

Spatial and temporal patterns of benthic macrofauna in Gorgan Bay, south Caspian Sea, Iran

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Abstract

We quantified the distribution, abundance and assemblage structure of macrofauna at 22 stations in Gorgan bay, seasonally in 2012-2013. Also, depth, temperature, salinity, DO, TOM and sediment particle size were measured in each station. The highest concentration of TOM was measured near the western littoral zone (10.22) while the mouth part and north-eastern area was characterized by the lowest values (2.65 % and 4.69). A total of 31658 individuals belonging to 12 families and 14 species were identified. Polychaeta with 3 species was the most dominant group in terms of abundance. The four most abundant taxa making up 85% of all specimens were *Streblospio gynobranchiata*, Tubificidae, *Hediste diversicolor* and *Abra segmentum*. The maximum density (7,893 ind/m²) was obtained at station 1 while the minimum (1,777 ind/m²) was observed at station 16. The western area was characterized by the highest species diversity (H', 1.94) and the stations 10, 8 and 7 were characterized by the lowest diversity indices (H', 0.72, 0.77 and 0.87, respectively). The PCA showed that water parameters with more temporary variations had a greater significance in explaining the system variability, and a not marked but evident difference between the two parts of Gorgan Bay was observed and supported by nmMDS test. So Gorgan Bay presents transitional macrobenthic assemblages that are spatially distributed along substrate gradients but it seems that the coastal ecosystem of the south Caspian Sea and mouth-eastern part of Gorgan Bay is very dynamic and some species are forming a metapopulation toward western sites.

Keywords: Spatial, Temporal, Benthic macrofauna, Metapopulation, Gorgan Bay

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Introduction

Transitional coastal ecosystems, a term used for a variety of ecosystems such as lagoons, estuaries, semi-enclosed bays and saltmarshes, characterized by heterogeneity within the ecosystem, constitute areas of special ecological and economical interest since they are located to the inter-surface of land and sea (Nixon, 1988). These habitat islands play the role of land/water ecotones among freshwater and marine biotopes, where the abiotic structure is therefore shaped by hydrological processes, natural vegetation and land use in a watershed (Magni *et al.*, 2008). Such transitional heterogeneous ecosystems with strong thresholds of variation, confinement gradients or ergoclines are known to be harsh ecosystems due to their strong gradients of salinity, temperature and dissolved oxygen in space and time (Koutsoubas *et al.*, 2007). At small spatial scales (on an ecosystem level), transitional unstable ecosystems tend to be characterized by relatively low diversity but at large spatial scales such as at the Eco-regional level, they have several physiographic attributes which increase their habitat heterogeneity to provide refuge for unique and diverse fauna. Despite the high biological productivity of coastal wetlands, they are among the least understood wetland ecosystems and represent an ideal study environment for evaluation of the significance of various potential drivers of community and guild structure in the world (Blanchet *et al.*, 2008). However in these systems, water-quality criteria

that are suited for deep lakes and marine ecosystems cannot be used because in shallow transitional wetlands, the water parameters are quantitatively more important than the benthic subsystem. There is therefore a need for a common, integrated set of indicators and monitoring approaches for use in shallow transitional waters that takes the unique properties of these systems into account (Fisher *et al.*, 2001). Macrobenthos constitute important parts of fauna of any water bodies and mainly consist of polychaetes, crustaceans and mollusks. They are mostly without considerable movements and feed mainly on bottom sediments and detritus. Therefore, if they are identified in a region, they are a good indicator of environmental changes and pollution and hence suitable for monitoring purposes of an ecosystem.

In these coastal ecosystems, sediments play an important role in biogeochemical cycles (Pomeroy *et al.*, 1965). Much of allochthonous material is incorporated in the sediments, through assimilation, adsorption and direct sedimentation processes of suspended particulate, so they act as a trap of detritus material and mineral nutrients supply (Lijklema, 1986).

South Caspian Sea water shores are unique brackish water bodies and the enclosed Gorgan shallow wetland Bay with high ecological status is influenced by hydromorphological elements such as depth variation, freshwater flow and wave exposure. The Gorgan Bay (36°48'N, 53°35'E and 36°55'N,

54°03'E, 400 km², 60 km ×12 km, maximum depth of 6.5 m and average depth 1.5 m) is a semi-confined triangular-shaped bay, located at the south-east extremity of the Caspian Sea along the Iranian coastline in the Golestan Province (Fig. 1). Gorgan Bay was formed during the Newcasian /Holocene period by a sandy spit which is named Miankaleh coastal barrier system. The bay basin is bounded on the west, south and north by Mazandaran Province, Golestan Province and Miankaleh Peninsula, respectively. There are no tides in the Gorgan Bay. It is connected to the Caspian Sea through the mouth of Ashoradeh-Bandar Torkaman situated in the northeastern part of the Bay (Approximately; width of 400m, 3km long). There are strong currents in the Ashoradeh-Bandartorkaman mouth affected by storm surge and inter annual water level fluctuations in the Caspian Sea. This bay is more influenced by its processes within the basin. Water balance in the Gorgan Bay is influenced by water intrusion from the Caspian Sea, precipitation, evaporation and to a lesser extent by fresh river water. It receives freshwater inflow from a number of small rivers and streams, among them two rivers affect the bay, Gorgan-rood from the north of the inlet and Qaresoo enters from the east. These two rivers drain runoffs from residential and agricultural areas into the bay.

Generally, there is a counter-clockwise flow pattern in the Gorgan Bay in four seasons. This current

pattern is driven primarily by prominent wind stress and then is affected by bottom topography and domain geometry. In the northern and southern shores, currents are along the coastal areas and move from west to east by effecting dominant winds (Sharbaty, 2011, 2012). The bay is surrounded by urban areas and agricultural lands. It is the marine part of a larger protected area including a peninsula called "Miankaleh Wildlife Refuge" and an international wetland (Ramsar Convention Site). *Roppia maritima* is a seagrass species that dominates the eastern and shallow parts of the lagoon and in some places becomes so intensive that makes boating impossible. The remaining vegetation is very important for the organic load of the bottom sediments.

Several works have been carried out on Caspian Sea benthos such as Kasymov (1989), Tait *et al.* (2004), Parr *et al.* (2007) and Nasrolahi *et al.* (2017). A few researches have also been carried out regarding the Gorgan Bay including Taheri *et al.* (2007), Ghorabi *et al.* (2009), Taheri and Yazdani (2011), Saghali *et al.* (2013) and Eghtesadi *et al.* (2014). But all these studies were not comprehensive regarding the species diversity and community structures with regard to the environmental conditions.

