Iranian Journal of Fisheries Sciences 20(6) 1704-1726 2021
DOI: 10.22092/ijfs.2021.125455

Research Article

Assessing the diversity of macroinvertebrates communities and their relationship with environmental factors in the Persian Gulf and the Gulf of Oman

Aghajari Khazaei Sh.[1]; Safaie M.[1*]; Valinassab T.[2]; Noorinezhad M.[3]; Mortazavi M.S.[4]

Received: August 2021 Accepted: October 2021

Abstract

Marine benthic macrofauna plays an important role in ecosystem processes in the marine benthic zone. This study aims to investigate the biodiversity pattern and identifying benthic macroinvertebrates in the coastal zones of the Persian Gulf and the Gulf of Oman. Two sampling periods were performed in this study; the first: from November 2018 to January 2019 and the second: from December 2019 to January 2020. Sampling was carried out at 19 sites with three replicates (171 samples). A total of 164 species belonging to 85 families and 31 orders were identified. The most abundant families were Ampeliscidae and Apseudidae with mean values of 19.5±42 and 11.1±18 in m^2, respectively. The most abundant class were Malacostraca and Polychaeta. The family Nephtyidae with eight identified species was the most in all stations. *Amphipholis squamata*, *Byblis* sp., *Capitella capitate*, and *Amphioplus* sp. were the significant species that contributed to the differentiation between stations. Furthermore, according to CCA analysis, dissolved oxygen (DO) showed a strong direct relationship with Callianassidae, Anthuridae, Paraonidae, Maeridae, and Corophiidae. Also, a strong indirect relationship was found between Haminoeidae and DO. Turbidity showed a strong direct relationship with Flabelligeridae and as well as weak direct with Cirratulidae. Furthermore, chlorophyll-a showed a strong direct relationship with Nereididae, and other parameters showed a medium direct relationship with Maldanidae and Haminoeidae. The Composition of bed sediment was also showed a strong relationship with macroinvertebrates communities in the study area. The diverse health status was not totally in a good condition and needs to be improved. These findings could be applied in further studies for habitat management and monitoring programs.

Keywords: Macroinvertebrate assemblages, Diversity index, Persian Gulf, Gulf of Oman

1-Department of Fisheries, Faculty of Marine Science and Technology, University of Hormozgan, Hormozgan, Bandar Abbas, Iran
2-Iranian Fisheries Science Research Institute (IFSRI), Agricultural Research, Education and Extension Organization (AREEO), Tehran, Iran
3-Iran Shrimp Research Center, Iranian Fisheries Science Research Institute (IFSRI), Agricultural Research, Education and Extension Organization (AREEO), Bushehr, Iran
4-Persian Gulf and Oman Sea Ecology Research Center, Iranian Fisheries Science Research Institute (IFSRI), Agricultural Research, Education and Extension Organization (AREEO), Bandar Abbas, Iran
*Corresponding author's Email: msn_safaie@yahoo.com

Introduction

Marine benthic macrofauna plays an important role in ecosystem processes such as dispersion and burial, pollutant metabolism, nutrient cycling, and secondary production (Snelgrove, 1998). Although biomass and diversity of benthic macroinvertebrates represent a temporal and seasonal pattern, they are employed as aquatic ecosystem health indicators (Marques *et al*., 2009). Benthic macroinvertebrates react to anthropogenic disturbances and natural changes such as temperature, pH, DO, and pollution in their habitats in different ways (Saghali *et al*., 2013; Gerami *et al*., 2016). Climate change affected the marine ecosystem and the complexity of the food webs (Schofield *et al*., 2010). Increased global average temperature, declining aquatic oxygen concentrations, and changes in wind strength are the main factors that impact the behavior of ocean currents behavior, leading to changes in the distribution and abundance of marine ecosystems (Hoegh-Guldberg and Bruno, 2010). Fluctuation in the diversity pattern of marine macroinvertebrates as marine food web secondary production can affect trophic networks and cause complex changes to trophic relationships (Nordström and Bonsdorff, 2017).

Environmental variables at multiple scales affected the diversity and density of macroinvertebrates communities differently (Townsend *et al*., 1983). Therefore, it is essential to study their relationship spatially and temporally to develop our understanding of marine ecosystems. A better understanding of macroinvertebrates-environmental variables relation increases the accuracy and precision of macroinvertebrate-based bioassessment (Li *et al*., 2012). Many studies have been reported the effect of environmental variables on marine benthic communities around the world (Teske and Wooldridge, 2004; Gamboa-García *et al*., 2018; Xu *et al*., 2019; Wu *et al*., 2019; Alsaffar *et al*., 2020; Patang and Soegianto, 2020). However, data about the status of marine macroinvertebrate communities of the Persian Gulf is limited especially at the species level and scant information is available to address how environmental variables influence macroinvertebrate communities in the Persian Gulf. Gerami *et al*. (2016) studied spatial and temporal variation of macroinvertebrates in the shrimp fishing grounds of the Hormozgan waters and reported the seasonal variation of 19 macroinvertebrate orders. Hajializadeh *et al.* (2020) investigated microbenthic species diversity and their biological trait patterns in mangrove-associated habitats of Hormozgan province waters and reported total of 122 macrofauna taxa in their study. They declared that deposit-feeding, crawlers, medium-size, and free-living were the dominant trait modalities in all habitats. Azizi *et al.* (2020) studied macrobenthic fauna in rocky habitats of Bushehr province coastal waters and reported total of 66 taxa in all studied stations. They indicated that mollusks were abundant in all three sites and Portunid crabs and

Polychaets were the lowest abundant groups. Kosari *et al*. (2021) conducted a study on dentification of macrobenthos in the Yekshabe Estuary in the Persian Gulf and reported 80 species. They found that Polychaeta was the dominant group in all stations and there was no significant difference between species richness in all stations.

The objectives of this study were (i) to investigate the influence of the most important environmental variables on macroinvertebrates; (ii) to identify and evaluate the diversity of macroinvertebrates, and (iii) assess the relationship between the composition of bed sediment and macroinvertebrates communities. The results of this study could be used in the monitoring of marine species habitat health and assessing the productivity of the marine food web.

Materials and methods

Two sampling periods were performed in this study. The first period started from November 2018 to January 2019, and the second period from December 2019 to January 2020. Sampling started form station one in North-West coastal waters of the Hormozgan Province and continued to station 19 to the east up to coastal waters of Sistan and Balouchistan Province (Fig. 1).

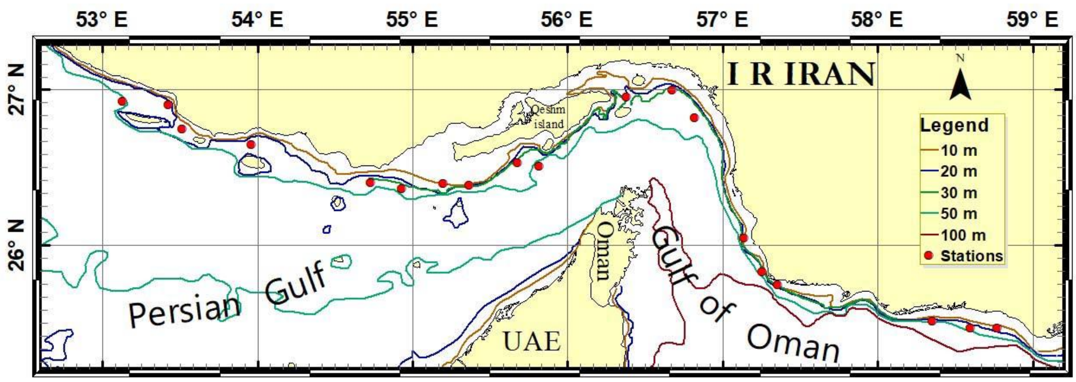

Figure 1: Locations of sampling sites in the Persian Gulf and the Gulf of Oman, Iran (2018-2020).

