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Temporal variability in macroinvertebrates diversity patterns and their relation with environmental factors

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Abstract. *Gerami MH, Patimar R, Negarestan H, Jafarian H, Mortazavi MS. 2015. Temporal variability in macroinvertebrates diversity patterns and their relation with environmental factors. Biodiversitas 17: 36-43.* Seasonal changes are the most important factor in temporal variability of macroinvertebrates communities in marine benthic zone. Realizing the pattern of these changes are the key attributes to maintain benthic resources. For this purpose this study aimed to investigate temporal variability of macroinvertebrates diversity patterns in different seasons in Hormozgan province waters, Persian Gulf. Five sites were identified and sampling was carried out randomly at three places with three replicate in each site from autumn 2014 to spring 2015. Physiochemical properties of water were recorded in each sampling site. Total of 19 macroinvertebrate orders were identified form four seasons in all sites. Results showed that Polychaeta were dominant taxa in all seasons and maximum diversity of benthic macroinvertebrates exhibitedin winter. According to evenness index (E1), abundances of species were most balanced in spring. Analysis of weight and density revealed that the species diversity and mean weight of macroinvertebrates had maximum in winter and minimum in summer. Macroinvertebrate community structure was similar in the spring and summer and partly discriminated from remaining two seasons. SIMPER analysis confirmed these dissimilarities and revealed that Foraminifera, Gastropoda and Polychaeta have three major contributions in dissimilarities between seasons. According to BIO-ENV analysis, oxygen and chlorophyll a were the best variables (r = 0.7143) explaining changes in the abundance over time of the benthic fauna under study. On the contrary, eight orders (Amphipoda, Secernentea, Cumacea, Euphausiacea, Gastropoda, Isopoda, Anthozoa and Sagittoidea) did not show any convergence with environmental factors in this study.

Keywords: Macroinvertebrate assemblages, diversity indices, seasonal changes, Persian Gulf

INTRODUCTION

Macrobenthic invertebrates are key components in the functioning of coastal and marine ecosystems and also play a significant role in marine benthic food chain (Lu 2005). In addition, macrofauna of marine sediments play an important role in ecosystem processes such as dispersion and burial, pollutant metabolism, nutrient cycling, and secondary production (Snelgrove 1998). Therefore, they can be employed as ecological indicators to provide synoptic information about the state of ecosystems, and help in developmental planning and decision-making processes (Marques et al. 2009).

The aquatic organisms are exposed to anthropogenic disturbances and natural changes in their habitats, which makes them react in different ways (Saghali et al. 2013; Nouri et al. 2008). Macrobenthic invertebrates'structure is affected by environmental factors such as temperature, pH, dissolved oxygen and pollution (Saghali et al. 2013; Sharma and Rawat 2009). Seasonal changes in these factors cause variation in rate of supply of organic matter and consequently affect the spatial and temporal distribution of marine organisms, such as macrobenthic communities (Bachelet et al. 2000; Erftemeijer and Herman 1994).

Seasonal changes in macrobenthic communities in aquatic environment have been studied by many researchers. Chapman and Brinkhurst (1981) declared that seasonal movements of subtidal benthic invertebrates in the Fraser River estuary were affected by runoff and salt-wedge seasonal changes. These changes were most apparent in the oligochaetes and polychaetes. Morrisey et al. (1992) reported significant temporal variation of soft-sediment benthos ranging in length from days to months in Botany Bay, New South Wales, Australia.Furthermore, Livingston (1987) found variations in the abundance and composition of infauna at scales from weeks to years.

Consideration of the diverse environmental factors that might potentially cause variation in macroinvertebrate abundance over long-short period would suggest that seasonal or monthly fluctuations are common. In addition, revealing the relationship between macroinvertebrates and environmental factors could describe seasonal changes more accurately. As a consequence, any spatial heterogeneity in the macroinvertebrates is likely to be interpreted as an effect of time, not the effect of pollution, for example. This process shows the importance of studying seasonal changes.

The aim of this study is to investigate seasonal variation in macroinvertebrates diversity in a part of Persian Gulf and their relation to environmental factors. The initial step for such a survey is the identification of organisms living in the aquatic ecosystem (Niemi and McDonald 2004). The results have relevance to studies of macroinvertebrates of soft sediments other parts of Persian Gulf (or elsewhere with the same conditions) and also to the sampling of other marine habitats and other variables, such as pollutants.