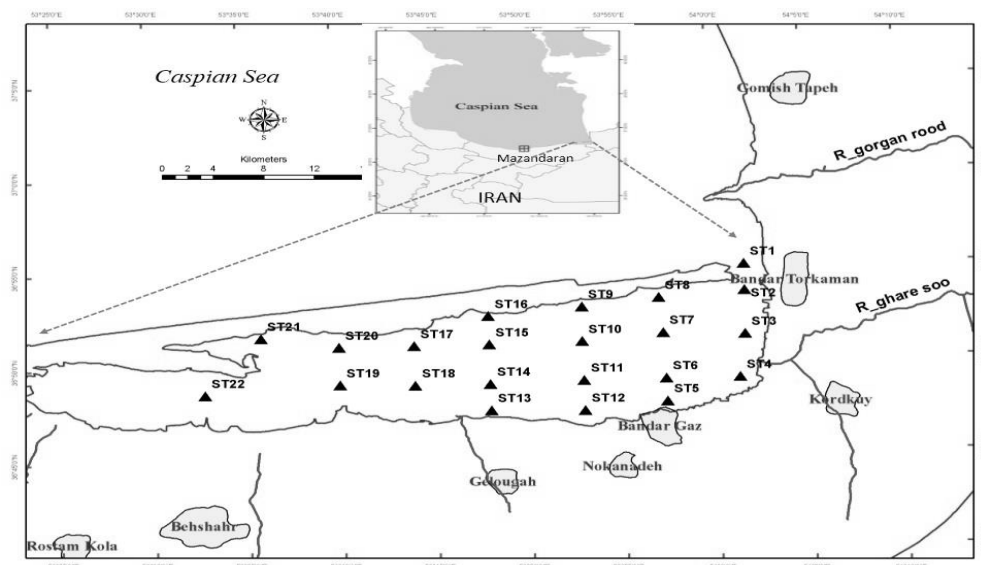


Figure 1: Map of the studied sites at Gorgan Bay, South Caspian Sea, Iran.

The south Caspian Sea, with 13 ppt salinity and the highest depth, is a unique ecosystem and in comparison to other seas, the biodiversity of the Caspian is low (Zenkevitch, 1963; Roohi *et al.*, 2010; Taheri and Yazdani, 2011; Ghasemi, 2011). Probably the main reasons are: i) low salinity, i.e., (maximum 13 ppt), and ii) the long geographical isolation of the Caspian Sea from open seas. Throughout different parts of Iranian shallow waters with different environmental conditions, less than 22 species of benthic macrofauna have been reported (Roohi *et al.* 2010; Ghasemi, 2011; Taheri and Yazdani, 2011).

The aims of this study were: (1) to analyze water and sediment characteristics and macrobenthic assemblages; (2) to evaluate the effects of brackish water of Caspian Sea water and freshwater inputs on distribution patterns of both sediment variables and macrofaunal community.

Materials and methods

Three replicate samples of both physico-chemical factors and benthic sediments were collected in June, September, December 2012 and March 2013 at 22 stations to cover different parts of the bay (Fig. 1). The measured physico-chemical parameters were salinity, dissolved oxygen (DO), pH, temperature and turbidity, which were measured using a Water Quality Checker (Model: TOA DKK and HACH water quality test kit, Model: HQ40d). The depths of the stations were assessed using The Hondex PS-7 Depth Sounder.

The sediment samples were collected with a Van Veen grab (0.025 m²) and screened using a sieve (0.5 mm). The organisms retained in the sieves were preserved in 5% formalin for detailed examination in the laboratory. Prior to sorting out the organisms, the samples were dyed with

Eosin to enhance their visibility. The organisms found were identified to the lowest taxon possible (Birstein, 1938; Birstein and Romanova, 1968; Konstantinov, 1968; Logvinenko and Starobogatov 1968; Stock, 1974; Kasymov and Bagirov, 1977; Mordukhai-Bolotovskoi, 1979; Barnes, 1987;; Milligan, 1995; Stock *et al.*, 1998; Nikula and Vainola, 2003; Bouchet, 2014). The counts of individuals belonging to each taxon in a sample and their density in each station was determined as number of counts per square meter. The classification of fine and coarse sediments followed the scale of Shepard (1954). Grain-size analyses were carried out, after elimination of the organic fraction with H₂O₂, by wet sieving, to separate sand from the fine fractions. For sandy fractions, a sieve size >63 µm was used. The weight of the sand trapped in the sieves was measured, and the percentage with respect to the total weight of sandy sediment fraction was determined. These separate fractions were classified in the soil texture triangle (Folk *et al.*, 1970; Flemming, 2000)

Total organic matter (TOM) was analyzed using electrical furnace method (loss on Ignition, 24 hours at 90°C; 4 hours at 550°C, Abrantes *et al.* (1999).

All data were analyzed using univariate and multivariate methods in order to evaluate: differences among sampling sites and seasons. Before the analysis, the normality and

homoscedasticity assumptions were checked using the Shapiro–Wilk normality test and the Bartlett test. The significant differences in the calculated parameters among different seasons and stations were determined by one way ANOVA and t-test or Kruskal- Wallis and Mann-Whitney test analysis for parametric and non-parametric data, respectively. The statistical analysis of macrobenthic community structure was first performed for calculating the univariate diversity indices: abundance (N), total number of species (S), diversity index of Shannon–Wiener and Pielou’s evenness index. Principal Components Analysis (PCA) was applied to investigate the similarity of water and sediment variables. Similarity among sites was analyzed by ordination techniques (nmMDS) based on Bray–Curtis similarity matrix. Canonical correspondence analysis (CCA) was carried out on complete environmental and biotic data sets to establish which set provided the optimum model to describe the response of species to measured environmental variables. Prior to analyses, species data were $\log_{10}(x+1)$ transformed and the abundance of rarer species was down weighted. These statistical methods were analyzed using SPSS 18 and Primer 5.

Results

The mean values of selected environmental parameters are summarized in Table 1.

Table1: Seasonal (a) and spatial (b) variations (mean± SD) of water parameters recorded from the different stations in Gorgan Bay.

Season	T (°C)	Salinity(ppt)	pH	DO (mg/L)	Turbidity (NTU)
Spring	29.17±0.9	9.98±0.6	8.2±0.22	6.57±1.2	14.77±10
Summer	27.06±0.7	11.53±0.6	8.1±0.18	6.39±0.9	9.2±7.3
Autumn	9.59±1	10.12±0.8	8.07±0.18	8.07±0.4	11.06±8.3
Winter	11.31±0.7	8.63±0.8	8.16±0.16	8.92±0.6	48.37±39
Mean	19.28±10.26	10.07±1.19	8.13±0.06	7.49±1.22	20.85±18.49

(a)

