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Gorgan Bay: a microcosm for study on macrobenthos species-environment relationships in the southeastern Caspian Sea

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Abstract

The relationship between spatial patterns of macrobenthos community characteristics and environmental conditions (salinity, temperature, dissolved oxygen, organic matter content, sand, silt and clay) was investigated throughout the Gorgan Bay in June 2010. Principal components analysis (PCA) based on environmental data separated eastern and western stations. The maximum (4 500 ind./m^2) and minimum (411 ind./m^2) densities were observed at Stas 1 and 6, respectively. Polychaeta was the major group and *Streblospio gynobranchiata* was dominant species in the bay. According to Distance Based Linear Models results, macrofaunal total density was correlated with silt percentage and salinity and these two factors explaining 64% of the variability while macrofaunal community structure just correlated with salinity (22% total variation). In general, western part of the bay showed the highest number of species and biodiversity while, the highest density was found at Sta. 1 and in the middle part of the bay. Furthermore, relationship between diversity indices and macrobenthic species with measured factors is also discussed. Our results confirm the effect of salinity as an important factor on distribution of macrobenthic fauna in south Caspian brackish waters.

Key words: salinity, macrobenthos, species-environment relationship, Gorgan Bay, Caspian Sea

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1 Introduction

The macrofauna play important roles in marine ecosystems, involving nutrient cycling, dispersion, sediment burial, and secondary production. Distribution patterns in general are related to environmental factors such as tidal currents, depth, food supply, salinity, sediment texture, organic matter content and current velocity (Gogina et al., 2010; Baldanzi et al., 2013; Nicastro and Bishop, 2013). Hence, any changes in environmental conditions can be reflected in macrofauna community characteristics. Response of macrobenthic species to these conditions is different and related to their adaptation strategies (Veloso and Cardoso, 2001; Baldanzi et al., 2013; Conde et al., 2013). In fact, most of the species can not migrate out of the habitat, and adapt to the changes of environmental conditions (Dauer, 1993). Therefore, there is a growing need to understand species-environment relationships due to increasing pressure on the marine environment (Snickars et al., 2013).

The Caspian Sea is the largest continental body of water in the world. Because of long-term geographical isolation and independent evolution, most of Caspian fauna are endemic (Dumont, 2000) though they are derived from: (1) Caspian origin, (2) Arctic origin, (3) Atlantic and the Mediterranean origin, and (4) freshwater origin (Zenkevitch, 1963). Different salinities, temperature and depth regimes create different ecosystems so that animals based on their osmoregulation capacities can live in different area of the sea.

Gorgan Bay is a unique ecosystem in the south-eastern part of the Caspian Sea. It is separated by Miankaleh peninsula from the sea. Sediment texture is different from west to east (Lahijani et al., 2002; Lahijani et al., 2010). Salinity regime is different throughout the bay and it is influenced by internal current (Sharbaty, 2012) and some small rivers from east and west which created some freshwater marshes especially at the western part (Taheri et al., 2012). Therefore, different types of habitats are found in the bay (e.g., salt marsh, mud flat, sand flat, fresh and brackish water area) and each type is inhabited by different species (community structure). These variable conditions made it the most important natural ecosystem in the south part of the Caspian Sea that serves as a nursery area for a lot of juvenile fishes and very good place for breeding and wintering of the water birds.

Although a few studies have described macrobenthic fauna in the Gorgan Bay (Taheri et al., 2007; Bandany et al., 2008; Taheri et al., 2012) and South Caspian Sea (Roohi et al., 2010; Taheri and Yazdani, 2011; Ghasemi, 2014; Ghasemi et al., 2013, 2014), data about the species-environment relationships are almost absent. In this study, we attempt to find relationships between macrobenthic assemblages and each species separately with environmental factors. The results will provide important background for future ecosystem and resource management in the south Caspian Sea.