MATERIALS AND METHODS

Due to soft sediment and high nutrients enrichment, Hormozgan province waters are a favorablehabitat for macroinvertebratesin Persian Gulf (Pourjomeh et al. 2014). Five sampling sites were identified and selected (Figure 1). Stations were chosen to give broad geographic coverage of the most divers habitats of macroinvertebrates in Hormozgan province waters, Iran. Due to patchy distribution of macroinvertebrates, sampling was done randomly at three places with three replicate, in each site and 180 samples were analyzed during the study. Samples were taken by Van veen Grab with 0.0256 m^2 cross section. Sampling was performed seasonally, from autumn 2014 to spring 2015. Physiochemical properties of water were recorded by CTD device in each site. Samples were sieved through 0.5 mm mesh and the remaining was fixed and preserved by 97% ethanol and transferred to laboratory for further analysis. Organism were stained by Rose Bengal and sorted to major taxonomic groups. Macroinvertebrates were identified by illustrated keys such as: Fauchald (1997), Sterrer (1986), Bosch et al. (1995) and Debruyne (2003). Samples were weighted with 0.0001 gr accuracy and wet weight was determined as biomass measurement.

The following biodiversity indices were employed to compare seasons:

Shannon-Wiener Index (Shannon and Weaver 1963): This index is based on the Information Theory. It assumes that individuals are sampled at random, out of an “indefinitely large” community, and that all the species are represented in the sample and can be estimated according to the algorithm:

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

Where P_i is the proportion of individuals belonging to species *i* in the sample. The index can usually take values between 0 and 5, and maximal values above 5 bits/individual are very rare (Marques et al. 2009). For instance, Molvær et al. (1997) established the following relation between the Shannon-Wiener Index values and the different levels of ecological quality (Table 1), in accordance with that recommended by the Water Framework Directive (WFD, 2000/60/CE).

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

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

Simpson Index (Simpson 1949):

$$\lambda = \sum P_i^2$$

Where P_i is the proportion of individuals from species *i* in the community. The Simpson Index may vary from 0 to 1, it has no dimensions and, in the same way, higher values correspond to lower diversity.

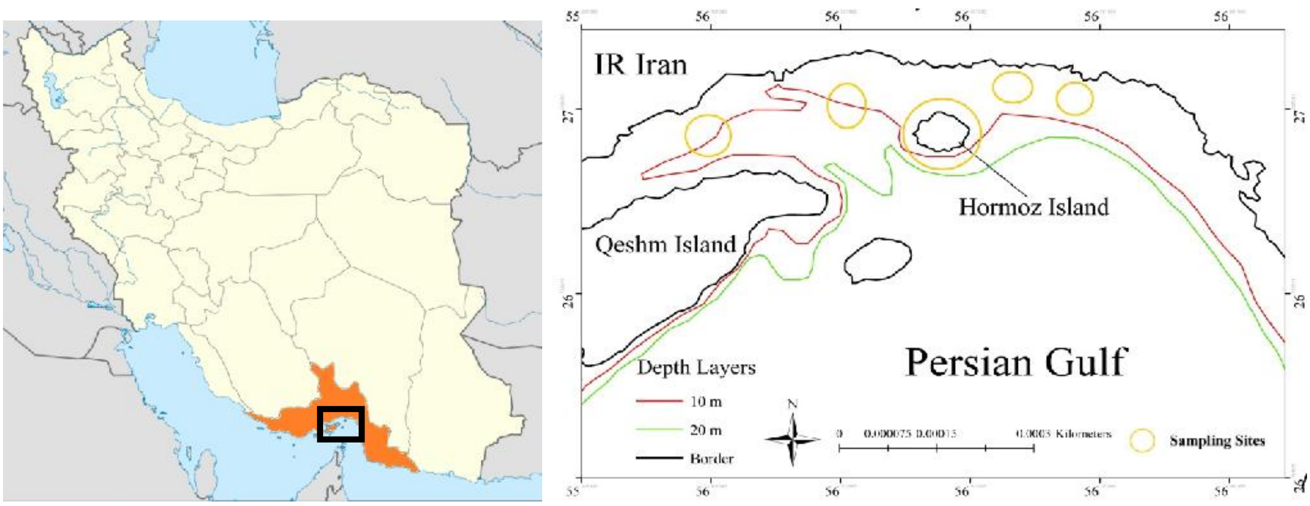

Figure 1. Location of the sampling sites at Hormozgan province waters, Persian Gulf

According to H' the following diversity indices are available (Ludwig and Reynolds 1988; Gerami et al. 2014):

$$N1 = e^{H'}$$
$$N2 = 1/\lambda$$

N1 and N2 show effective numbers of species with common species in population. Lower values shows incompatible conditions for taxa.