The vessel R / V Ferdows-1 was used which was equipped with GPS. Sampling stations were selected randomly to cover most coastal waters of Hormozgan province coastal waters. Sampling depths were varied between 10 to 50 meters. Three replicate samples of macroinvertebrates per station (171 samples) were covered in the study period. Sampling was carried out by Van Veen grab with a 0.0256 m^2 cross section. Physicochemical properties of water were measured by CTD including Temperature (°C), Conductivity (ms/cm), Salinity (ppm), DO (g/L), pH, Chlorophyll-a (mg/L), and Turbidity. Samples were sieved through 0.5 mm mesh. The remained samples were fixed with 97% ethanol and transferred to the laboratory. Most illustrated keys such as Naderloo (2017); Al- Yamani *et al.* (2012);

Debruyne (2003); Fauchald (1997); Bosch *et al*. (1995) and Sterrer (1986) were used to identify macroinvertebrates up to species level.

In order to compare biodiversity between sampling sites and the health status, the Shannon-Wiener Index (Shannon and Wiener, 1948) was used. The algorithm was:

$$H' = -\sum P_i log_2 P_i$$

Where: P_i is the proportion of individuals belonging to species i in the sample. The Shannon-Wiener index usually varies between 0 to 5 (Marques *et al*., 2009). However, Molvær *et al*. (1997) introduced a classification table for assessing habitat health status based on the Shannon-Wiener index (Table 1).

Table 1: Categories considered as a function of Shannon-Wiener Index values.

Shannon-Wiener index	Shannon-Wiener value
High status	>4 bits/individual
Good status	3-4 bits/individual
Moderate status	2-3 bits/ individual
Poor status	1-2 bits/ individual
Bad status	0-1 bit / individual

Margalef Index (Margalef, 1969) was also employed to quantify the diversity of identified species in the study area. The formula was:

$$D = \frac{(S-1)}{Log_e N}$$

Where S = number of species and N = total number of individuals. Margalef Index values below four identified as typical of polluted areas (Ros and Cardell, 1991). The Composition of bed sediment aggregation was measured through a method explained by Buchannan (1984) and the percent of total organic matter was also calculated by method Holme and McIntyre (1984).

In order to assess the similarity between stations and founding significant discriminant species SIMPER analysis preformed. Significant differences between stations were analyzed through the PERMANOVA method. Canonical correspondence analysis (CCA) was applied to extract major gradients among combinations of macrobenthic assemblages and environmental variables. Principal component analysis (PCA) was performed to find the main component before CCA analysis. The analysis of similarities (ANOSIM) was used to examine the spatial patterns of macroinvertebrate assemblages. For parametric analyses, the abundance data were square-root transformed to reduce heteroscedasticity before running the similarity matrix. All the analyses were carried out with R statistical packages and a vegan package was used to run analysis (Oksanen *et al*., 2015).

Results

The results showed that a total of 164 species were identified in all sites, belonging to 85 families and 31 orders. The most abundant families were Ampeliscidae and Apseudidae with mean values of 19.5±42 (n/m^2) and 11.1±18 numbers in square meter in all stations, respectively. In addition, the most abundant class was Malacostraca and Polychaeta, respectively (Fig. 2).

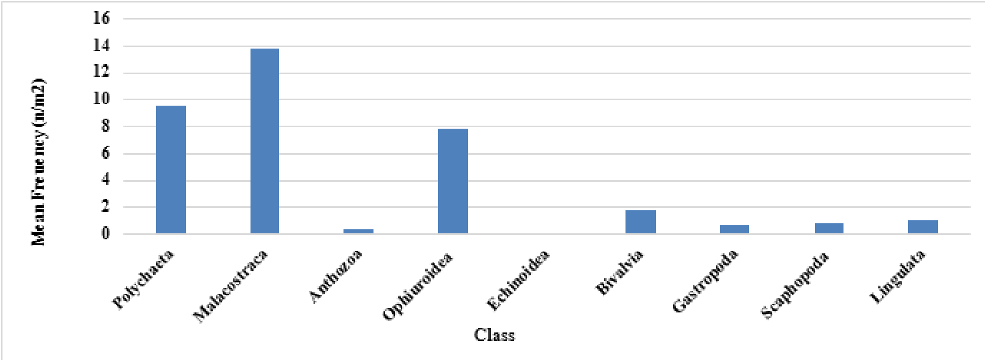

Figure 2: Mean abundance of benthic macroinvertebrates of the Persian Gulf and the Gulf of Oman (2018-2020).

The most diverse family was Nephtyidae with 8 identified species in all stations (Table 2).

Table 2: Identified macroinvertebrates in all sampling sites of the Persian Gulf and the Gulf of Oman (2018-2020)

Species	Family	Suborder	Order	Subclass	Class	Phylum
Magelona longicornis Johnson, 1901	Magelonidae		Canalipalpata	Polychaeta incertae sedis	Polychaeta	**Annelida**
Owenia fusiformis Delle Chiaje, 1844	Oweniidae					
Maldane cristata Treadwell, 1923	Maldanidae			Sedentaria		
Praxillella gracilis (M. Sars, 1861)						
Clymenella torquata (Leidy, 1855)						
Aricidea (Aricidea) wassi Pettibone, 1965	Paraonidae					
Aricidea longobranchiata Day, 1961						
Aricidea (Acmira) assimilis Tebble, 1959						
Leodamas chevalieri (Fauvel, 1902)	Orbiniidae					
Orbiniella sp. Day, 1954						
Orbinia sp. Quatrefages, 1866						
Ophelia sp. Savigny, 1822	Opheliidae					
Ophelina acuminata Örsted, 1843						
Ophelina cylindricaudata (Hansen, 1879)						
Capitella capitata (Fabricius, 1780)	Capitellidae					
Capitella sp.1 Blainville, 1828						

Table 2 (continued):

Species	Family	Suborder	Order	Subclass	Class	Phylum
Capitella sp.2						
Blainville, 1828						
Rashgua rubrocincta Wesenberg-Lund, 1949						
Cossura laeviseta Hartmann-Schröder, 1962	Cossuridae					
Cossura longocirrata Webster & Benedict, 1887						
Cossura pygodactylata Jones, 1956						
Cossura sp.						
Webster & Benedict, 1887						
Cirrophorus sp.	Paraonidae					
Ehlers, 1908						
Poecilochaetus serpens Allen, 1904	Poecilochaetidae	Spioniformia	Spionida			
Paraprionospio pinnata (Ehlers, 1901)	Spionidae					
Prionospio rotalis Mohammad, 1970						
Scolelepis bonnieri (Mesnil, 1896)						
Genus sp.1						
Acrocirrus sp.	Acrocirridae	Cirratuliformia	Terebellida			
Grube, 1873						
Amage auricula Malmgren, 1866	Ampharetidae					
Amphicteis sp.						
Grube, 1850						
Samythopsis grubei McIntosh, 1885						
Chaetozone corona Berkeley & Berkeley, 1941	Cirratulidae					
Chaetozone sp. Malmgren, 1867						
Cirriformia tentaculata (Montagu, 1808)						
Tharyx sp.						
Webster & Benedict, 1887						
Brada incrustata	Flabelligeridae					
Støp-Bowitz, 1948						
Brada sp.						
Stimpson, 1853						
Diplocirrus glaucus (Malmgren, 1867)						
Pherusa plumosa (Müller, 1776)						
Sternaspis scutata (Ranzani, 1817)	Sternaspidae					
Pista brevibranchiata Moore, 1923	Terebellidae	Terebelliformia				
Pista sp.						
Malmgren, 1866						
Terebella sp.						
Linnaeus, 1767						