Stations	Parameters					
	Depth (m)	DO(mg/L)	Salinity (ppt)	T(°C)	pH	Turbidity (NTU)
ST1	2.63±0.5	7.16±1.3	9.9±1.2	18.5±9.8	8.22±0.1	36.18±60.4
ST2	2.55±0.3	7.04±1.3	10.03±0.9	18.88±10	8.16±0.1	40.85±46
ST3	2.16±0.2	7.19±1.6	10.1±0.8	19.05±10	8.14±0.1	30.58±36.3
ST4	1.75±0.1	7.57±1.6	9.95±1	19.48±10.2	8.18±0.1	27.2±19.4
ST5	1.83±0.1	7.3±1.2	10.33±0.7	19.58±10.2	8.19±0.1	43.53±43.4
ST6	2.95±0.2	7.23±1.2	10.18±1.2	19.83±10.1	8.2±0	33.23±42.8
ST7	3.33±0.1	7.01±1.4	10.25±1	19.4±9.9	8.16±0.1	19.15±14.7
ST8	2.53±0.1	7.6±1.2	9.88±1.4	19.33±10.5	8.15±0	13.38±6.8
ST9	2.25±0.4	7.28±1.5	10.18±0.8	19.2±10.3	8.12±0	10.85±3.8
ST10	3.78±0.1	7.54±1.3	10.23±1.2	19.73±10	7.99±0.3	11.38±7.9
ST11	3.1±0.1	6.76±1.9	9.88±0.7	18.88±9.5	8.18±0.1	10.7±8.1
ST12	1.8±0	7.17±0.9	10.48±1.5	19±10.2	8.21±0.1	12.93±9.5
ST13	0.85±0.1	7.47±1.2	9.83±1.3	18.75±10.7	8.09±0.1	14.98±11.3
ST14	2.55±0.3	7.3±1.3	10.38±2	19.73±10.1	8.22±0.3	28.93±37.7
ST15	3.5±0.1	7.62±1.3	10.3±1.1	19.38±10.2	8.09±0.1	7.55±3.7
ST16	1.08±0.1	7.47±1.5	10.18±0.8	18.88±10.3	8.1±0.1	9.28±4.1
ST17	2.65±0.3	7.46±1.4	10.28±1.3	19.53±10.3	8.17±0.2	16.83±14
ST18	2±0.1	8.97±1	10.58±1.3	19.55±10.8	8.07±0.3	6.98±4.5
ST19	0.83±0.1	7.62±1.6	9.83±2.9	20.13±12	8.22±0.6	14.46±18.7
ST20	1.6±0.1	7.33±1.5	9.5±1.9	18.88±10.2	8.01±0.3	13.25±5.3
ST21	0.98±0.1	7.73±2.2	9.1±1.9	18.8±10.3	8±0.2	40.48±40
ST22	0.6±0.3	8.92±1.2	10.13±1.6	19.8±10.6	8.04±0.3	16.13±18
Mean	2.15±0.91	7.49±0.53	10.07±0.33	19.29±0.43	8.13±0.07	20.86±11.91
Min	0.6	6.76	9.1	18.5	7.99	6.98
Max	3.78	8.97	10.58	20.13	8.22	43.53

T: temperature, DO: dissolved oxygen

(b)

Gorgan Bay shows a regular seasonal cycle of temperature, with the highest average reached in Spring (June; 29.17°C) and the lowest means in

autumn (December; 9.59°C), while salinity values varied between 8.63‰ in winter to 11.53‰ in summer, with an average of 10.07‰ and significantly

different between seasons with one-way ANOVA ($p < 0.05$). Therefore its values showed that the bay is hyposaline to slightly brackish.

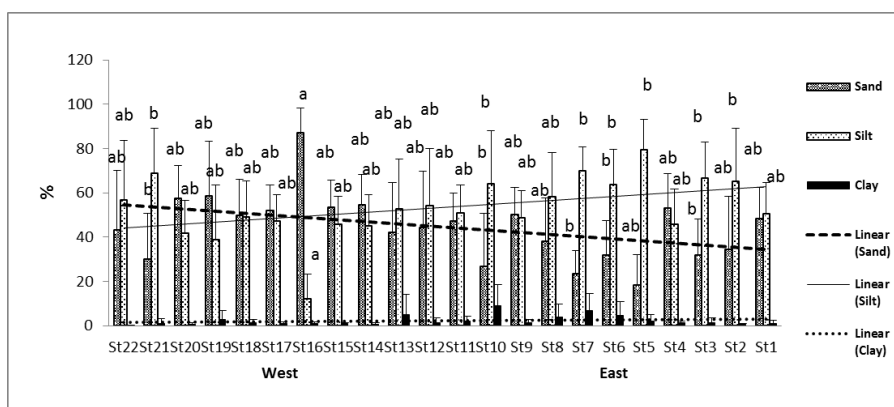
DO averaged with 7.49 mg/L with a minimum of 6.39 in summer and 8.92 mg/L in winter and again with significant difference amongst months (one-way ANOVA, $p < 0.001$) and levels seemed to decline from the western portions to the mouth. The bay water was alkaline (8.13). The turbidity did not vary much from station 1 to 22 (range from 6.98 to 43.53 NTU), the mouth of the bay at winter was highly turbid while the middle portion was the most transparent (5 NTU).

Sediment analysis

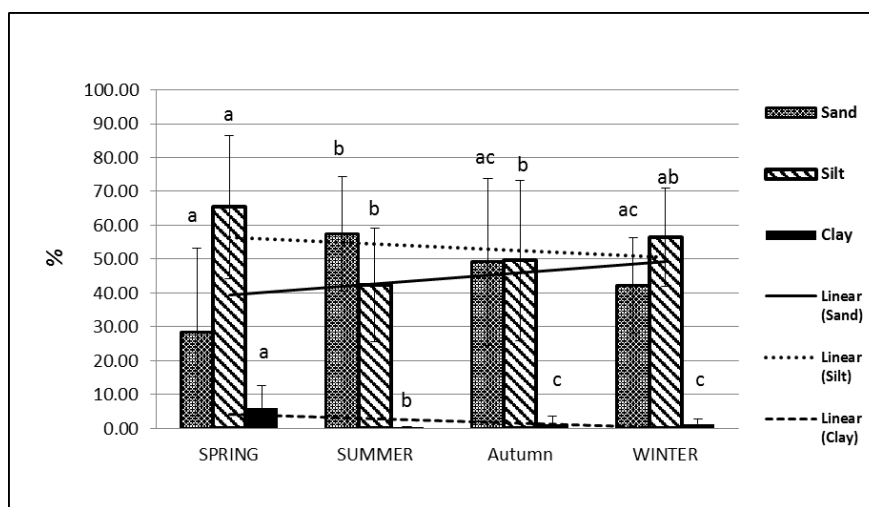
Silt and sand accounted for about 90% of the bay sediment component. The USDA soil texture triangle showed a silty loam dominant texture of Gorgan Bay. The highest mean percentage of sand was recorded at station 16 (87.13%) and the lowest at station 5 (18.31%; Fig. 2a). The silt and clay percentages followed an opposite trend in respect to that of sand. The sediments of western and almost all northern shoreline stations had coarser composition, mostly composed of sand where current dynamics prevent the accumulation of fine particles and toward the eastern shoreline, mouth and southern part of the bay, the textural gradient shows a shift towards lower sand content and it can be seen that the sediments are dominated sharply by silt component. The different textural

properties of the sediments in the two parts of the bay indicate special hydrodynamic processes, and hence depositional conditions. Also one-way ANOVA and Tukey test showed that there is significant difference between the mean values of silt at different seasons ($p < 0.05$). Kruskal-Wallis and Mann-Whitney test showed significant difference between the mean values of sand at different seasons, similar to clay ($p < 0.05$; Fig. 2b), especially in Spring (Sand; 28.5, Silt; 65.41, Clay; 6.1) and Summer (Sand; 57.43, Silt; 42.43, Clay; 0.15).