Margalef Index (Margalef 1969): The Margalef Index quantifies diversity by relating specific richness to the total number of individuals.

$$M = \frac{(S-1)}{\log_e N}$$

Where S = number of species and N = total number of individuals. According to Margalef (1969) higher level of the index represents better environmental conditions in ecosystem.

Pielou Evenness Index (Pielou 1969): This index is a measure of how evenly distributed abundance is among the species that exist in a community and estimated by following equations:

$$E1 = H'/Ln\,(S)$$
$$E2 = e^{H'}/S$$
$$E3 = e^{H'} - 1/S - 1$$
$$E4 = N2/N1$$
$$E5 = (N2-1)/(N1-1)$$

For E1, E2 and E3 the values may vary from 0 to 1, where 1 represents a community with perfect evenness, and decreases to zero as the relative abundances of the species diverge from evenness. E4 and E5 demonstrate dominance in community. Higher values of E4 and with lower values of E5 show harsh condition due to tendency of dominant species to increase.

One way ANOVA test was performed for assessing significant differences between environmental factors in different seasons. In addition, normality test (Chi-square test) was done before analysis. The non-parametric multidimensional-scaling (nMDS) and analysis of similarities (ANOSIM) were used to examine the spatial patterns of macroinvertebrate assemblages. For parametric analyses the abundance data were square-root transformed to reduce heteroscedasticity before running similarity matrix. Bray-Curtis coefficient was used as the measure of similarity. The level of significance was calculated by means 999 permutations between groups. BIO-ENV analysis was used to find the best subset of environmental variables and community-development pattern. In addition, Canonical correspondence analysis (CCA) was applied to extracts major gradients among combinations of macrobenthic assemblages and environmental variables. Canonical discriminant analysis (CDA) was used to assess differences between seasonal environmental parameters. All the analyses were carried out with R statistical packages (Version 3.13) and vegan package were used to run MDS, ANOSIM, BIO-ENV, CCA and CDA analysis (Oksanen et al. 2015)

RESULTS AND DISCUSSION

Physico-chemical parameters

The mean values of physico-chemical parameters at Hormozgan province waters were represented in Table 2. One way ANOVA analysis showed that there was a significant difference in mean temperature, Oxygen, pH and Chlorophyll a between seasons, while this difference in salinity was not significant (Table 2, Figure 2). Normality test showed that distribution of data was not normal ($p<0.05$).

Diversity indices

Total of 21 macroinvertebrate orders were identified from four seasons in all sites. Results showed that Polychaeta were dominant taxa in all seasons (Figure 3-6). Results of diversity indices showed that maximum diversity of benthic macroinvertebrates was found in winter. In addition, evenness indices (E1) had its maximum in spring (Table 2). Analysis of weight and density reveled that maximum species diversity and species density occurred in winterwhile these amounts were minimum at summer (Figure 7). Canonical analysis of all orders in all seasons showed that winter was separated from all seasons.

ANOSIM analysis revealed that there was a significant difference between benthic community structures (R = 0.125, P = 0.001). However, R value showed that different between environmental data was not strong. nMDS showed that summer and spring were similar in community structure. Moreover, results indicated that winter and autumn were partly discriminated in macrobenthic community structure from other two seasons (Figure 8). In addition, SIMPER analysis confirmed these dissimilarities and revealed that Foraminifera, Gastropoda and Polychaeta have three major contributions in dissimilarities between seasons (Table 3).