Table 2 (continued):

Species	Family	Suborder	Order	Subclass	Class	Phylum
Loimia sp. Malmgren, 1866						
Terebellides stroemii Sars, 1835	Trichobranchidae					
Branchiomma sp. Kölliker, 1858	Trichobranchidae		Sabellida			
Parasabella aberrans (Augener, 1926)						
Sabella sp. Linnaeus, 1767						
Bhawania goodie Webster, 1884	Chrysopetalidae	Nereidiformia	Phyllodocida	Errantia		
Chrysopetalum sp. Ehlers, 1864						
Syllis cornuta Rathke, 1843	Chrysopetalidae					
Hediste diversicolor (O.F. Müller, 1776)	Nereididae					
Leonnates indicus Kinberg, 1865						
Perinereis aibuhitensis (Grube, 1878)						
Perinereis nigropunctata (Horst ,1889)						
Perinereis sp. Kinberg, 1865						
Ancistrosyllis sp. McIntosh, 1878	Pilargidae					
Sigambra tentaculata (Treadwell, 1941)						
Sirsoe methanicola (Desbruyeres & Toulmond, 1998)	Hesionidae					
Glycera amboinensis McIntosh, 1885	Glyceridae	Glyceriformia				
Glycera capitata Örsted, 1843						
Glycera sp1. Lamarck, 1818						
Glycera sp2. Lamarck, 1818						
Glycera tridactyla Schmarda, 1861						
Glycera unicornis Lamarck, 1818						
Glycinde bonhourei Gravier, 1904	Goniadidae					
Glycinde sp. Müller, 1858						
Aglaophamus sp. Kinberg, 1866	Nephtyidae	Phyllodocida incertae sedis				
Micronephtys sphaerocirrata (Wesenberg-Lund, 1949)						
Nephtys californiensis Hartman, 1938						
Nephtys cirrosa Ehlers, 1868						

Table 2 (continued):

Species	Family	Suborder	Order	Subclass	Class	Phylum
Micronephthys cornuta (Berkeley & Berkeley, 1945)						
Nephtys glabra Hartman, 1950						
Nephtys sp. Cuvier, 1817						
Nephtys tulearensis Fauvel, 1919						
Eteone sp. Savigny, 1822	Phyllodocidae	Phyllodociformia				
Harmothoe dictyophora (Grube, 1878)	Polynoidae	Aphroditiformia				
Harmothoe sp. Kinberg, 1856						
Euthalenessa sp. Darboux, 1899	Sigalionidae					
Leodice laticeps (Ehlers, 1868)	Eunicidae		Eunicida			
Scoletoma laurentiana (Grube, 1863)	Lumbrineridae					
Lumbrineris bifurcata McIntosh, 1885						
Ninoe pulchra Wesenberg-Lund, 1949						
Diopatra chiliensis Quatrefages, 1866	Onuphidae					
Diopatra cuprea (Bosc, 1802)						
Diopatra micrura Pires, Paxton, Quintino & Rodrigues, 2010						
Diopatra sp. Audouin & Milne Edwards, 1833						
Chloeia sp. Lamarck, 1818	Amphinomidae		Amphinomida			
Linopherus hirsute (Wesenberg-Lund, 1949)						
Genus sp.1	Leptoplanidae	Acotylea	Polycladida			Platyhelminthes
Prosthiostomum sp. Quatrefages, 1845	Prosthiostomidae	Cotylea				
Pseudoceros sp. Lang, 1884	Pseudocerotidae					
Ampithoe sp. Leach, 1814	Ampithoidae	Senticaudata	Amphipoda	Eumalacostraca	Malacostraca	Arthropoda
Cheiriphotis sp. Walker, 1904	Corophiidae					
Microphotis blachei Ruffo, 1952	Photidae					
Elasmopus pectenicrus (Spence Bate, 1862)	Maeridae					
Ceradocus sp. Costa, 1853						
Maera sp. Leach, 1814						

Table 2 (continued):

Species	Family	Suborder	Order	Subclass	Class	Phylum
Maera schieckei Karaman & Ruffo, 1971						
Melita sp. Leach, 1814	Melitidae					
Platorchestia monodi (Mateus, Mateus & Afonso, 1986)	Talitridae					
Cyproidea sp. Haswell, 1880	Cyproideidae	Amphilochidea				
Orchomene sp. Boeck, 1871	Tryphosidae					
Byblis sp. Boeck, 1871	Ampeliscidae					
Eobrolgus spinosus (Holmes, 1905)	Phoxocephalidae					
Penaeus sp. Fabricius, 1798	Penaeidae	Dendrobranchiata	Decapoda			
Alpheus estuariensis Christoffersen, 1984	Alpheidae	Pleocyemata				
Alpheus lobidens De Haan, 1849 [in De Haan, 1833-1850]						
Athanas nitescens (Leach, 1814 [in Leach, 1813-1815])						
Athanas sp. Leach, 1814 [in Leach, 1813-1815]						
Callianassa sp. Leach, 1814 [in Leach, 1813-1815]	Callianassidae					
Myra pernix Galil, 2001	Leucosiidae					
Philyra sagittifera (Alcock, 1896)						
Heteropanope glabra Stimpson, 1858	Pilumnidae					
Pilumnus longicornis Hilgendorf, 1879						
Pilumnus minutus De Haan, 1835 [in De Haan, 1833-1850]						
Charybdis (Goniohellenus) longicollis Leene, 1938	Portunidae					
Portunus segnis (Forskål, 1775)						
Apanthura sandalensis Stebbing, 1900	Anthuridae	Cymothoida	Isopoda			
Gnathia maxillaris (Montagu, 1804)	Gnathiidae					
Gnathia sp. Leach, 1814						
Bodotria sp. Goodsir, 1843	Bodotriidae		Cumacea			
Eocuma affine Calman, 1904						

Table 2 (continued):

Species	Family	Suborder	Order	Subclass	Class	Phylum
Eocuma rosae Corbera & Galil, 2007						
Apseudes sp. Leach, 1814	Apseudidae	Apseudomorpha	Tanaidacea			
Ctenapseudes chilkensis (Chilton, 1924)	Parapseudidae					
Squilla mantis (Linnaeus, 1758)	Squillidae	Unipeltata	Stomatopoda	Hoplocarida		
Genus sp.1	Acricoactinidae	Enthemonae	Actiniaria	Hexacorallia	Anthozoa	Cnidaria
Genus sp.2						
Amphioplus (Lymanella) hastatus (Ljungman, 1867)	Amphiuridae	Gnathophiurina	Amphilepidida	Myophiuroidea	Ophiuroidea	Echinodermta
Amphioplus sp. Verrill, 1899						
Amphipholis squamata (Delle Chiaje, 1828)						
Clypeaster humilis (Leske, 1778)	Clypeasteridae	Clypeasterina	Clypeasteroida	Euechinoidea	Echinoidea	
Cardiomya sp. A. Adams, 1864	Cuspidariidae					
Hiatula rosea (Gmelin, 1791)	Psammobiidae		Cardiida	Autobranchia	Bivalvia	Mollusca
Pharaonella wallaceae (A. E. Salisbury, 1934)	Tellinidae					
Serratina capsoides (Lamarck, 1818)						
Tellina sp. Linnaeus, 1758						
Hanleyanus vestalis (Hanley, 1844)						
Irus carditoides (Lamarck, 1818)	Veneridae		Venerida			
Protapes gallus (Gmelin, 1791)						
Timoclea sp. T. Brown, 1827						
Lamellolucina dentifera (Jonas, 1846)	Lucinidae		Lucinida			
Corbula taitensis Lamarck, 1818	Corbulidae		Myida			
Arcuatula senhousia (Benson, 1842)	Mytilidae		Mytilida	Autobranchia		
Anadara ehrenbergi (Dunker, 1868)	Arcidae		Arcida			
Scissileda tropica (Melvill, 1897)	Yoldiidae		Nuculanida	Protobranchia		
Cylichna collyra Melvill, 1906	Cylichnidae		Cephalaspidea	Heterobranchia	Gastropoda	
Bakawan rotundata (A. Adams, 1850)	Haminoeidae					
Ellobium sp. Röding, 1798	Ellobiidae		Ellobiida			
Omalogyra atomus (Philippi, 1841)	Omalogyridae					
Linatella caudate (Gmelin, 1791)	Cymatiidae		Littorinimorpha	Caenogastropoda		