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2 Materials and methods

Gorgan Bay is located in an east-west direction in the Golestan Province, southeast coast of the Caspian Sea, Iran. Its area is around 400 km^2 with the maximum length of 70 km. Most part of the bay has low depth (less than 2 m), the maximum depth is 5 m and it decreases from east to west.

Sampling was carried out at fifteen stations throughout the Bay in June 2010 (Fig. 1). At each station for the biological study, three replicate samples were collected using Van Veen grab. In the field, the contents of each grab were stored in the separate plastic containers. In the laboratory, sediment of each container is gently sieved by 0.5 mm mesh and the retained material is fixed in 4% buffered formalin and stained with Rose Bengal (Taheri and Yazdani, 2011). Then, macrofauna were separated, identified and counted under stereomicroscope. The World Register of Marine Species (WORMS, 2011) was used to harmonize species names.

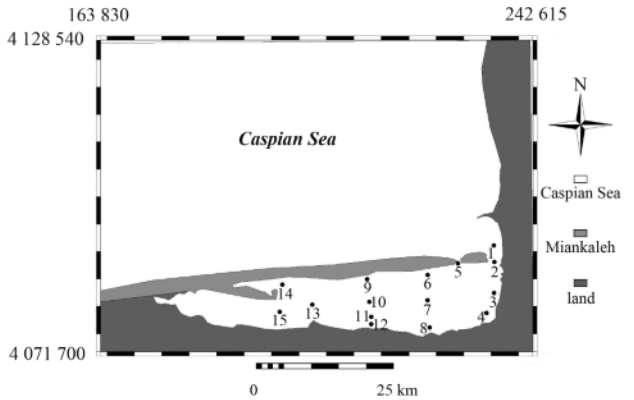

Fig. 1. Location of the sampling stations on the Gorgan Bay—south east of the Caspian Sea.

Another three replicate sediment samples were taken at each station to measure the percentage of the total organic matter (TOM) and the sediment grain size by Van Veen grab. The surface sediments (4 cm) were sub-sampled and stored in cleaned plastic containers. Total organic matter was determined by loss weight on ignition (4 h at 550°C) after drying (24 h at 90°C) to constant weight. Grain size analysis was performed using a Particle Size Analyzer in the Iranian National Institute for Oceanography and the sediment fractions (sand, silt and clay) were reported as percentages and defined according to the Wentworth scale. Physicochemical data (depth, temperature, salinity and dissolved oxygen) were measured using a CTD at each station and the data of near 30 cm depth above the sediment surface were used for the analysis.

Principal components analysis (PCA) was used in order to find different groups of sampling stations based on the environmental variables. All environmental data were log transformed and normalized prior to this analysis. The scores of the stations on the first two axes were correlated with environmental parameters using the Spearman Rank correlation (Clarke and Warwick, 1994).

Prior to the analysis of the variation in the abundance of total macrofauna and each species, data were tested for the normality (using Shapiro-Wilk) and the homogeneity of variance (using Levene's test). Whenever data were normal and homogenous, one-way analysis of variance (ANOVA) was used to test the differences among stations. Tukey's test ($P < 0.05$) was used to assess the significant differences among the stations (in SPSS Version 14). When assumptions for parametric analyses were not fulfilled, to test differences in each species densities (univariate, Euclidean distance) and macrofauna community composition (multivariate, Bray-Curtis), one-way permutational ANOVA (Permanova) were applied to test differences among stations. Whenever significant differences were observed, pairwise tests of stations were performed to investigate differentiations among stations. Due to the restricted number of possible permutations in pairwise tests, *p*-values were obtained from Monte Carlo test. A non-metrical Multi-dimensional scaling plot (MDS) based on $\log(X+1)$ transformed data and Bray-Curtis similarity visualized the community composition (Anderson and Robinson, 2003). All the mentioned analyses were performed in PRIMER v6 with PERMANOVA+ add-on (Anderson et al., 2008).