The highest TOM content was measured in the sample collected near the western littoral zone covered with macrophytes (1.22%, station 21), and values relatively high were observed in the deeper area of the basin (stations of 6, 7, 8 and 10), while the mouth part and north-eastern area was characterized by the lowest values, with a minimum value (2.65% and 4.69) measured at the stations of 16 and 2 (Fig. 3a). Based on one-way ANOVA there is a significant difference between spring (8.1%) and summer (6.3%) ($p = 0.0192$) and the trend is decreasing from spring to winter (Fig. 3b).

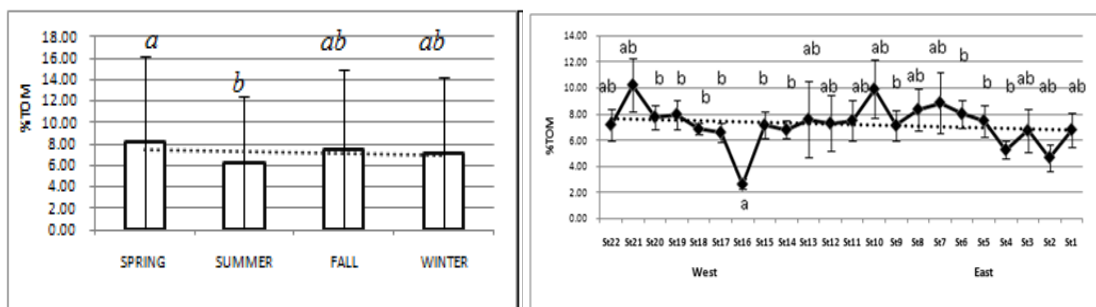


(a)



(b)

Figure 2: Seasonal (b) and spatial (a) variations (mean± SD) of grain size in Gorgan Bay sediment samples. Different letters above the bars show significant difference (a; one way ANOVA and Test-Tukey; $p < 0.05$, b; Kruskal- Wallis and Mann-Whitney test; $p < 0.05$).



(b)

(a)

Figure 3: Seasonal (b) and spatial (a) variations (mean± SD) of TOM (total organic matter) in Gorgan Bay sediments. Different letters above the bars show significant difference (one way ANOVA and Tukey; $p < 0.05$).

Benthic Communities

A total of 31658 organisms were collected from 22 sites, and 14 species (Fig. 4) were identified (*Hediste diversicolor*, *Streblospio gynobranchiata*, *Hypaniola kowalewskii*, Tubificidae, *Tubificoides fraseri*, *Abra segmentum*, *Didacna* sp, *Mytilaster lineatus*, *Cerastoderma lamarcki*, *Dressina polymorpha*, *Pontogammarus robustoides*, *Rhithropanopeus harrisii*, *Stenocuma gracilis*, *Chironomus albidus*).

Polychaeta with 3 species was the most dominant group in terms of abundance. It was followed by Mollusca (4 species) and Oligochaeta. The four most abundant taxa in the study area, making up 85% of all specimens, in decreasing order were *S. gynobranchiata*, Tubificidae, *H. diversicolor* and *A. segmentum*.

Temporal variation

S. gynobranchiata, *T. fraseri* and *H. diversicolor* were the most abundant species at all sites and throughout the study period. *S. gynobranchiata* was most intense in all seasons and presented highest abundance values in spring, while abundance of *T. fraseri* and *H. diversicolor* remained stable throughout the year evaluated (Fig. 5).

S. gracilis, *Didacna* sp and *R. harrisii* were rare species of stations 16 (1 individual was seen just in spring samples) and 21 (1 individual in spring) and 4 and 15 (1 individual in spring, summer and fall samples). The maximum density (7,893 ind/m²) was

obtained at station 1 while the minimum (1,777 ind/m²) was observed at station 16. The higher abundances were found along the mouth and eastern stations 1, 3 and 12 (>7200 Ind/m²), while lower abundances were registered in the western zone (Fig. 6).

Biological data showed that the abundance and diversity of macrobenthic communities varied in an opposite trend from mouth toward western and southern part of the bay (Figs. 6 and 7). In terms of number of species (S), the highest values were found at the station 21 and 16 with a prevalence of 3 Polychaete species (*S. gynobranchiata*, *H. diversicolor*, *H. kowalewskii*); and 4 bivalve species (*A. segmentum*, *C. lamarcki*, *M. lineatus*, *D. polymorpha*) while the station 12 and 13 was characterized by the highest diversity indices (Shannon–Wiener, 1.94 and 1.87; Pielou's Evenness, 0.89 and 0.74 respectively) (Fig. 7).

As it can be observed from the distributions of abundance and diversity indices, the western area was characterized by the lower number of individuals and higher species diversity and station 10, 8 and 7 (with transitional situation) was characterized by the lowest diversity indices (Shannon–Wiener, 0.72, 0.77 and 0.87 respectively; Pielou, 0.4 and number of taxa, 5) and Polychaeta (*S. gynobranchiata*, *H. diversicolor*, *H. kowalewskii*) were the most representative classes (Figs. 8a, b, and c).

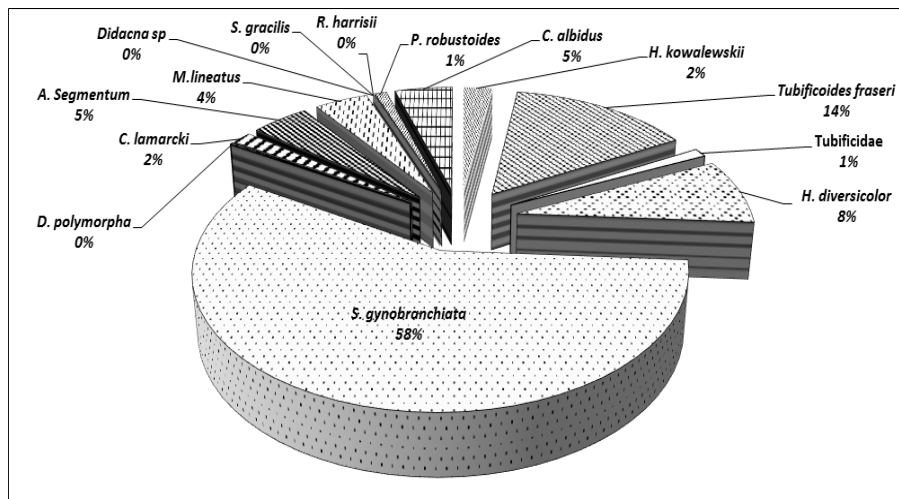


Figure 4: Percentage composition of macrozoobenthos species in the Gorgan Bay.