[DOR: 20.1001.1.15622916.2021.20.6.15.4]

[DOR: 20.1001.1.15622916.2021.20.6.15.4]

Table 2 (continued):

Species	Family	Suborder	Order	Subclass	Class	Phylum
Cheilea cicatricosa (Reeve, 1858)	Haminoeidae					
Hypermastus epiphanes (Melvill, 1897)	Eulimidae					
Pseudonoba sp. O. Boettger, 1902	Iravadiidae					
Natica vitellus (Linnaeus, 1758)	Naticidae					
Neverita didyma (Röding, 1798)						
Zafra selasphora (Melvill & Standen, 1901)	Columbellidae		Neogastropoda			
Crassispira sp. Swainson, 1840	Pseudomelatomidae					
Ethminolia degregorii (Caramagna, 1888)	Trochidae		Trochida	Vetigastropoda		
Antalis longitrorsa (Reeve, 1842)	Dentaliidae		Dentaliida		Scaphopoda	
Lingula sp. Bruguière, 1791	Lingulidae		Lingulida		Lingulata	Brachiopoda

Results of diversity indices are represented in Table 3. According to the findings, maximum Shannon-Wiener and Margalef indices of some species were observed in station 3 while the minimum was in station 15. In addition, Maximum density found in station 15. According to Table 1, the health status of station 3 was high while other stations were good except for stations 15, 16, 17, and 19. The health status of station 15 was distinguished as bad while 16, 17, and 19 were marked as poor status.

Table 3: Diversity indices of benthic macroinvertebrates of the Persian Gulf and the Gulf of Oman (2018-2020)

Station	Shanon	Margalof	Mean density	number of species
1	3.33	6.58	5.0	34
2	3.77	9.26	4.35	50
3	4.10	11.65	4.64	67
4	3.42	9.75	7.7	60
5	3.60	8.20	4.7	43
6	3.23	9.16	7.92	57
7	3.74	9.14	5.57	53
8	3.53	9.05	5.87	53
9	3.81	10.0	7.78	63
10	3.32	6.87	5.06	37
11	3.65	8.80	5.23	50
12	3.40	7.93	6.31	46
13	3.68	8.16	5.06	49
14	3.62	8.15	5.41	46
15	1.86	2.42	30.0	15
16	2.61	3.46	4.48	16
17	2.34	4.49	25.49	31
18	3.29	4.54	12.97	57
19	2.62	3.57	5.14	17

SIMPER analysis

Results of SIMPER analysis revealed that there were significant differences between stations in composition and abundance of macroinvertebrates ($p<0.05$). In addition, *Amphipholis squamata*, *Byblis* sp., *Capitella capitate*, and *Amphioplus* sp. were the most effective species that caused differentiation between stations.

Results of total organic matter and sediment composition analysis are represented in Table 4. According to the results, maximum TOM found in station 9 and minimum in 20. The maximum amounts of sand and silt were found in stations 15 while minimum amounts were found in 7 and 4, respectively. The minimum and maximum amounts of clay were found in stations 20 and 14, respectively.

Table 4: Total organic matter and sediment composition analysis of sediments of the Persian Gulf and the Gulf of Oman (2018-2020)

Station	TOM (%)	Sand (%)	Silt (%)	Clay (%)
1	4.75	32.9	63.0	4.1
2	4.15	46.6	49.3	4.1
3	7.12	22.6	72.6	4.8
4	7.29	30.3	67.6	2.1
5	8.58	24.3	72.6	3.1
6	6.84	26.3	71.6	2.1
7	9.71	22.6	72.3	5.1
8	7.02	46.6	52.1	1.3
9	7.29	70.6	26.3	3.1
10	14.97	59.8	34.9	5.3
11	17.52	65.4	31.3	3.3
12	12.91	38.3	57.4	4.3
13	9.98	54.3	43.1	2.6
14	14.99	61.7	33.0	5.3
15	4.57	98.0	2.3	4.3
16	14.47	73.7	21.0	5.3
17	12.68	61.7	33.0	5.3
18	4.15	93.7	5.0	1.3
19	2.68	83.7	13.0	3.3

Physico-chemical properties

Results of Physico -Chemical properties of water are represented in Table 5. The minimum and maximum amounts of temperature were found in stations 17 and 3, respectively, while these values for salinity were in stations 2 and 15. Conductivity and pH were minimum in station 4. Minimum amounts of DO were found in station 12 while maximum chlorophyll-a was measured in station 1. Maximum and minimum of turbidity found in stations 11 and 3, respectively.

PCA and CCA analysis

PCA analysis revealed that among 85 identified families, 33 family were the most effective component for dimension reduction. The identified

[DOR: 20.1001.1.15622916.2021.20.6.15.4]

families were Ampeliscidae, Melitidae, Apseudidae, Prosthiostomidae, Maeridae, Bodotriidae, Photidae, Callianassidae, Cirratulidae, Anthuridae, Cossuridae, Flabelligeridae, Sabellidae, Glyceridae, Haminoeidae, Hesionidae, Lingulidae, Paraonidae, Alpheidae, Spionidae, Corophiidae, Terebellidae, Amphinomidae, Amphiuridae, Nereididae, Talitridae, Ampharetidae, Maldanidae, Clypeasteridae, Nephtyidae, Lumbrineridae, Opheliidae and Capitellidae and there upon, these families were selected for CCA analysis.

Table 5: The mean values of physiochemical properties of water of the Persian Gulf and the Gulf of Oman (2018-2020).

Station	Temperature (°C)	Conductivity (ms/cm)	Salinity (ppm)	DO (g/L)	pH	Chlorophyll-a (mg/L)	Turbidity
1	25.95	56.37	36.69	91.72	8.15	2.02	15.32
2	24.09	53.90	36.33	59.75	7.89	0.30	14.16
3	26.77	57.44	36.80	74.53	8.13	1.22	7.48
4	22.82	52.59	36.36	38.48	7.83	0.20	8.68
5	25.77	56.16	36.66	88.48	8.07	0.56	14.08
6	25.71	56.09	36.66	72.56	8.08	0.44	14.18
7	25.94	56.40	36.71	101.63	8.14	0.86	19.68
8	25.96	56.40	36.70	102.65	8.15	0.60	17.32
9	24.53	55.60	37.26	57.16	8.27	0.60	12.04
10	24.55	55.94	37.51	3.86	8.25	2.00	33.64
11	24.82	56.39	37.63	8.71	8.24	1.36	60.38
12	24.83	56.73	37.87	2.62	8.26	1.38	18.22
13	24.25	57.39	38.87	49.34	8.25	0.88	13.04
14	23.48	56.29	38.70	65.72	8.18	1.36	11.68
15	24.28	57.68	39.06	87.45	8.24	0.88	11.82
16	23.05	54.74	37.86	79.35	8.18	1.24	13.46
17	22.78	54.41	37.85	90.51	8.25	1.48	11.68
18	24.58	57.73	38.83	87.76	8.19	0.42	16.26
19	23.69	55.91	38.22	114.71	8.11	0.84	10.58

According to CCA results (Fig. 3), DO showed a strong direct relationship with Callianassidae, Anthuridae, Paraonidae, Maeridae, and Corophiidae. In addition, the strong indirect relationship was found between Haminoeidae and DO. Turbidity showed a strong direct relationship with Flabelligeridae and a weak direct with Cirratulidae as well. Furthermore, chlorophyll-a showed a strong direct relationship with Nereididae, and other parameters showed a medium direct relationship with Maldanidae and Haminoeidae.