In order to understand how environmental factors affect the macrofauna characteristics, Distance Based Linear Models (DistLM) was used to investigate the role of measured factors in explaining the variation in total density, diversity indices (Euclidian distance) and the community composition (Bray-Curtis, $\log(X+1)$) of macrofauna. We also tested significant relationships between single species and each environmental variable. Euclidian distance was used as the basis for the analysis. The test was performed after removing highly correlated independent variables (Draftsmans plot, $\geqslant 0.90$). Prior to analyses, values of salinity, oxygen and sand were square root transformed to remove right-skewness in the raw data. Predictor variables were then subjected to a sequential step-wise selection procedure using the Akaike's information selection criterion (AIC) and 9 999 permutations in PRIMER v6 with PERMANOVA+ add-on (Anderson et al., 2008; Ingels et al., 2011; Van Colen et al., 2012).

3 Results

3.1 *Environmental parameters*

Environmental conditions are given in Table 1. Depth decreased westward and its range was from 0.62 m at Sta. 11 to 4.12 m at Sta. 7. The total organic matter values were varied between 3.60% at Sta. 14 and 15.68% at Sta. 5. The range of water temperature was between 23.9°C at Sta. 1 to 27.48°C at Sta. 7. The highest and lowest salinity were obtained at Stas 13 and 15, respectively. Except at southern stations (Stas 8, 12 and 15) dissolved oxygen value did not show clearly variation and it was from 5.16 mg/L at Sta. 7 to 8.26 mg/L at Sta. 8. Sediment texture was different in the bay. According to the grain size composition, Sta. 14 had the coarsest sediment while Sta. 7 had the finest sediment.

The result of the PCA is shown in Fig. 2. PCA1 and PCA2 accounted for 41.22% and 28.83% of the total variance, respectively. First axis (PCA1) was related to percentage of sand (coefficient=–0.790), silt (coefficient=0.866) and clay (0.921). PCA2 summarized variance due to salinity (–0.928) and percentage of oxygen (0.838). In summary, western stations with lowest depth and salinity separated from eastern deeper stations with higher salinity.

3.2 *Density and community structure*

A total of 3 356 individuals belonging to eight families and ten species were identified. Polychaeta with two species (*Hediste diversicolor*, *Streblospio gynobranchiata*) was the numerically dominant group and *S. gynobranchiata* was the dominant species with 60.28% of the total density. Two oligochaete worms,

Table 1. Environmental parameters measured in sampling stations

Station	Depth/m	TOM/%	Temperature/°C	Salinity	Oxygen/mg·L^{-1}	Sand/%	Silt/%	Clay/%
1	3.65	5.79	23.95	11.96	5.55	20.42	42.02	37.56
2	3.07	4.52	24.74	11.01	5.44	11.85	52.80	35.35
3	2.24	7.53	25.41	10.80	5.38	0.79	65.46	33.75
4	1.46	6.60	25.91	10.88	5.34	0.66	66.66	32.68
5	1.50	15.68	26.55	11.31	5.26	18.22	31.16	50.62
6	2.87	8.03	26.74	11.38	5.24	8.48	45.06	46.46
7	4.12	8.37	27.48	11.67	5.16	0.44	40.52	59.04
8	2.35	5.29	27.27	7.63	8.26	34.42	24.07	41.51
9	1.54	8.78	25.22	11.35	5.38	26.90	28.36	44.74
10	1.05	12.25	26.20	11.33	5.30	4.88	39.46	55.66
11	0.62	10.32	26.47	5.18	5.25	58.71	13.54	27.75
12	0.76	9.91	27.38	5.37	7.54	17.39	45.85	36.76
13	0.77	8.57	25.54	12.40	5.32	65.10	11.28	23.62
14	0.65	3.60	26.91	11.67	5.22	89.62	3.88	6.50
15	1.53	14.76	25.38	4.95	8.02	1.37	37.58	61.05