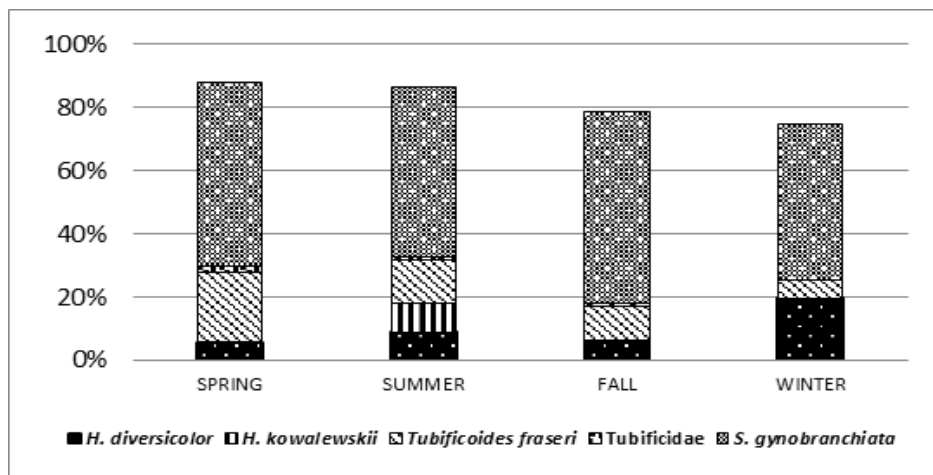


Figure 5: Temporal occurrence of Annelida in Gorgan Bay.

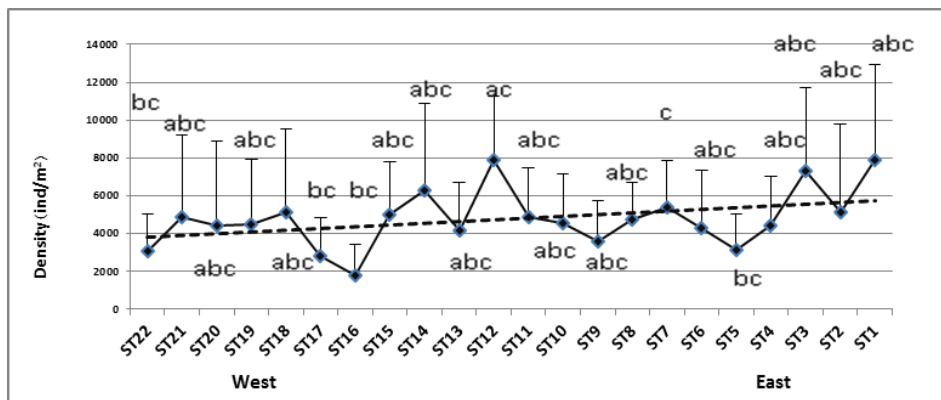
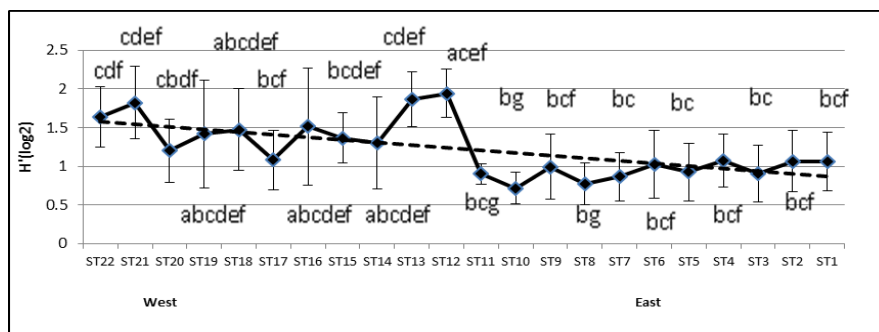
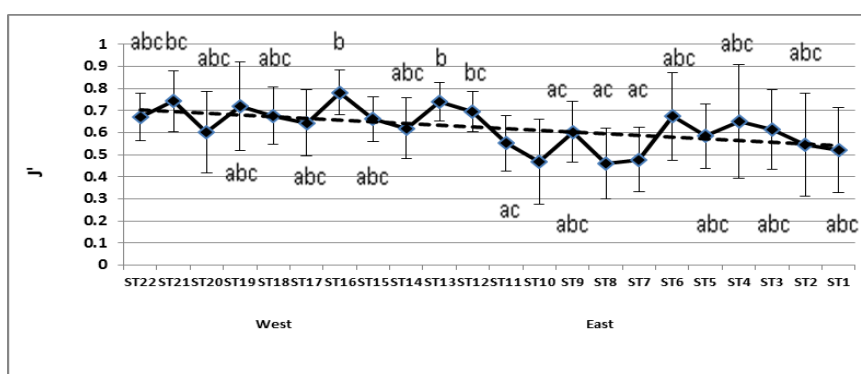


Figure 6: Mean total density (\pm SD) of macrofauna at different stations in the Gorgan Bay. Different letters above the bars show significant difference (Kruskal- Wallis and Mann-whitney U tests; $p < 0.05$).

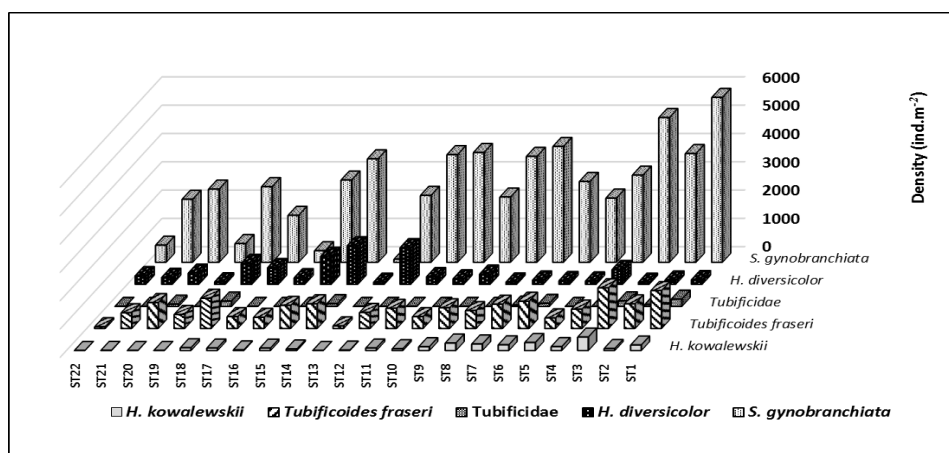


(a)