Table 2. The mean values (mean ± SE) of physiochemical properties of Hormozgan province waters, Persian Gulf (2014-2015)

Season	Temperature (°C)	Salinity (psu)	Oxygen (ppm)	pH	Chlorophyll a (mg/m^3)
Spring	31.83±1.22^a	37.47±0.13^a	4.04±0.89^a	8.4±0.00^a	0.91±0.26^a
Summer	33.35±0.26^b	37.27±0.06^a	5.17±0.04^b	8.19±0.00^b	0.61±0.04^b
Autumn	27.45±2.33^c	38.17±0.35^a	5.17±0.40^b	8.26±0.00^c	1.45±0.23^c
Winter	22.11±1.83^d	36.14±1.37^a	5.70±0.35^c	8.19±0.00^d	0.952±0.13^d

Note: Different uppercase letters indicating significant difference in columns (ANOVA, P<0.05).

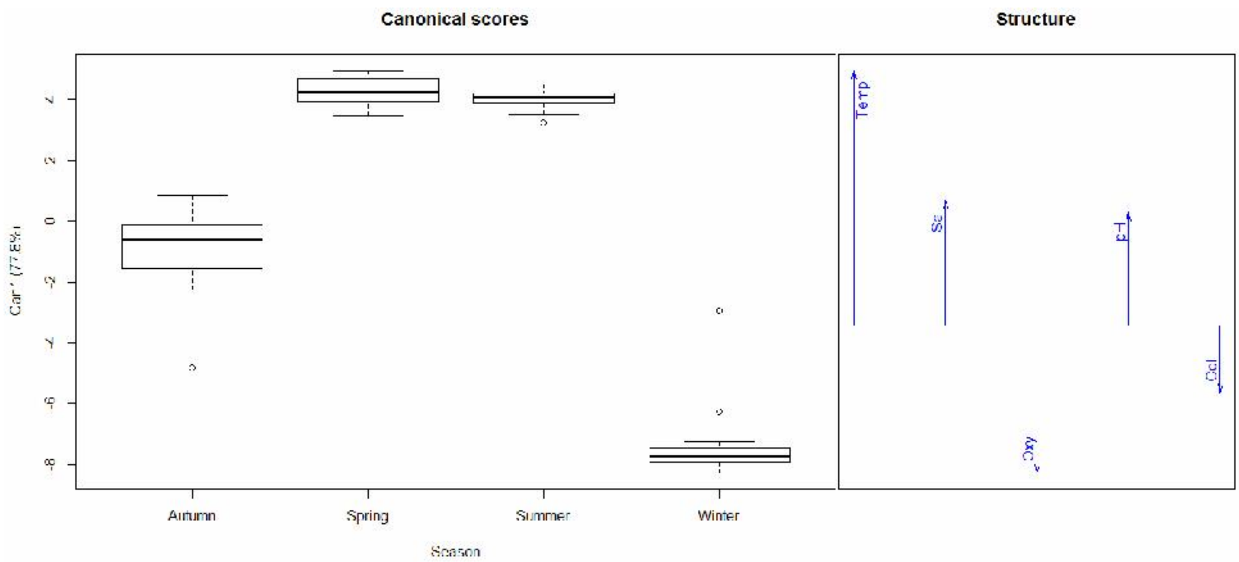

Figure 2. Canonical discriminant analysis plot for physiochemical properties of water in Hormozgan province waters. Note: Sal: Salinity, Coll: Chlorophyll a, Oxy: Oxygen, Temp: Temperature

Table2. Seasonal changes in diversity indices of benthic macroinvertebrates of Hormozgan province waters, Persian Gulf

Season	H'	M	λ	N1	N2	E1	E2	E3	E4	E5
Winter	1.762	3.353	0.234	5.826	5.960	0.598	0.307	0.268	0.733	0.677
Spring	1.713	3.023	0.287	5.542	3.472	0.633	0.369	0.324	0.626	0.549
Summer	1.515	2.736	0.193	4.551	5.161	0.590	0.350	0.295	1.133	1.171
Autumn	1.512	3.537	0.208	3.166	4.795	0.406	0.186	0.135	1.513	1.761

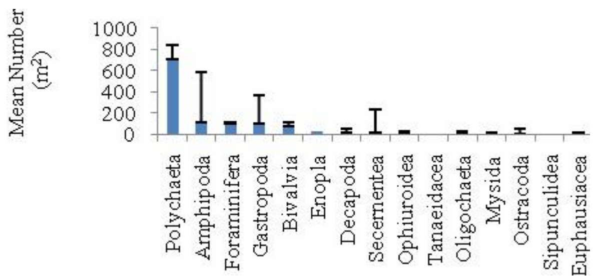

Figure 3. Mean frequency of benthic macroinvertebrates of Hormozgan province waters in autumn