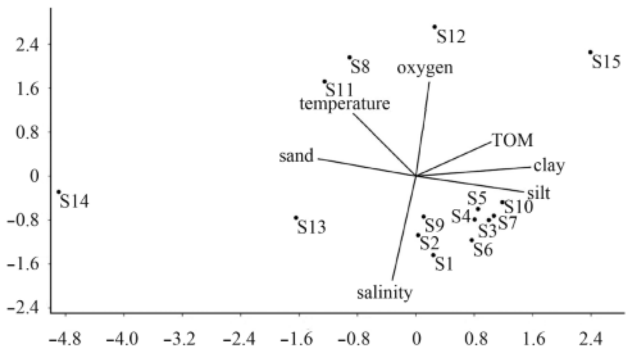

Fig. 2. Principal component analysis: spatial presentation of stations based on environmental data. S represents station.

Tubificoides fraseri and *Potamothrix moldaviensis* were the second dominant species. Bivalvia, with four species (*Abra segmentum*, *Cerastoderma glaucum*, *Mytilaster lineatus* and *Didacna* sp.), had the highest species number but low density. Also, one species of Amphipoda (*Gammarus aequicauda*) and Diptera (*Chironomus albidus*) were observed (Fig. 3).

Total macrofauna density varied spatially (F=5.879, df=14, P=0.000). The maximum density (4 500 ind./m^2) was observed at Sta. 1 while the minimum (411 ind./m^2) was at Sta. 6. The macrobenthic community composition based on density of identified species, showed a significant differences among stations (Pseudo–F=8.394, df=14, P=0.000). nMDS ordination by station also reflected these differences so that stations with highest number of species separated (Stas 11, 12, 13, 14 and 15) from stations with medium (Stas 1, 5, 8, 9 and 10) and lowest number of species (Fig. 4). Stress value of 0.07 was obtained.

Mean values of diversity indices in sampling stations are presented in Fig. 5. Except evenness, there were significant differences in diversity and richness indices among stations (F_{Shannon}=4.883, F_{Margalef}=3.006, df=14, P<0.05). The highest diversity index (1.46) was observed at Sta. 12 while the lowest (0.24) was at Sta. 2. Furthermore, the maximum and minimum on the richness index were observed at Stas 13 and 7, respectively. The highest mean number of species (6.33 species) was observed at Sta. 12 and the lowest (2 species) at Stas 6 and 7. In general, the

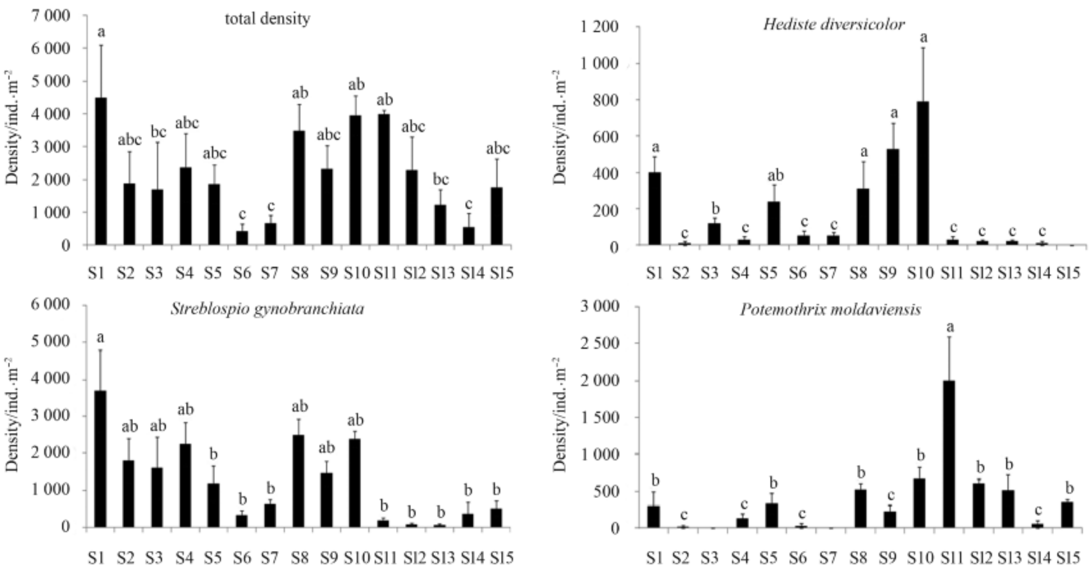

Fig. 3.