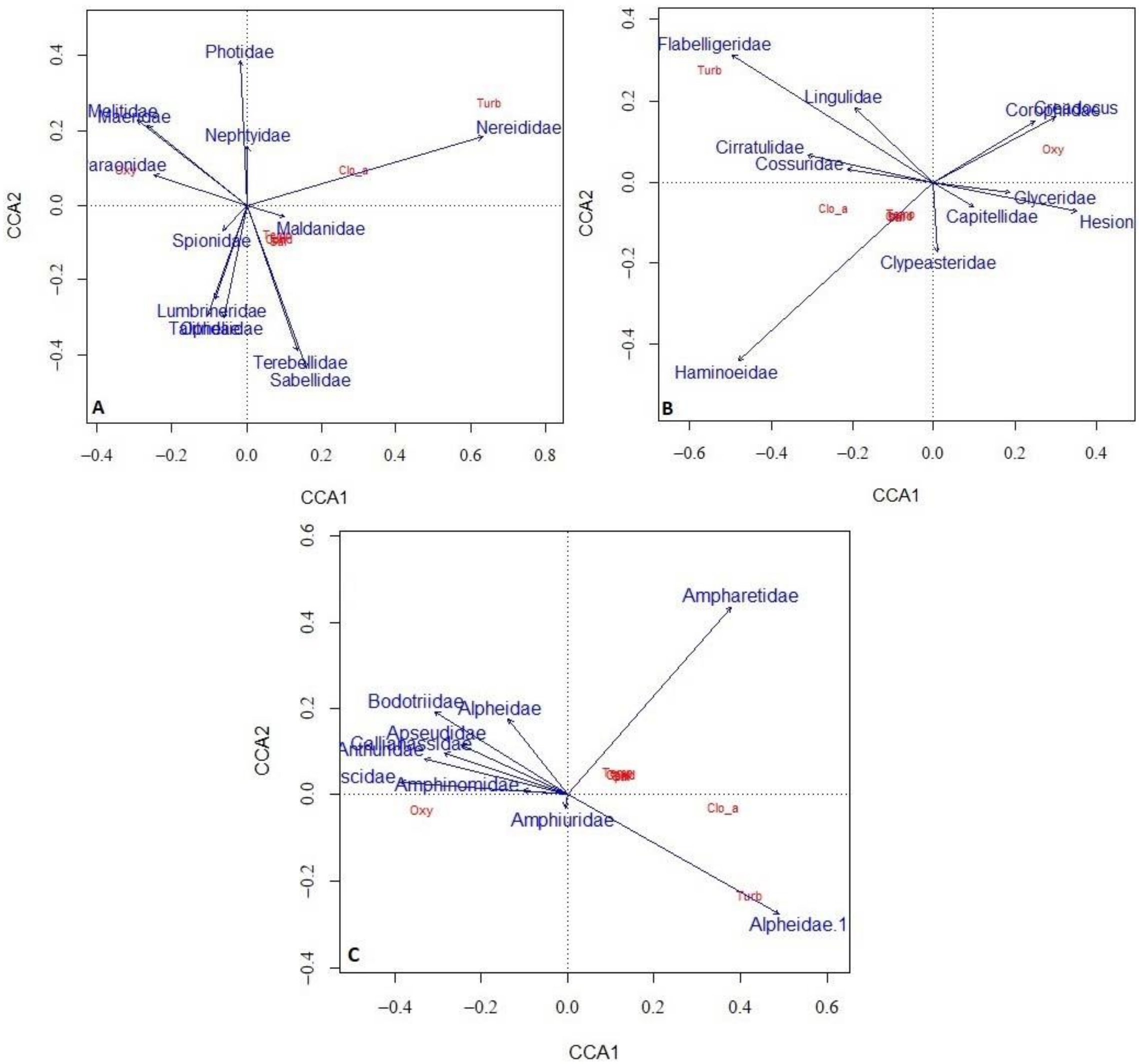

Figure 3: Results of CCA analysis between physiochemical properties of water and main macroinvertebrates families of the Persian Gulf and the Gulf of Oman (2018-2020). Note: Temp: Temperature, Ras: Conductivity, Shor: Salinity, O: DO, Cl: Chlorophyll-a, COD: Turbidity

According to CCA analysis (Fig. 4) and sediment composition results, clay was located in the center of the chart and did not show a remarkable relationship with microbenthic families. Although a weak indirect relationship with all families could be considered for clay, sand showed a significant strong relationship with Bodotriidae, Maeridae, and Melitidae directly and with Amphiuridae and Spionidae, indirectly. On the other hand, silt showed a significant direct relationship with Spionidae and Amphiuridae and indirect with Maeridae and Melitidae. Finally, TOM showed a strong direct relationship with Nereididae and weak direct with Photidae.