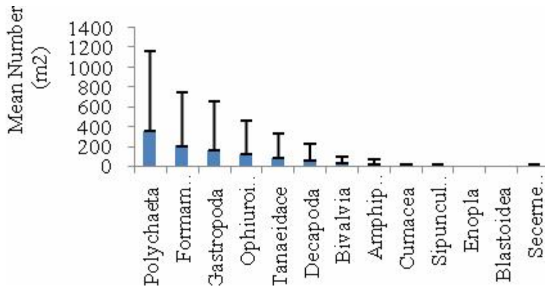

Figure 5. Mean frequency of benthic macroinvertebrates of Hormozgan province waters in autumn summer

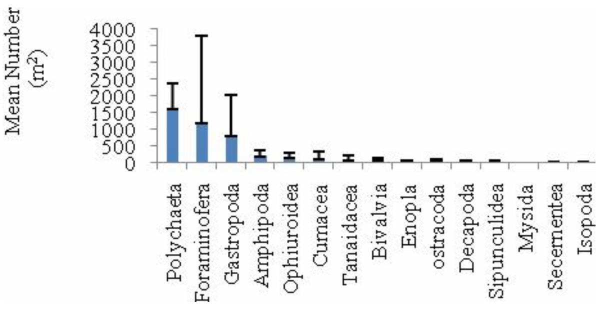

Figure 4. Mean frequency of benthic macroinvertebrates of Hormozgan province waters in autumn spring

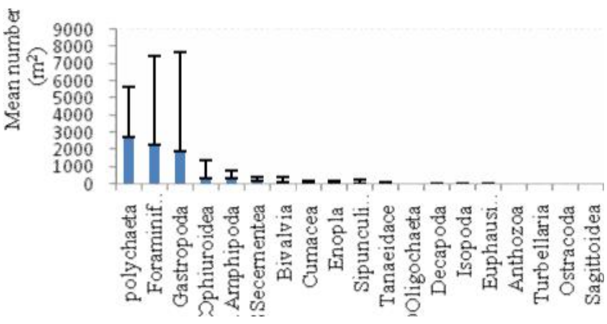

Figure 6. Mean frequency of benthic macroinvertebrates of Hormozgan province waters in winter

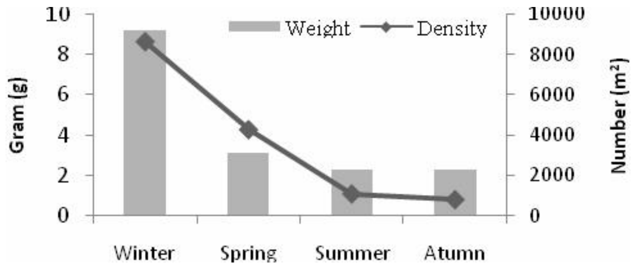

Figure 7. Weight and density of benthic macroinvertebrates of Hormozgan province waters

Table 3. BIO-ENV analysis for various sets of Spearman's correlations between environmental variables and abundances of taxa.

Environmental factors	Size	Correlation
Oxy	1	0.4857
Oxy Col	2	**0.7143**
Sal Oxy Col	3	0.5429
Sal Oxy pH Col	4	0.4286
Temp Sal Oxy pH Col	5	0.0857