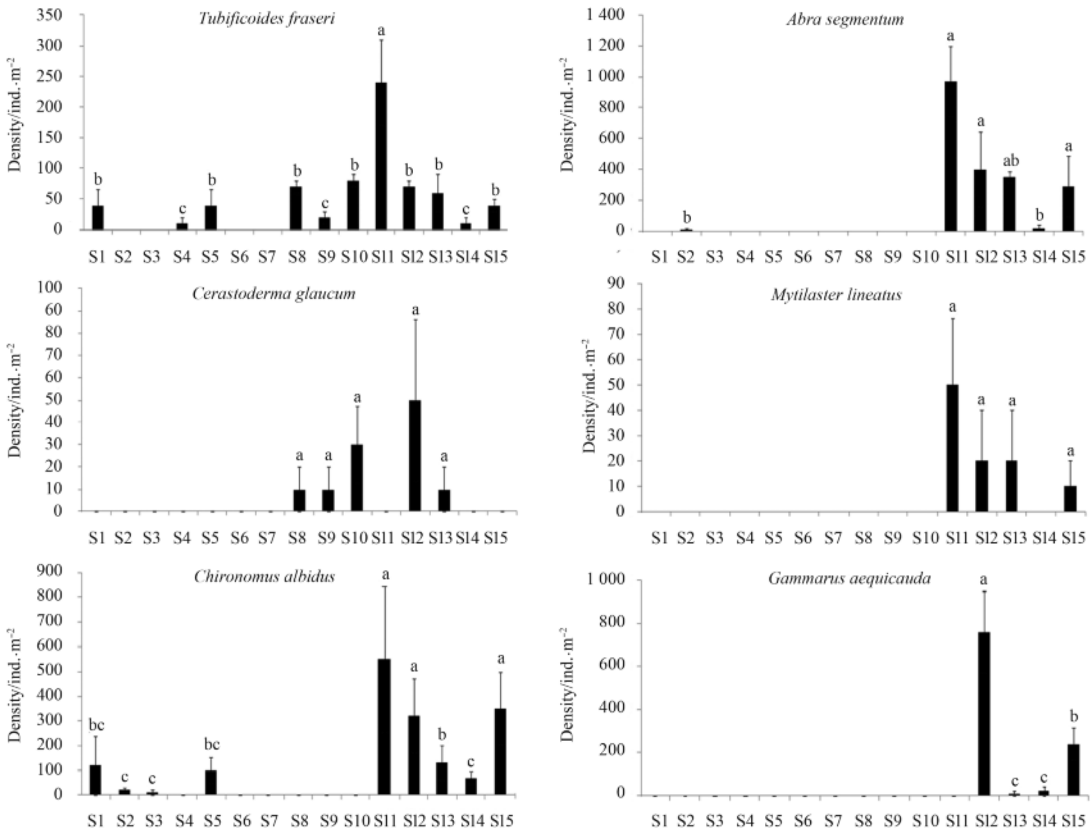

Fig. 3. Mean values of densities (ind./m^2) of the macrofauna species (case letters show spatial significant variations among stations).

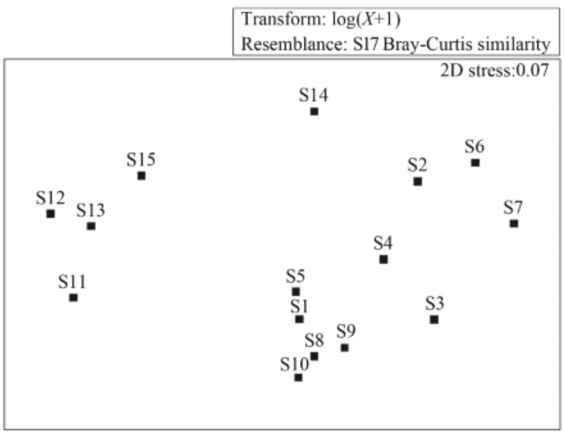

Fig. 4. Non-metric multidimensional plot of macrofauna communities (based on Bray-Curtis similarity and log (X+1) transformed data on macrofauna species density data).

values of the mentioned indices decreased from the west to the east.