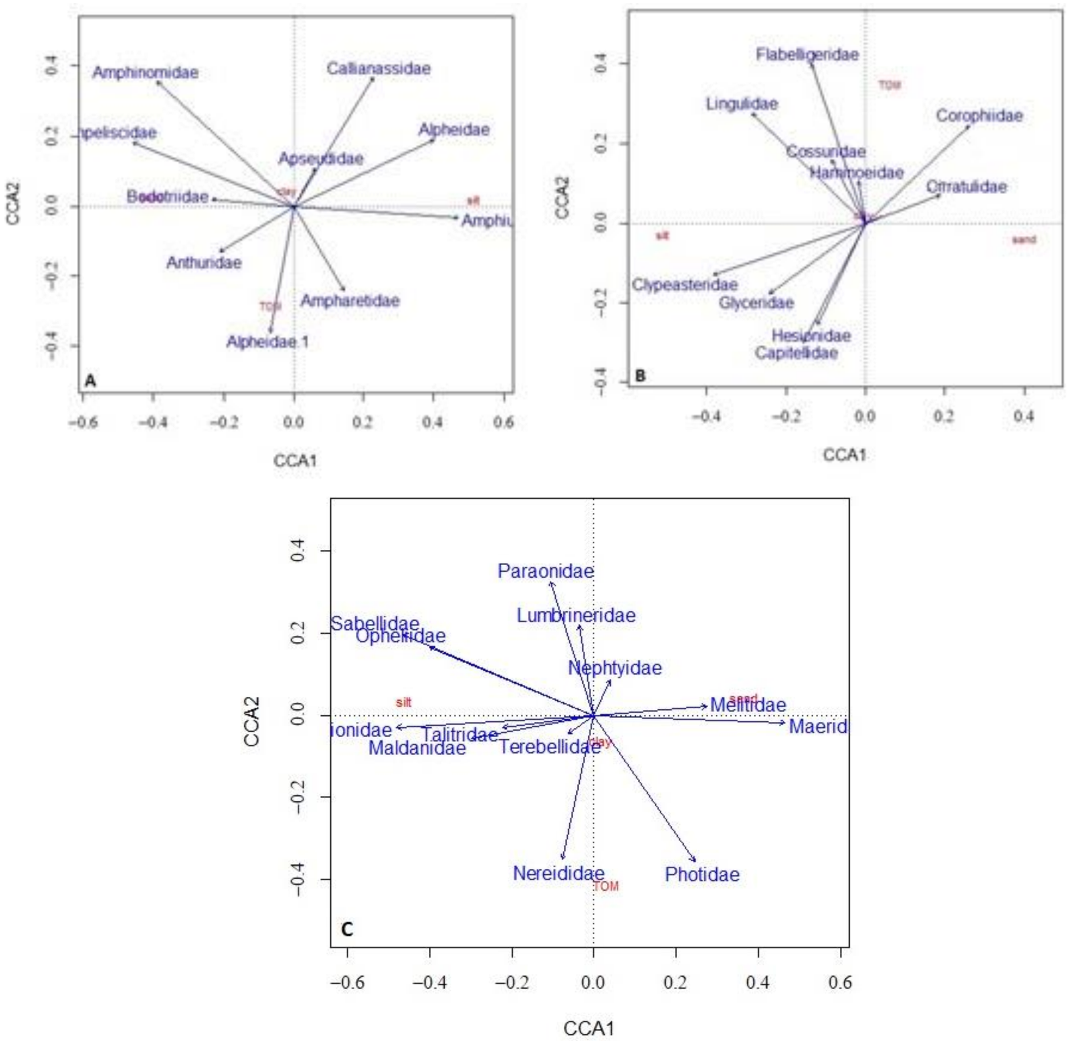

Figure 4: Results of CCA analysis between sediment composition, TOM, and main macroinvertebrates families of the Persian Gulf and the Gulf of Oman (2018-2020).

Discussion

Marine macroinvertebrates as secondary producers play an important role in feeding benthic animals in the ecosystem (Dolbeth *et al*., 2003). The Persian Gulf and the Gulf of Oman are considered as high productive ecosystems (Owfi *et al*., 2016), therefore biodiversity in these two regions is high. Understanding the biodervisty and abundance of macroinvertebrates species is a fundamental step towards achieving sustainable management of ecosystems in this region. Our results indicated that in 4 stations in the studied area, we faced harsh environmental challenges for macroinvertebrates (Table 3). In addition, only one station showed high biodervisty status while others were near the border of moderate and good status (Table 3). Several researchers reported a decreasing trend in macroinvertebrates in marine ecosystems in different regions of the world (Schofield *et al*., 2010; Bumbeer *et al*., 2016; Wu *et al*., 2019). In addition, Lahijanzadeh *et al*. (2019) declared that concentrations of toxic elements such as Al, Fe, Cu, and Zn increased gradually in tissues and shells of benthic macroinvertebrates in the Persian Gulf. Therefore, the risk of pollutants threatens biodervisty of macroinvertebrates in the region and affects the food web. During this study, the number of 164 species belonging to 85 families and 31 orders of macroinvertebrates were identified in the Persian Gulf and the Gulf of Oman (Table 2). Dehghan Madiseh *et al*. (2012) sampled benthic invertebrates from the North-West of the Persian Gulf and reported 29 identified species. They were also noted that most sampling sites showed slightly polluted status through slightly AZTI's Marine Biotic Index. Furthermore, Gerami *et al*. (2016) sampled from macroinvertebrates communities in the Persian Gulf and their sampling sites had overlap with sampling sites in this study. However, 15 orders of macroinvertebrates containing all identified orders in their study, and the biodiversity health status of the Shannon-Wiener index was the poor status for all sites.

Spatial variation in the composition of macroinvertebrates communities in all sites was observed and SIMPER analysis showed that *Amphipholis squamata*, *Byblis* sp., *Capitella capitate* and *Amphioplus* sp. were the most effective species in differences between stations. This might indicate that these species tend to have more temporal or spatial variation in the region. *A. squamata* and *Amphioplus* sp. belonging to class Ophiuroidea are the most distributed species in the Persian Gulf (Fatemi and Stöhr, 2019) and accustomed to a huge variety of habitats such as boulders, sand, or muds (Boissin *et al*., 2008). *Byblis* is also an abundant genus of order Amphipoda that is distributed in all parts of the Persian Gulf and the Gulf of Oman (Mohammadi Dehcheshme *et al*., 2016).

The relationship between macroinvertebrates families and environmental factors was estimated based on CCA analysis (Fig. 3). DO, turbidity, and chlorophyll-a were the dominant environmental factors that directly or indirectly affected the distribution and community composition of macroinvertebrates in the study area. Gerami *et al*. (2016) were also reported that DO and chlorophyll-a were the best variables for explaining changes in abundance over time. Although they did not analyze turbidity in their analysis. It is well known that oxygen availability is a major factor influencing the composition of macrobenthic communities. Indeed, oxygen is the first factor in macrobenthic respiration (Steel, 1980). Furthermore, the amount of oxygen production in water bodies has connection with the concentration of chlorophyll. Kuhnt *et al*. (2013) suggested that there is a species-specific relationship between benthic foraminiferal species and bottom-water oxygen content. However, benthic habitats are complex, and a variety of environmental variables affect the diversity and density of macroinvertebrates. The composition of bed sediments and sediment's food availability are significant factors that affect composition of macroinvertebrates communities (Bumbeer *et al*., 2016; Jun *et al*., 2016; Mehdipour *et al*., 2018). According to the results, sand, silt, and TOM showed a strong relationship with main macroinvertebrates families and affected their distribution. Several researchers reported the response of macrobenthic communities to sediment treatment (Doeg and Milledge, 1991; Suren and Jowett, 2001; Connolly and Pearson, 2007). Aliakbarian *et al.* (2020) reported the relation between the type of sediment and macrobenthic species in the southeast of the Caspian Sea. Although their results were based on RDA analysis instead of CCA, they also reported that sand and slit were most related in comparison with clay. According to figure 4, some families of identified macroinvertebrates showed relation with sediment composition. Data for comparison is scarce in literature. However, the results of this study were in accordance with researchers around the world. Anderson *et al*. (2013) found that there is a relationship between seafloor structure and infaunal biodiversity and reported that Polychaeta especially the Maeridae family has a correlation with sand in the studied area. Furthermore, Toba and Sate (2013) stated that the Nereididae family is a Filter-feeder benthic macroinvertebrates that has a positive correlation with TOM of the sediments. Their results were similar to the results of this study.

In fact, sediment as the habitat of benthic species plays a major role in their lifestyle and suspension-feeders are more abundant in sandy flats due to better water current situation (Aliakbarian *et al.*, 2020). Grazing process of fauna and infauna species in marine bed directly related to the sediment composition and amounts of organic materials in sediments (Mermillod-Blondin *et al*., 2005). In addition, wastewater inputs could penetrate the sediments and adversely affect macroinvertebrate diversity in aquatic ecosystems (Foomani *et al*., 2020). The same results were observed by Mancinelli *et al*. (1998) for the effect of TOM on microbenthic communities. They reported that the presence of organic matter significantly affects distribution of soft-bottom macrobenthos of the Northern Adriatic Sea.

This study reported the main benthic macroinvertebrates families and species in the Persian Gulf and the Gulf of Oman. Diversity of macroinvertebrates reported and identified species in this study showed a strong relationship with DO and chlorophyll-a concentration (Fig. 3). Other measured environmental factors were also showed a slight influence on the diversity of marine macroinvertebrates. The diverse health status was not totally in a good condition and needs to be improved. These findings could be useful in

[DOR: 20.1001.1.15622916.2021.20.6.15.4]

further studies for habitat management and monitoring programs.

Acknowledgments

We would like to extend our thanks to the Persian Gulf and Oman Sea Ecology Research Center (Bandar Abbas) for its support in implementing the project. The authors also would like to thank colleagues Reza Dehghani, Arash Haghshenas and Esmat Salimi for their technical assistance and contribution in conducting some of the experiments for the research.