Note: * Sal: Salinity, Col: Chlorophyll a, Oxy: Oxygen, Temp: Temperature

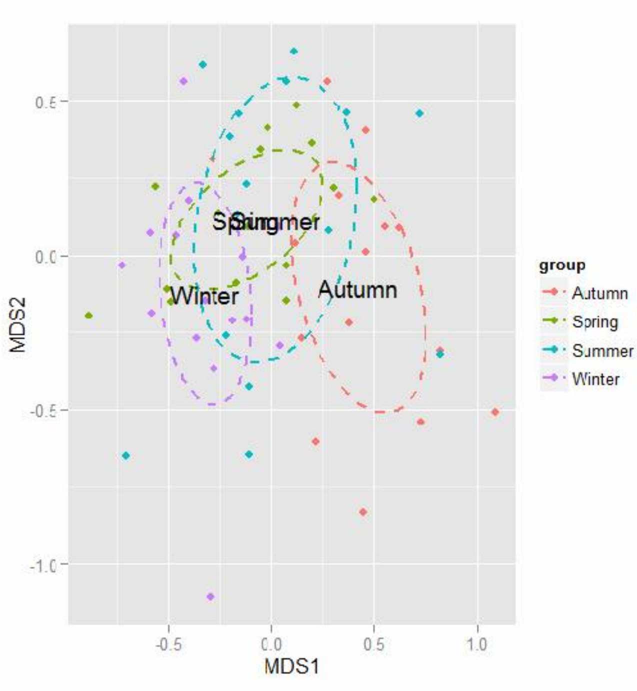

Figure 8. Two-dimensional nMDS ordination plots of the benthic community during different seasons in Persian Gulf. (stress = 0.3)

According to BIO-ENV analysis, oxygen and chlorophyll a, were the best variables (r = 0.7143) for explaining changes in the abundance over time of the benthic fauna under study (Table 4). However, Amphipoda, Secernentea, Cumacea, Euphausiacea, Gastropda, Isopoda, Anthozoa and Sagittoidea did not show any convergence with environmental factors in this study. Moreover; Blastoidea, Foraminifera, Sipunculidea and Decapoda showed convergence with oxygen and temperature, and Bivalvia, Enopla, Oligochaeta, Ophiurida, Ostracoda, Turbellaria, Polychaeta, Tanaeidace and Mysida showed convergence with pH, chlorophyll a and salinity in CCA analysis (Figure 9).

Table 4. SIMPER analysis of dissimilarity among seasons based on taxa abundance

Taxa	% contribution					
	Winter vs. Autumn	**Winter vs. Summer**	**Winter vs. Spring**	**Autumn vs. Summer**	**Autumn vs. Spring**	**Summer vs. Spring**
Amphipoda	6.48	6.01	4.97	7.47	6.92	5.93
Anthozoa	-	-	-	-	-	-
Bivalvia	5.57	4.62	3.96	4.35	4.27	3.90
Sagittoidea	-	-	-	-	-	-
Cumacea	5.13	4.14	3.93		4.51	4.20
Decapoda	2.49	3.21	2.24	5.23	2.24	3.40
Euphausiacea	-	-	-	-	-	-
Foraminifera	20.96	21.30	24.36	**25.05**	**25.57**	**26.55**
Gastropoda	**24.10**	**24.24**	**26.13**	15.35	22.60	22.73
Isopoda	-	-	-	-	-	-
Secernentea	4.65	4.19	4.06	-	-	-
Enopla	3.12		2.72	4.78	3.46	2.95
Oligochaeta	-	-	-	-	-	-
Ophiurida	4.44	6.11	5.86	8.07	5.89	7.59
Ostracoda	-	-	-	-	-	-
Turbellaria	-	-	-	-	-	-
Polychaeta	12.38	12.62	9.17	14.07	10.72	10.31
Sipunculidea	-	-	-	-	-	-
Tanaeidace	2.27	3.93	3.93	5.98	4.05	5.34
Mysida	-	-	-	-	-	-
Blastoidea	-	-	-	-	-	-
Average	61.63	59.03	49.22	57.78	57.34	54.49