Mean values of densities of the macrofauna species with significant differences are given in Fig. 3. *H. diversicolor*, was found at all stations except Sta. 15 (Pseudo-F= 12.467, df=14, P=0.001). The highest density was observed at middle part while the lowest at western stations. Density of *S. gynobranchiata* significantly varied in the bay (Pseudo-F=7.671, df=14, P=0.001) and the highest density was at Sta. 1 and the lowest at western stations. Density of *T. fraseri* varied at different stations (Pseudo–F=8.310, df=14, P=0.001). Maximum density was observed at Sta. 11 and minimum at eastern part. Changes in density of *P. moldaviensis* was similar to *T. fraseri* (Pseudo-F=9.979, df=14, P=0.001). *A. segmentum* was found at six stations with the highest densities at Stas 11, 12 and 15 (Pseudo–F=9.289, df=14, P=0.001). Distribution of *C. glaucum* and *M. lineatus* was limited at western part and there were no significant differences between stations (p>0.05). Density of *C. albidus* were significantly higher at Sta. 11, 12 and 15 (Pseudo–F=6.616, df=14, P=0.001). Finally, *G. aequicauda* was only found in western parts where sediment surface was fully covered with *Potamogeton* sp., with the highest and lowest density at Stas 12 and 13, respectively (Pseudo-F=44.492, df=14, P=0.001).

3.3 *Species–environment relationships*

The results of the DistLM showed different macrofauna responses to environmental factors (Table 2). Macrofaunal total density was correlated with silt percentage and salinity. These two factors comprised 64% of the variability. Macrofaunal community structure just correlated with salinity (22% total variation). Salinity, sand, TOM and clay explained 77% of total variation of Shannon diversity. Evenness index was not affected by environmental factors but Margalef index was affected by silt and salinity (64%). Distribution of *H. diversicolor* was not affected by any measured factors while *S. gynobranchiata* was just affected by temperature (27%). The factors dominating in the explanation of variability of *T. fraseri* were salinity and sand percentage (41%). Distributions of *P. moldaviensis* (73%), *A. segmentum* (87%) and *M. lineatus* (83%) were explained by salinity, oxygen and sand, respectively. Distribution of *C. glaucum* was not