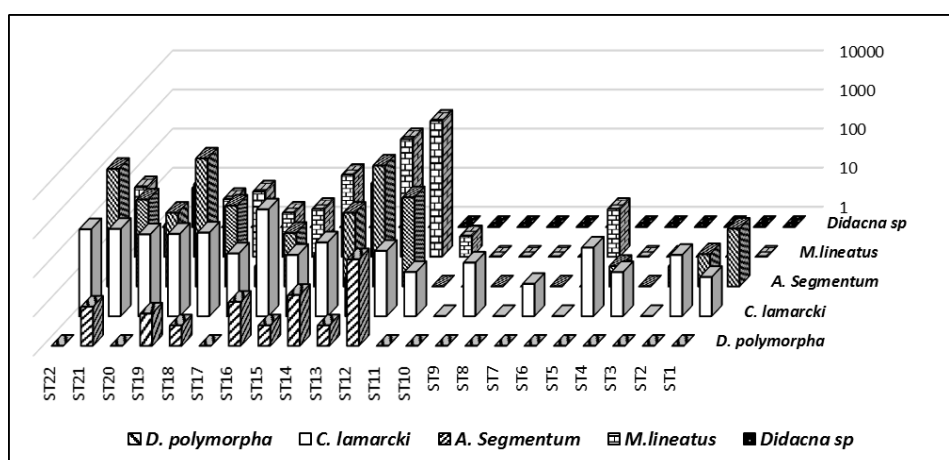


(b)

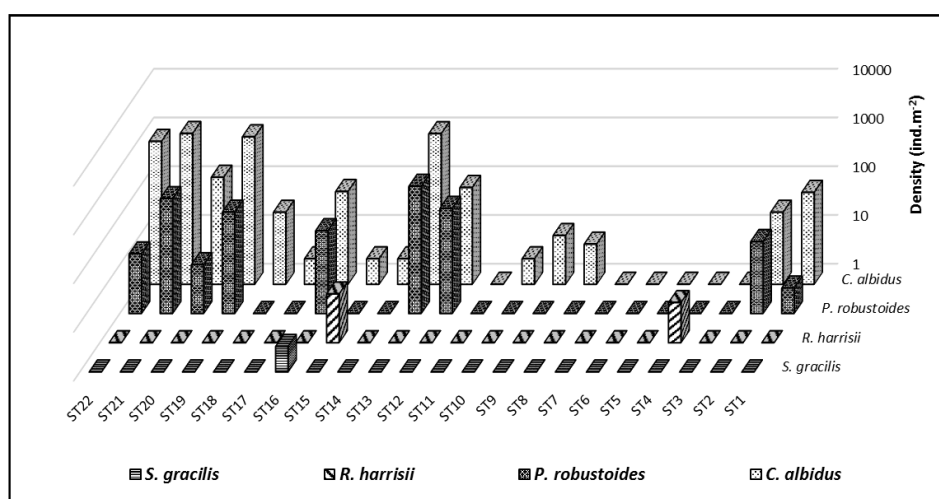
Figure 7: Diversity (H') and Evenness (J') indices (\pm SD) for benthic macrofauna communities in Gorgan Bay. Different letters above the bars show significant difference (one way ANOVA and Test-Tukey; $p < 0.05$).



(a)



(b)



(c)

Figure 8: Distribution of Benthic Macrofauna along the Study Area (in the inlet and inner part of the bay, (a) Most common species (Annelida), (b) Mollusca species(log₁₀), (c); Arthropoda species (log₁₀).

PCA analysis was run on transformed and normalized levels of sediment variables (i.e. TOM, grain size) and water variables (including TOM, temperature, pH, DO, salinity, turbidity). By plotting all data together, the first three components (30%, 28%, and 14%) accounted for 72% of the total variance (Fig. 9). The first axis PC1 was characterized by strong correlation with water variables; the

strongest correlations were found with salinity, temperature, DO and turbidity, sediment variables had strong positive correlations with the second axis PC2, and only the pH of the water had strong positive correlation with the PC3.

Similarity among sites was analyzed by ordination techniques (nmMDS, stress: 0.1) based on Bray–Curtis similarity matrix and according to sediment and water variables in Gorgan Bay (Fig. 10).

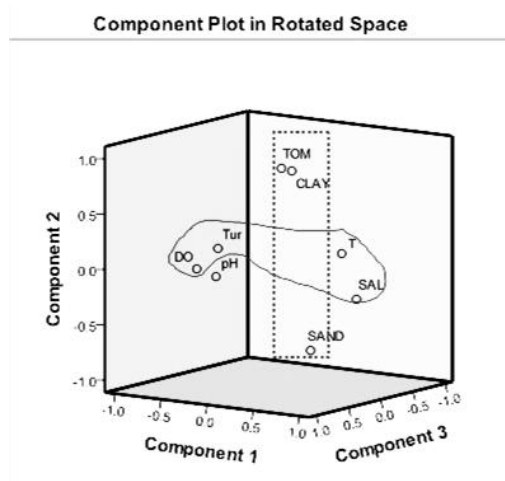


Figure 9: PCA diagram of environmental variables (based on stations and seasons) for Gorgan Bay. TOM; total organic matters, DO: dissolved oxygen, S: salinity, T: temperature, Tur: turbidity.

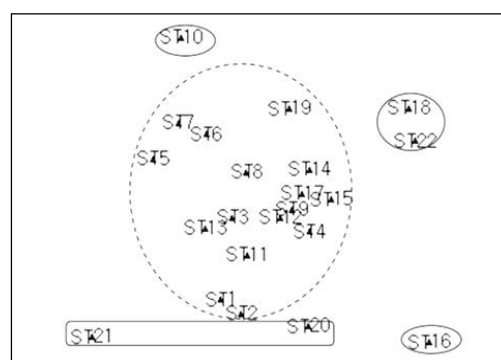


Figure 10: nm-MDS (stress: 0.1) ordination diagram of sediment and water variables in Gorgan Bay.

Two-dimensional ordination diagrams confirmed the distinct grouping of some sites in Gorgan Bay and stations were clearly separated on the basis of water and sediment variables. Stations 10, 18 (inner part of the bay) and 22, 20 and 21 (western shallow littoral sites) were separated from the other stations and from station 16. This result suggested that external factors, linked with water inputs, could not influence the distribution of water and sediment variables in the bay and contributes to the sites segregation.

The CCA procedure was applied to better evaluate the relationship between macrobenthic assemblages and sediment characteristics in Gorgan Bay. The results of this analysis showed that macrobenthic assemblages were most strongly correlated with the distribution of sand %, clay % and TOM.

Discussion

Based on sediment characteristics in the Gorgan Bay, a clear spatial variability was observed, which was generally dominated by coarse-grained sediments (Fig. 2); in particular, sand component

was predominant. Almost all of the northern shoreline and western stations had coarsest composition, mostly composed of sand where current dynamics prevent the accumulation of fine particles and toward the eastern and southern part of the bay, the textural gradient shows a shift towards lower sand content and it can be seen that the sediments are dominated sharply by silt component and just deeper station sediments had more clay (Sharbaty, 2011). According to Fig.9, the result of PCA indicated that sediment variables correlated with the second axis (TOM, sand% and clay%) and water parameters had a great significance in explaining the system variability (Pomeroy *et al.* 1965; Lijklema 1986). With regard to TOM content (Fig. 3), the results of this study were not comparable and were lower than those typically found in organic enriched or eutrophic lagoons.