Note: Bold numbers shows maximum contribution in columns

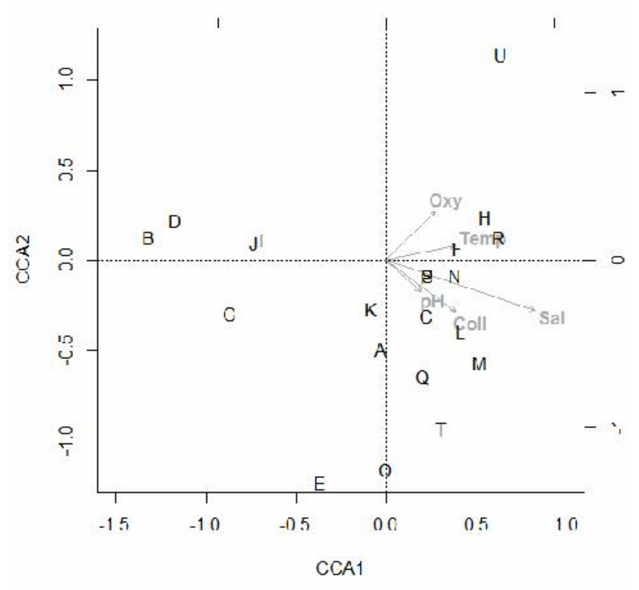

Figure 9. CCA plot of environmental variables and macroinvertebrates (A = Amphipoda, B = Anthozoa, C = Bivalvia, D = Sagittoidea, E = Cumacea, F = Decapoda, G = Euphausiacea, H = Foraminifera, I = Gastropda, J = Isopoda, K = Secernentea, L = Enopla, M = Oligochaeta, N = Ophiurida, O = Ostracoda, P = Turbellaria, Q = Polychaeta, R = Sipunculidea, S = Tanaeidace, T = Mysida, U = Blastoidea, Sal: Salinity, Coll: Chlorophyll a, Oxy: Oxygen, Temp: Temperature)

Discussion

Persian Gulf is an important place in terms of fisheries. Commercial fisheries (especially shrimp fisheries) are preformed every year in fishing seasons (Gerami et al. 2013). Macrobenthos as secondary producers, play an important role in feeding of the fish and shrimp in aquatic ecosystems (Dolbeth et al. 2003). However, due to limited studies on macrobenthic communities of the Persian Gulf, data for comparison of seasonal changes and diversity pattern is scarce.

In the present study, measured physico-chemical parameters were significantly different among seasons. However, summer and spring overlapped in Canonical discriminant analysis (Figure 2). Actually, two climatological regimes have been described for Persian Gulf area: short cold spring and long warm summer (Alijani 1998; Akbari and Masoudian 2009). However, results indicated three seasons in this study (spring-summer, autumn, and winter). This combination of seasons was also observed in nMDS analysis (Figure 8). This analysis showed that macroinvertebrates had similar abundance and pattern in spring and summer while dissimilarities in winter and autumn was higher than in other seasons.

In this study, Polychaeta was the most abundant taxa in all seasons which is not surprising giving the fact that this group is dominant taxa in all brackish aquatic ecosystems such as estuaries or lagoons. Results indicate that the most dominant taxa in terms of abundance were Polychaeta, Foraminifera and Gastropoda, respectively. Other taxa exhibited high abundance fluctuations during seasons and had not high contribution in dissimilarities between seasons (Table 3). Cusson and Bourget (2003) used published data of 15 major marine ecology journals (from 1970 to 1999) and declared that the major taxonomic groups in global patterns of macroinvertebrate inhabiting marine ecosystems were bivalves (36%), polychaetes (20%), amphipods (15%), gastropods (7%) and echinoderms (5%). Foraminifera were not included among dominant taxa in this perspective; although in this study they were abundant in all seasons. There is an apparent conflict in consideration of Foraminifera as a meio- or macro-benthos from the past to the present (Mare 1942; Zobrist and Coull 1992; Gooday et al. 1995; Bett 2014). Bridges et al. (1994) stated that Polychaeta are the most opportunist species with more flexible response to environmental condition than other macroinvertebrates. Chapman and Brinkhurst (1981) declared that Polychaeta comprised over 25% of the total taxa collected and over 60% of the individuals collected in the Fraser River estuary. Furthermore, Salen-Picard and Arlhac (2002) stated that Polychaeta numerically dominated the Calcasieu Estuary macrobenthic communities, and were the dominant species of surface-deposit feeders throughout the estuary. In addition, Ansari et al. (1986), Mohammed (1995) and Kumar (2001) reported Polychaeta, Gastropoda, and Crustacea as dominant taxa in their studies.

The values of H' at different seasons varied from 1.512 to 1.762. According to Table 1 and analyzing the diversity, evenness and dominance indices, macroinvertebrates community had poor health status in all seasons. Many researchers reported that Persian Gulf experienced high risk of various types of environmental degradation and harsh conditions for marine communities due to anthropogenic pressure. Sale et al. (2011) reported that artisanal fisheries, hydrocarbon pollution, wastewater and desalination have substantial negative impacts on marine ecosystems in Persian Gulf and Carpenter et al. (1997) found that Crustacea, Mollusca, and Echinodermata are depauperate in Persian Gulf in comparison with Gulf of Oman.