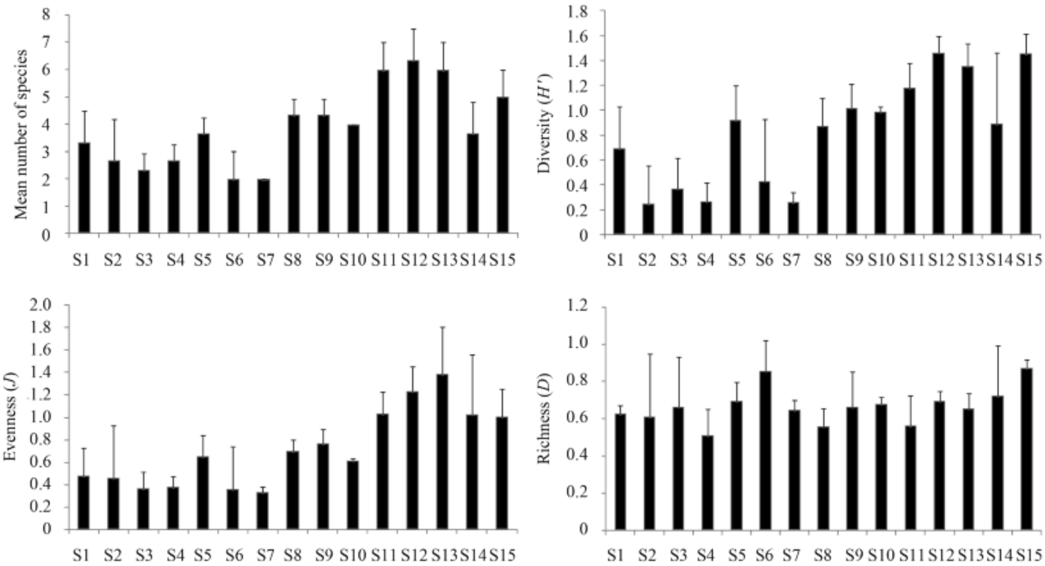

Fig. 5. Mean values of diversity indices (species number (*S*), diversity (*H'*), richness (*D*) and evenness (*J*)) in sampling stations.

Table 2. Relationship proportions of the environmental variables with diversity indices and species densities

	Variables	AIC	Ss (trace)	Pseudo-*F*	*P* value	Proportion/%
Total density	silt	–37.22	0.69	9.32	0.007	41.7
	salinity	–42.49	0.37	7.49	0.019	22.3
Community structure	salinity	113.74	6 342.70	3.65	0.019	21.9
Shannon	salinity	–28.42	0.92	6.95	0.021	34.8
	sand	–32.16	0.55	5.58	0.037	20.6
	TOM	–39.40	0.54	9.37	0.009	20.4
	clay	–49.69	0.23	8.15	0.016	0.09
Margalef	silt	–37.22	0.69	9.32	0.006	41.7
	salinity	–42.49	0.37	7.49	0.017	22.3
S. gynobranchiata	temperature	107.65	5 733.10	4.96	0.046	27.6
T. fraseri	salinity	17.33	21.26	7.57	0.017	36.8
	sand	9.21	8.10	5.48	0.039	14.0
P. moldaviensis	salinity	80.53	1 471.4	7.76	0.016	37.3
	oxygen	75.51	920.24	7.15	0.046	23.3
	sand	71.65	499.83	5.26	0.037	12.7
A. segmentum	salinity	58.46	577.6	13.27	0.007	50.5
	oxygen	47.85	321.7	15.81	0.006	28.1
	sand	42.44	95.16	7.02	0.012	0.08
M. lineatus	salinity	–28.30	1.29	9.67	0.011	42.6
	oxygen	–37.61	0.92	13.50	0.010	30.3
	sand	–43.04	0.32	7.05	0.016	10.5
C. albidus	salinity	36.99	286.21	27.49	0.002	67.8
	oxygen	27.81	71.09	13.28	0.010	16.8
G. aequicauda	salinity	52.74	241.02	8.10	0.024	38.3

Notes: Ss represents some of square.

affected by any measured factors. Salinity and oxygen explained 85% variability of distribution of *C. albidus*. Finally, distribution of *G. aequicauda* was affected by salinity (38%).

4 Discussion

Based on our results, sampling stations were divided in two different parts: western stations with lowest depth and salinity separated from eastern deeper stations with higher salinity. In general, macrofauna diversity decreased from the west to the east. Further results showed that salinity and sediment texture were the most influencing factors on macrofauna community characteristics while macrobenthos species was mostly affected by salinity and dissolved oxygen.