Moreover, the dependence of the species on the environmental variables may be indirect through biological interactions (Beukema *et al.*, 2000). The benthic community in Gorgan Bay was characterized by low species richness but constant temporal and spatial abundance of individuals, mainly polychaetes (Fig. 8). As for sandy bottom communities of the Caspian Sea, dominant groups in Gorgan Bay were Annelida (83%), molluscs (11%) and crustaceans (6%) (Fig. 4). This feature has been mentioned for different transitional areas, especially in comparison with the

adjacent marine ecosystems (Hutchinson and Williams, 2001).

In Gorgan Bay and during the study period all common and dominant species were present at a frequency rate of 100% with only 1 recruitment peak a year (spring) and in multivariate analysis (PCA), water parameters had a greater significance in explaining the system variability because of their temporary variations. It seems a compensatory adaptation to relatively short-term temporal variations in the environment is a prerequisite for them (common and dominant species) to survive in the intrinsically variable transitional environment of the Gorgan Bay and the Caspian Sea (McIntyre, 1969; Stora, 1995; Specchiulli, 2010; Ghasemi, 2011).

In this study, 14 species were identified. The maximum density (7160 ind/m²) was obtained at station 1 in spring while the minimum (80 ind/m²) was observed at station 16 in winter. The higher abundances were found along the mouth and eastern stations 1, 3 and 12 (>7200 Ind/m²), while lower abundances were registered in the western zone (Fig. 6). At the Noor coast, in the spring, the maximum and minimum density of macrofauna were recorded at 4,211 and 455 ind/m², respectively (Taheri and Yazdani, 2011) and in the same season in Gorgan Bay, the maximum density of Polychaeta was recorded at 6,051 ind/m² while the minimum was found to be 2,591 ind/m² (Taheri *et al.*, 2007). At the Noshahr coast the maximum and minimum density of macrofauna were recorded as

1,891 and 735 ind/m², respectively (Ghasemi, 2011).

In most bays, macrofauna distribution patterns vary with environmental conditions following a hydrodynamic gradient (Stora, 1995; Specchiulli, 2010). This pattern has been observed in our study, for Mollusca and Arthropoda (Fig. 9) but distribution of three Annelid species *S. gynobranchiata*, *H. diversicolor* and *Tubificoides fraseri* in the different habitats remained constant throughout the Bay. Also, *S. gynobranchiata* was the dominant species with 60.28% of the total individuals. Similar results were obtained at the Noor coast and Gorgan Bay (Taheri *et al.*, 2007; Bandany *et al.*, 2008; Taheri and Yazdani, 2011). Also in the present study density of this species recorded (58%) was similar to that in previous studies. Despite Annelida having the highest density in the Caspian Sea among different fauna, fewer than ten species are known in the southern part (Tait *et al.*, 2004; Taheri and Yazdani 2011). In this study five species of Annelida and three species of Polychaeta were recorded. Previous studies recorded five species of Polychaeta in the south Caspian Sea and Gorgan Bay (Parr *et al.*, 2007; Taheri *et al.*, 2007; Bandany *et al.*, 2008; Taheri *et al.*, 2008) and in a spatial case study in June 2010 (without any temporal approach) 10 species of macrofauna and only one polychaet species were recorded in the Gorgan Bay (Taheri *et al.*, 2012). According to

Taheri *et al.* (2012), the endemic polychaetes (*H. invalida*; *H. kowalewskii* and *Manayunkia caspica*), observed before in Gorgan Bay, have been entirely replaced by *S. gynobranchiata* but during our study *S. gynobranchiata*, *H. diversicolor* and *Hypniola kowalewskii* were observed in all sites (Fig. 8a). Similar results were also obtained by Bastami *et al.* (2014). The class Polychaeta (*N. diversicolor* and *S. gynobranchiata*) and *T. fraseri* were present at most stations. This finding might be due to the resistance ability of these species in response to different ecological conditions at the Gorgan Bay after which they become dominant at all stations (Bastami *et al.*, 2014).

In addition, we observed two species of Oligochaetes and similar results were reported by Taheri and Yazdani (2011) at the Noor coast while six species were reported in the south Caspian Sea (Parr *et al.*, 2007). Similar results were reported by (Ghasemi, 2011; Taheri and Yazdani, 2011).

In this study in Gorgan Bay, according to CCA, the exotic spionid *S. gynobranchiata* (2756 ind/m²) and *T. fraseri* (692 ind/m²) showing a correlation with depth, dominated numerically. *S. gynobranchiata*, *T. fraseri* and *H. diversicolor* were the most abundant species at all sites and throughout the study period. *S. gynobranchiata* was most intense in all seasons and presented highest abundance values in spring, abundance of *T. fraseri* and *H. diversicolor*

together remained stable throughout the year evaluated (Fig. 5). In fact, larval and post-larval stages of *S. gynobranchiata* and *T. fraseri* were observed to colonize patches of sediment at all sites (from sandy western sites with higher number of taxa to eastern sites with lower number of taxa) and year round in the Gorgan Bay. According to some authors, spionids are tolerant benthic polychaetes, known to switch their feeding mode from filter feeding to deposit feeding depending on the environmental conditions such as hydrodynamics (Kihlslinger and Woodin, 2000) and food competitive interactions (Hansen, 1999). Also, dominant species, *S. gynobranchiata* and *T. fraseri* are new invasive species in the south Caspian Sea. According to Parr *et al.* (2007), *H. invalida* was the dominant species before their arrival.

H. diversicolor was competitively inferior to the invasive polychaete *S. gynobranchiata* and *T. fraseri* even in the food limited bottom habitat of the sandy parts of the Gorgan Bay (like stations 2 and 16). It also showed constant density with a recruitment peak in spring (449 ind/m²), reaching annual averages of 390 ind/m². *H. diversicolor*, a widely distributed species in transitional habitats shows high physiological tolerance to extreme variations in environmental factors, and can grow and reproduce in different sediment types and in stressed environments (Scaps, 2002).

In the Gorgan Bay and according to CCA, endemic assemblages of *H.*

kowalewskii were associated to fine sediments, clay, silt, and depth showing a correlation with more turbid but deep eastern stations. It seems *H. kowalewskii* prefers riverine conditions and avoids littoral zones covered with macrophytes.

Mollusca are one of the most important groups of macrofauna in the Caspian Sea and they have been observed in all parts of it (Malinovskaja *et al.*, 1998; Parr *et al.*, 2007; Roohi *et al.*, 2010). In our study, Bivalvia, with four species, had the most diversity (with the mean density of 11%), but they were not observed in all parts of the bay. They were observed in the middle and western parts and *Didacna sp.* was one observed at one station. In other studies, one species (*C. lamarcki*) of Bivalvia was reported in the Mazandaran Province (Ghasemi, 2011; Taheri and Yazdani, 2011).

Amphipoda are another important group of macrofauna in the Caspian Sea (Karpinsky, 2005). In the present study one species (*P. robustoides*) was found. This species is herbivorous and in this case was often observed in stations that were covered with plants (a continuous dispersion in stations 22, 21, 20, 19, and discontinuous patches in sites 12 and 13; in the middle parts and stations 1 and 2, in mouthparts of the bay).