Temporal variation in benthic community is mostly driven by changes in temperature, which affects salinity, dissolved oxygen and pH of sea water (Amini-Yekta et al. 2013). Grey (1981) stated that seasonal changes of physical and chemical environmental variables are the most probable reason causing temporal patterns of benthic assemblages. According to diversity indices, in comparison with other seasons, winter had better ecological condition in taxa diversity. However, according to dominance and evenness indices, ecological condition was in poor status in winter. Therefore, it could be suggested that species diversity was higher in winter, but opportunist species dominated in the community of macroinvertebrates. Table 2 shows higher amounts of oxygen, lower temperature and high amounts of chlorophyll ain winter. Better physic-chemical conditions of water for macroinvertebrates in winter were reported by others in Persian Gulf (Tabatabaie et al. 2009; Yekta et al. 2013; Allesi et al. 1999; Johns et al. 2003; Nabavi et al. 2011). In addition, Discriminant analysis distinguished winter macrobenthic assemblage from other seasons and showed no significant differences between spring and autumn assemblages (Figure 2, Table 2). Values of diversity indices decreased in spring but the evenness indices improved from winter. It was suggested that due to continuing suitable condition from winter to spring, non-opportunist species reproducedgradually and increased the evenness of community. Values of diversity and evenness indices decreased in summer, while dominant index was in appropriate condition. Table 2 indicates that shortage of chlorophyll a and oxygen, together with high values of pH caused harsh living conditions for macroinvertebrates in summer. In autumn, by changes in physicochemical properties of water; diversity and evenness indices improved in macroinvertebrates community.

Figure 7 shows seasonal changes in biomass (weight and density) of macroinvertebrates in Homrozgan province waters. Results revealed that maximum biomass of macroinvertebrates in this region occur in winter, while minimum was found in summer. It is thus hypothesized that winter have better condition for macroinvertebrates growth in Hormozgan province waters or their species spawning and recruitment may occur in late autumn or early winter. Gaughan and Potter (1995) declared that high values of species richness and density of zooplankton in Wilson Inlet was found in summer because of recruitment and spawning season. This finding was also confirmed for polychaete *Ceratonereis aequisetis* in Broke Inlet in south-eastern Australian estuaries (Glasby 1986). However, high seasonal differences in taxa richness, density and diversity that were detected in this study must partly reflect the fact that some of the taxa spawn seasonally and cannot tolerate a harsh conditions or seasonal changes in environmental factors such as temperature, salinity, oxygen or chlorophyll a. In addition, changes between weight and density of macroinvertebrates are due to differences in sizes.Such as, high values of density with decrease in weight represent small sizes of macroinvertebrates.

BIO-ENV analysis revealed that macroinvertebrates community had best correlation with oxygen and chlorophyll a (Table 4). Therefore, seasonal variation between sites could be explained by these factors. It is well known that oxygen availability is a major factor influencing the composition of macrobenthic communities. Furthermore, dissolved oxygen levels depend primarily on the relative magnitudes of photosynthetic oxygen production and total plankton respiration (Steel 1980). Plankton is the main source of chlorophyll a in marine ecosystems; therefore, oxygen-plankton relationship could be described as oxygen-chlorophyll relationship. However, Kunlasak et al. (2013) studied the relationships of dissolved oxygen with chlorophyll a and concluded that the relationships between chlorophyll a, and dissolved oxygen is complex, being affected by season, nutrient inputs and elevation. In addition, Kuhnt et al. (2013) suggested that the pore density of some benthic foraminiferal species is controlled by bottom-water oxygen content. However, they declared that this relation is species-specific. In this respect, CCA analysis revealed that there was not specific relationship between all the taxa and environmental factors in this study (Figure 9). Amphipoda, Secernentea, Cumacea, Isopoda, Anthozoa and Sagittoidea did not show any relationship with environmental factors. This phenomenon was more important for Gastropoda as this taxon had high contribution in between-season dissimilarity (Table 3). Euphausiacea showed negative correlation with oxygen and temperature and Gastropoda showed strong negative relation to salinity and little weaker, but still quite strong, negative respond to pH values and amount of chlorophyll a.

In conclusion, this study showed that macroinvertebrates in Persian Gulf have strong temporal variation among seasons. This variation was affected by changes in physico-chemical properties of water especially oxygen and chlorophyll a. In addition, diversity and evenness indices revealed that macroinvertebrates ecological conditions is poor in this region and needs to be improved. These finding could be useful in furthers studies for habitat management and monitoring programs.

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