in Kuwait's waters, Persian Gulf that showed meaningless dominance, high diversity and low density of species (Al-Yamani *et al.*, 2009). The highest and lowest Margalef species richness index was observed during spring and summer respectively. Moreover, station 1 showed higher species richness than station 2. The favorable environmental conditions of spring including lower temperature and higher organic matter can explain higher species richness during this season.

The PCA analyses indicated that the most significant factors influencing macrobenthic abundance were phosphate, dissolved oxygen, and TOM. A close relationship between environmental factors and the characteristics of benthic communities was observed in many studies (Anderson *et al.*, 2004; Veiga *et al.*, 2016). The main factors include sediment grain size, salinity, currents and pollutants as controlling factors of community structure of macrobenthos in tropical and subtropical regions, including the Persian Gulf (Gomes Veloso *et al.*, 2003).

In this study, the summer and autumn seasons were characterized by the lowest level of dissolved oxygen. The increasing temperature can induce the decreasing concentration of the dissolved oxygen of coastal waters during the summer season with a direct effect on macrobenthic density (Seitz *et al.*, 2009). The decrease in the density of macrobenthos during summer could be then related to the decrease of dissolved oxygen and the increase of temperature. The hypoxia can reduce the overall availability of secondary production to higher trophic levels and affect overall productivity (Seitz *et al.*, 2009). The results of the PCA indicated also a negative effect of turbidity on total abundance of macrobenthos that could be explained by the fact that the maximum turbidity and minimum total abundance were observed during the summer season at both stations. Turbidity has been already reported to alter the structure of communities, and the density and reproduction of organisms in marine environments (Henley, 2000).

In terms of sediment properties, the PCA analysis showed that the TOM was the most significant factor controlling the densities of the dominant species including *C. cirratus* and *S. dactylus* as reported in previous studies (Thilagavathi *et al.*, 2013; Veiga *et al.*, 2017). The organic matter content can increase the growth of macrofauna through the supplying of food sources (Schelske & Odum, 1962). Subsequently, the abundance of benthic organisms is highly dependent on organic carbon (Thilagavathi *et al.*, 2013) even if organic matter was rarely known as a limiting factor of seasonal abundance of macrobenthos (Qasim *et al.*, 1974). Marine sediments enriched with organic matter may produce hydrogen sulfide resulting in the reduction of oxygen with deleterious effects on macrofauna (Dittmann, 2012). On the other hand, there is an inverse relationship between the size of sediment particles and the amount of organic matter in the sediment (Veiga *et al.*, 2017).

The range of sediment grain size tolerated by each species can reflect the relationship between sediment and macrobenthos (Hily *et al.*, 2008) and the lifestyle of macrobenthic species can be determined by sediment features in their environment (Pinedo *et al.*, 2000). Furthermore, the significance of sediment characteristics could become higher at smaller spatial scales (Schückel *et al.*, 2015). In our study, the percentage of sediment particles at the two stations was relatively similar with a higher percentage of sandy grains and low organic matter and do not contribute to discriminate the community structure and composition described at both stations.

The salinity and sediment grain size were reported as the most significant factors on the communities of macrobenthos in the Persian Gulf (Coles & McCain, 1990). Koampf & Sadrinasab (2006) reported minimum and maximum salinity of the Persian Gulf during spring and autumn, respectively in agreement with our observations. Moreover, the results of our study confirm the salinity as one of the most important factors influencing the communities of macrobenthos in addition with temperature.

5 Conclusion

Our results have the potential for providing baseline date to design the monitoring programs for the detection of anthropogenic perturbations on coastal habitats. In general, the results reflected low density of coral macrobenthic communities in Larak Island. The present study was one of the first evaluating the influence of environmental conditions on macrofauna in soft bottoms around coral reefs of Larak Island from Persian Gulf, a very poorly studied area on earth.

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Conflict of interest

The authors declare that they have no conflict of interest.

Ethical approval

All applicable international, national, and/or institutional guidelines for the care and use of animals were followed by the authors

Sampling and field studies

All necessary permits for sampling and observational field studies have been obtained by the authors from the competent authorities

Data availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Author contribution

ST original hypothesis, data collection. SS data preparation, statistical analysis, writing the paper. EK contributing in original hypothesis, advice in the methods. MSM guidance in the methods and results. SB helping for the fieldworks and data collection.

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