References

Aliakbarian, A., Ghorbani, R., Fazli, H., Salman Mahiny, A., Yelghi, S. and Naddafi, R., 2020. Diversity and spatial distribution patterns of the benthic macrofauna communities in the southeast of the Caspian Sea (Golestan Province–Iran) in relation to environmental conditions. *Iranian Journal of Fisheries Sciences*, 19(**2**), 525-540. DOI: 10.22092/ijfs.2019.120647

Alsaffar, Z., Pearman, J.K., Curdia, J., Ellis, J., Calleja, M.L., Ruiz-Compean, P., Roth, F., Villalobos, R., Jones, B.H., Moran, X.A.G. and Carvalho, S., 2020. The role of seagrass vegetation and local environmental conditions in shaping benthic bacterial and macroinvertebrate communities in a tropical coastal lagoon. *Scientific Reports,* 10(**1**), 1-17. DOI: 10.1038/s41598-020-70318-1

Al-Yamani, F., Skryabin, V., Boltachova, N., Revkov, N., Makarov, M., Grintsov. and Kolesnikova, E., 2012. Illustrated Atlas On The Zoobenthos of Kuwait. Kuwait Institute for Scientific Research. 383 P.

Anderson, T.J., McArthur, M.A., Syms, C., Nichol, S. and Brooke, B., 2013. Infaunal biodiversity and ecological function on a remote oceanic island: The role of biogeography and bio-physical surrogates. *Estuarine, Coastal and Shelf Science*, 117, 227-237. DOI: 10.1016/j.ecss.2012.11.013

Azizi, N., Sari, A., Fatemi, M.R., Farshchi, P. and Mousavi-Nadushan, R., 2020. esearch Article: Analyses of macro benthic fauna in rocky habitats along the coast of Bushehr, ersian Gulf, Iran. *Iranian Journal of Fisheries Sciences*, 19(**6**), 3127-3150. DOI: 10.22092/ijfs.2020.122797

Boissin, E., Féral, J.P. and Chenuil, A., 2008. Defining reproductively isolated units in a cryptic and syntopic species complex using mitochondrial and nuclear markers: the brooding brittle star, *Amphipholis squamata* (Ophiuroidea). *Molecular Ecology*, 17(**7**), 1732-1744. DOI: 10.1111/j.1365-294X.2007.03652

Bosch, T., Dance, S,P., Goolenbeek, R. and Oliver, P.G., 1995. Seashells of Eastern Arabia. Motivate Publishing, UAE.

Buchanan, J., 1984. Sediment Analysis. In: N.A. Holme and A.D. McIntyre, editors. Method for the study of marine benthos. Oxford:

Blackwell Scientific Publications. pp. 41-65.

Bumbeer, J., Cattani, A.P., Chierigatti, N.B. and Rocha, R.M.D., 2016. Biodiversity of benthic macroinvertebrates on hard substrates in the Currais Marine Protected Area, in southern Brazil. *Biota Neotropica*, 16(**4**), e20160246. DOI: 10.1590/1676-0611-BN-2016-0246

Connolly, N.M. and Pearson, R.G., 2007. The effect of fine sedimentation on tropical stream macroinvertebrate assemblages: a comparison using flow-through artificial stream channels and recirculating mesocosms. *Hydrobiologia*, 592(**1**), 423-438. DOI: 10.1007/s10750-007-0774-7

Debruyne, R.H., 2003. The complete encyclopedia of shells. Rebo Publisher, Lisse Netherlands.

Dehghan Madiseh, S., Esmaily, F., Marammazi, J.G., Koochaknejad, E. and Farokhimoghadam S. 2012. Benthic invertebrate community in Khur-e-Mussa creeks in northwest of Persian Gulf and the application of the AMBI (AZTI's Marine Biotic Index) . *Iranian Journal of Fisheries Sience,* 11(**3**), 460-474.

Doeg, T.J. and Milledge, G.A., 1991. Effect of experimentally increasing concentrations of suspended sediment on macroinvertebrate drift. *Australian Journal of Marine and Freshwater Research*, 42(**5**), 519-526. DOI: 10.1071/MF9910519

Dolbeth, M., Pardal, M.A., Lillebø, A.I., Azeiteiro, U. and Marques, J.C. 2003. Short-and long-term effects of eutrophication on the secondary production of an intertidal macrobenthic community. *Marine Biology*, 143(**6**), 1229-1238. DOI: 10.1007/s00227-003-1133-5

Fatemi, Y. and Stöhr, S., 2019. Annotated species list of Ophiuroidea (Echinodermata) from the Persian Gulf and Gulf of Oman with new records. *Zootaxa*, 4711(**1**), 77-106. DOI: 10.11646/ZOOTAXA.4711.1.3

Fauchald, K., 1977. The polychaete worms, definition and keys to the order, families and genera. Natural History Museum of Los Angeles in conjuction with the Allan Hanccock Foundation, University of Southern Califotnia, USA.

Foomani, A., Gholizadeh, M., Harsij, M. and Salavatian, M., 2020. River health assessment using macroinvertebrates and water quality parameters: A case of the Shanbeh-Bazar River, Anzali Wetland, Iran. *Iranian Journal of Fisheries Sciences*, 19(**5**), 2274-2292. DOI: 10.22092/ijfs.2020.122380

Gamboa-García, D.E., Duque, G. and Cogua, P., 2018. Structural and compositional dynamics of macroinvertebrates and their relation to environmental variables in Buenaventura Bay. *Boletín de Investigaciones Marinas y Costeras-INVEMAR*, 47(**1**), 67-83. DOI: 10.25268/bimc.invemar.2018.47.1.738.

Gerami, M.H., Patimar, R., Negarestan, H., Jafarian, H. and

Mortazavi, M.S., 2016. Temporal variability in macroinvertebrates diversity patterns and their relation with environmental factors. *Biodiversitas Journal of Biological Diversity*, 17(**1**). DOI: 10.13057/biodiv/d170106

Hajializadeh, P., Safaie, M., Naderloo, R., Shojaei, M.G., Gammal, J., Villnäs, A. and Norkko, A., 2020. Species composition and functional traits of macrofauna in different mangrove habitats in the Persian Gulf. *Frontiers in Marine Science*, 7, 809. DOI: 10.3389/fmars.2020.575480

Hoegh-Guldberg, O. and Bruno, J.F., 2010. The impact of climate change on the world's marine ecosystems. *Science*, 328(**5985**), 1523-1528. DOI: 10.1126/science.1189930

Holme, N.A. and McIntyre, A.D., 1984. Methods for the study of marine benthos, Second Edition, handbook, Oxford-London-Boston: Blackwell Scientific Publications. 399 P. DOI: 10.1002/iroh.19860710107.