Long-term isolation from the oceans and other seas made a unique brackish-water fauna in the Caspian Sea which was mostly affected by freshwater species. In this ecosystem many of the marine taxa are either absent or represented by only a small number of species (Karpinsky, 2005). Different salinity regime and ion composition (Yazdani et al., 2007, 2010) forced brackish and euryhaline marine species to inhabit in southern parts where salinity is 12–13. Besides, some taxa with freshwater origin (i.e., oligochaetes, leeches, chironomids and gastropods) have also adapted to live in this new condition, though they have small share in the total species number and biomass (Karpinsky, 2005). In southern Caspian Sea salinity also determines distribution and colonization potential of benthic, nektonic and pelagic organisms (Kasymov, 1994; Paavola et al., 2005; Yazdani et al., 2007, 2010; Ghasemi, 2014; Ghasemi et al., 2013, 2014). All species have to live in osmotic stress environments, thus, they have to expend additional energy to maintain the haemolymph osmolarity according to environment, which may compromise other physiological needs, such as growth and reproduction. In the past decades when the Volga-Don Canal connected Caspian Sea to Azov Sea (in 1952), some none indigenous benthic species might arrive to this sea but could not settle and develop populations because of different salinity regimes in it even though there were many empty ecological niches in this sea (Karpinsky, 2010). Therefore, these conditions are just favorable for brackish water species (Mordukhai-Boltovskoi, 1979; Karpinsky, 2005). In the present study, the influence of the freshwater from the western part induced a gradient in the environmental conditions in the bay and it could be a cause for spatial patterns of species distribution. Freshwater input led to regular decrease in salinity so that the lowest salinity and highest variability in salinity were observed in the shallow areas of western part of the bay. The salinity resulted in the variability of most species, total density and community structure (Table 2). Effect of salinity on distribution of *G. aequicauda* (Delgado et al., 2011), *M. lineatus* (Malinovskaya and Zinchenko, 2010), *A. segmentum* (Fabbrocini et al., 2008), *C. albidus* (Cartier et al., 2011) and oligochaete worms (Seys et al., 1999) were described in other ecosystems.

Total organic matter as a food item just affected Shannon diversity while previous studies showed that this factor were correlated with density and distribution of south Caspian Sea macrofauna (Taheri et al., 2007; Taheri and Yazdani, 2011). Temperature is one of the most important environmental factors on marine animal's life (Kevrekidis, 2004). The distribution of *S. gynobranchiata* was affected by water temperature in the present study. Apparently temperature has direct effect on reproduction cycle of this species in the southern Caspian Sea (Taheri et al., 2009). Sardá and Martin (1993) showed a significant positive relationship between density of *Streblospio* with annual average temperature while no significant correlation between density of *Streblospio benedicti* with temperature and sediment characteristics (García-Arberasand Rallo, 2004).

Dissolved oxygen, plays a significant physical as well as biochemical role in the life of Caspian Sea aquatic organisms (Kasymov, 1994). Variation in dissolved oxygen was another factor affecting distribution of *P. moldaviensis*, *A. segmentum*, *M. lineatus* and *C. albidus*, which is consistent with the results of Timm (2013), Correia et al. (2012), Karpinsky (2010) and Rajabipour et al. (2011). These species generally were found in the western part with low depth and freshwater inputs which can increase dissolved oxygen. On the other hand, existence of fresh water plants (mainly *Potamogeton* sp.) at Stas 11, 12 and 15 can be another reason for increasing oxygen variations.

Hydrodynamic regime in the bay affected the sediment texture (Lahijani et al., 2010; Sharbaty, 2012). Sediment as a habitat was another important factor on distribution of macrofauna (Van Hoey et al., 2004; Taheri and Yazdani, 2011). In general, the TOM content will increase with the decrease of sediment grain size (Taheri and Yazdani, 2011). Therefore, macrofauna species require specific sediment characteristics for tube building, burrowing and feeding (Pinedo et al., 2000) as we observed for *T. fraseri*, *P. moldaviensis*, *A. segmentum* and *M. lineatus*, which is consistent with the results from Timm (2013), Guseinov (2005) and Milbrink and Timm (2001).

Among macrofauna species *H. diversicolor* and *C. glaucum* did not show any significant relationship with measured environmental factors which suggest that other factors may control their distribution.

In conclusion, our results showed that salinity, sediment characteristics and dissolved oxygen were the most influencing factors on macrofauna community characteristics and species. Due to influence of these factors, western part of the bay showed the highest number of species and diversity while the highest density was found at Sta. 1 and in the middle part of the bay.

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