This study observed a clear trend related to the influence of environmental gradients on density and distribution of dominant bivalves and arthropods from the eastern to the western parts of the Gorgan Bay (Fig. 9). Recruitment or dispersion from the

sea seems to play a key role in determining the distribution of benthic species (Barnes, 1994; Magni *et al.*, 2008). Recruitment from marine populations and migration were evident in the area close to the Gorgan Bay sea inlet, according to supply side ecology but spatial distribution of *D. polymorpha* invasive and *M. lineatus*, native to the drainage basins of Caspian Sea, also showed a disjunction in eastern and central area of this bay. Multivariate analysis also revealed that,

the bivalve tolerant species, *D. polymorpha*, sensitive species *M. lineatus* and *C. lamarcki* in Gorgan Bay were exclusive to the sheltered western sites where macrophyte covered the bay, with relatively higher TOM, combined with the occurrence of different secondary substrates. It seems that most bay bivalves correlate positively with sand and the sediment sorting due to lower hydrodynamic energy (Fig. 11).

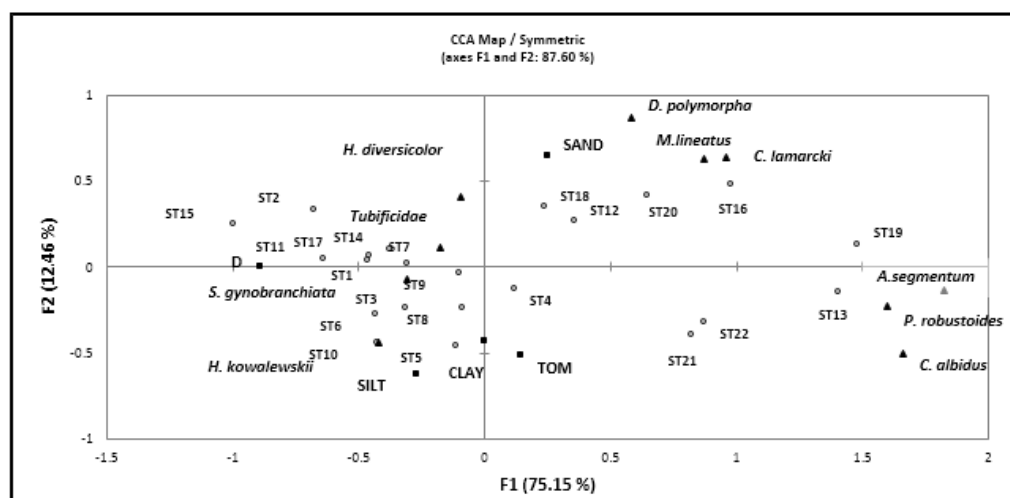


Figure 11: Canonical correspondence analysis (CCA) ordination diagram for macrobenthic species (Species abundance data for 22 stations) in relation to sediment variables (○, stations. ■ TOM, Sand, silt, clay and depth (D), ▲ species).

C. lamarcki has been widespread in inshore waters of the south Caspian Sea (before opening of the Volga-Don shipping canal and recent sea-level rise), but today the density of this species is restricted and it seems in small disjunct water bodies like Gorgan Bay, this species is forming a metapopulation toward the western part of the bay (Reise, 2003). This pattern

was also observed for *D. polymorpha*, *A. segmentum*, *M. lineatus*, *C. albidus* and *P. robustoides* (most common Ponto-Caspian amphipods and native species of all sandy bottoms of Caspian Sea coastal zones) (Fig. 9).

Singletons (or rare species) of Gorgan Bay, *S. gracilis* and *R. harrisii* and *Didacna sp* in a single or two stations presented 23% of the total

number of species. The presence of these species seems to be an important piece of information allowing the prediction of the total number of species in the community. *S. gracilis* was seen just in station 16. According to Jaume and Boxshall (2008), *S. gracilis* is one of 19 non-marine cumacean species belonging to the Pseudocumatidae; appears restricted to the Caspian Sea and its peripheral fluvial basins. Cumacea and Tanaidacea are marginal groups in continental waters and many euryhaline species from both groups are found in estuaries and coastal lagoons, most occur only temporarily in non-marine habitats, appearing unable to form stable populations there (Jaume and Boxshall, 2008).

Lymnocardiid bivalve *Didacna* sp. endemic to the Caspian Sea is thought to be an indicator of increasing salinity and more brackish-tolerant (Lahijani *et al.*, 2007), another rare species in Gorgan Bay was collected from station 21, with just an occurrence in spring. The third rare species in the Gorgan Bay (station 4 and 15), *R. harrisii* (white-fingered mud crab) is a highly successful estuarine invader and is one of the most widely distributed brachyuran crab species globally (Roche and Torchin, 2007). Also it has high fecundity, a long planktonic larval period, and a wide tolerance range for several environmental factors that have likely facilitated its invasion success. *R. harrisii* individuals are able to withstand cold winters and low salinities, and exhibit flexibility in their

ability to use various habitats (Hegele-Drywa and Normant, 2009).

In terms of number of species (S), the highest values were found at the stations 21 and 16 with a prevalence of 3 Polychaete species (*S. gynobranchiata*, *H. diversicolor*, *H. kowalewskii*); and 4 bivalve species (*A. segmentum*, *C. lamarcki*, *M. lineatus*, *D. polymorpha*) while the stations 12 and 13 were characterized by the highest diversity indices (Shannon–Wiener, 1.94 and 1.87; Pielou's Evenness, 0.89 and 0.74, respectively).

Similar results were reported in the Gorgan Bay about maximum mean species number (6.33), diversity (1.46) and richness (1.38) (Taheri *et al.*, 2007; Bandany *et al.*, 2008) and in the southern Caspian Sea at the Noor coast (Taheri and Yazdani, 2011). According to Taheri *et al.* (2012), the low numbers for these indices can be related to low number of species of macrofauna and the existence of *S. gynobranchiata* as the dominant species with very high density at all stations.

Finally the relationships between the dominance of benthic groups and the environmental factors that were established for the Gorgan Bay, only accounted for a small fraction of the total spatial variability. When all Gorgan Bay stations were evaluated from the perspective of the number of species and specimens, western stations had the highest number of species but mouth part of the bay had highest specimen numbers. On the basis of our observations (also highlighted by PCA analysis), water parameters with more

temporary variations had a greater significance in explaining the system variability, and a not marked but evident differences between the two parts of the Gorgan Bay were observed and supported by MDS test (Ghorbanzadeh *et al.*, 2016). It could be related to lower depth and high primary production of western *Roppia maritima* facies and eastern deeper facies suggested no influence of external sources on sediment parameter distributions.

In conclusion, Gorgan Bay presents transitional epifaunal and infaunal macrobenthic assemblages that are spatially distributed along substrate gradients but it is widely acknowledged that the coastal ecosystem of the south Caspian Sea and south-eastern part of Gorgan Bay is very dynamic and characterized by high physical disturbances, lower richness, evenness and it seems toward western sites some species have formed a metapopulation and two endemic (*S. gracilis* and *Didacna sp*) and one exotic rare species (*R. harrisii*) are newly making colonies.

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