Jun, Y.C., Kim, N.Y., Kim, S.H., Park, Y.S., Kong, D.S. and Hwang, S.J., 2016. Spatial distribution of benthic macroinvertebrate assemblages in relation to environmental variables in Korean nationwide streams. *Water*, 8(**1**), 27. DOI: 10.3390/w8010027

Kosari, S., Mousavi Nadushan, R., Faremi, R., Ejlali Khanghah, K. and Mashinchian, A., 2021. Macrobenthos as bioindicator of ecological status in the Yekshabe creek-estuary, Persian Gulf. *Iranian Journal of Fisheries Sciences*, 20(**2**), 514-528. DOI: 10.22092/ijfs.2021.123874

Kuhnt, T., Friedrich, O., Schmiedl, G., Milker, Y., Mackensen, A. and Lückge, A., 2013. Relationship between pore density and bottom-water oxygen content in benthic Foraminifera. *Deep-Sea Research Part I-Oceanographic Research Papers*, 76, 85-95. DOI: 10.1016/j.dsr.2012.11.013

Lahijanzadeh, A.R., Rouzbahani, M.M., Sabzalipour, S. and Nabavi, S.M.B., 2019. Ecological risk of potentially toxic elements (PTEs) in sediments, seawater, wastewater, and benthic macroinvertebrates, Persian Gulf. *Marine Pollution Bulletin*, 145, 377-389. DOI: 10.1016/j.marpolbul.2019.05.030

Li, F., Chung, N., Bae, M.J., Kwon, Y.S. and Park, Y.S., 2012. Relationships between stream macroinvertebrates and environmental variables at multiple spatial scales. *Freshwater Biology*, 57(**10**), 2107-2124. DOI: 10.1111/j.1365-2427.2012.02854.x

Mancinelli, G., Fazi, S. and Rossi, L., 1998. Sediment structural properties mediating dominant feeding type patterns in soft-bottom macrobenthos of the Northern Adriatic Sea. *Hydrobiologia*, 367(**1**), 211-222. DOI: 10.1023/a:1003292519784

Margalef, R., 1969. Perspectives in Ecological Theory. The University of Chicago Press, Chicago. 111 P.

Marques, J.C., Salas, F., Patricio, J., Teixeira, H. and Neto, J.M., 2009. Ecological Indicators for Coastal and Estuarine Environmental Assessment: A User Guide. WIT Press, Southampton UK.

Mehdipour, N., Gerami, M.H. and Nemati, H., 2018. Assessing benthic health of hard substratum macrobenthic community using soft bottom indicators and their relationship with environmental condition. *Iranian Journal of Fisheries Sciences*, 17(**4**), 641-656. DOI: 10.22092/ijfs.2018.116991

Mermillod-Blondin, F., François-Carcaillet, F. and Rosenberg, R., 2005. Biodiversity of benthic invertebrates and organic matter processing in shallow marine sediments: an experimental study. *Journal of Experimental Marine Biology and Ecology*, 315(**2**), 187-209. DOI: 10.1016/j.jembe.2004.09.013

Mohammadi Dehcheshme, L., Papahn Shoshtari, F., Dehghan Madise, S. and Chini Pardaz, R., 2016. Distribution and Diversity of Amphipoda of Eastern Bahracan shores in Persian Gulf. *Journal of Animal Environment*, 8(**2**), 173-180.

Molvær, J., Knutzen, J., Magnusson, J., Rygg, B., Skei, J. and Sørensen, J., 1997. Classification of environmental quality in Fjords and Coastal Waters. *SFT Guidelines*, 97(**3**), 36.

Naderloo, R., 2017. Atlas of crabs of the Persian Gulf. Springer, Switzerland: xi + 444 P.

Nordström, M.C. and Bonsdorff, E., 2017. Organic enrichment simplifies marine benthic food web structure. *Limnology and Oceanography*, 62(**5**), 2179-2188. DOI: 10.1002/lno.10558

Oksanen, J., Blanchet, F.G., Kindt, R., Legendre, P., Minchin, P.R., O'Hara, R.B., Simpson, G.L., Solymos, P.M., Stevens, M.H.M. and Wagner, H., 2015. Vegan: Community Ecology Package. R package version 2.3-0. http://CRAN.R-project.org/package = vegan.

Owfi, F., Braulik, G.T. and Rabbaniha, M., 2016. Review Papers: Species diversity and distribution pattern of marine mammals of the Persian Gulf and Gulf of Oman-Iranian Waters. *Iranian Journal of Fisheries Sciences*, 15(**2**), 927-944.

Patang, F. and Soegianto, A., 2020. Oxidative responses of macro-invertebrates in relation to environmental variables in rivers of East Kalimantan, Indonesia. *Chemistry and Ecology*, 36(**9**), 855-867. DOI: 10.1080/02757540.2020.1791101

Ros, J.D. and Cardell, M.J., 1991. La diversidad específica y otros descriptores de contaminación orgánica en comunidades bentónicas marinas. Actas del Symposium sobre Diversidad Biológica. Centro de Estudios Ramón Areces, Madrid. pp. 219-223.

Saghali, M., Baqraf, R., Hosseini, S.A. and Patimar, R., 2013.

Benthic community structure in the Gorgan Bay (Southeast of the Caspian Sea, Iran): Correlation to water physiochemical factors and heavy metal concentration of sediment. *International Journal of Aquatic Biology*, 1(**5**), 245-253. DOI: 10.22034/ijab.v1i5.155

Schofield, O., Ducklow, H.W., Martinson, D.G., Meredith, M.P., Moline, M.A. and Fraser, W.R., 2010. How do polar marine ecosystems respond to rapid climate change?. *Science*, 328(**5985**), 1520-1523. DOI: 10.1126/science.1185779

Shannon, C. E. and Wiener, W. 1948. The Mathematical Theory of Communication. University Illinois Press, Urbana, IL. 144 P.

Snelgrove, P.V., 1998. The biodiversity of macrofaunal organisms in marine sediments. *Biodiversity and Conservation*, 7(**9**), 1123-1132. DOI: 10.1023/A:1008867313340

Steel, J.A., 1980. Phytoplankton Models," In: LeCren ED, LoweMcConnell RH (Eds.). Functioning of Freshwater Ecosystems, Cambridge University Press, Cambridge, 2, pp. 220-227.

Sterrer, W., 1986. Marine Fauna and Flora of Bermuda A systematic guide to the identification of marine organisms, A Wiley-Interscience Publication John Wiley and Sons, New York.

Suren, A.M. and Jowett, I.A., 2001. Effects of deposited sediment on invertebrate drift: an experimental study. *New Zealand Journal of Marine and Freshwater Research*, 35(**4**), 725-737. DOI: 10.1080/00288330.2001.9517038

Teske, P.R. and Wooldridge, T.H., 2004. Affinities of some common estuarine macroinvertebrates to salinity and sediment type: empirical data from Eastern Cape estuaries, South Africa. *African Zoology*, 39(**2**), 183-192. DOI: 10.1080/15627020.2004.11657215

Toba, Y. and Sato, M., 2013. Filter-feeding behavior of three Asian Hediste species (Polychaeta: Nereididae). *Plankton and Benthos Research*, 8(**4**), 159-165. DOI: 10.3800/pbr.8.159

Townsend, C.R., Hildrew, A.G. and Francis, J., 1983. Community structure in some English streams: the influence of physicochemical factors. *Freshwater Biology*, 13(**6**), 521-544. DOI: 10.1111/j.1365-2427.1983.tb00011.x

Wu, H.Y., Fu, S.F., Cai, X.Q. and Chen, Q.H., 2019. Composition and distribution characteristics of macroinvertebrates in subtidal zone of the main marine bays in Fujian Province, China. *Ying yong sheng tai xue bao= The Journal of Applied Ecology*, 30(**12**), 4240-4248. DOI: 10.13287/j.1001-9332.201912.036

Wu, Z., Tweedley, J.R., Loneragan, N.R. and Zhang, X., 2019. Artificial reefs can mimic natural habitats for fish and macroinvertebrates in temperate coastal waters of the Yellow Sea. *Ecological Engineering*, 139, 105579. DOI: 10.1016/j.ecoleng.2019.08.009

Xu, Y., Sui, J., Ma, L., Dong, D., Kou, Q., Gan, Z., Gong, L., Yang, M., Li, X., Wang, J. and Wang, H., 2019. Spatial pattern of benthic macroinvertebrate communities and their relationship with environmental variables on the East China Sea shelf. *Deep Sea Research Part II: Topical Studies in Oceanography*, 169, 104633. DOI: 10.1016/j.dsr2.2019.07.021