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Spatial Pattern of Phytoplankton Communities from Iranian Waters of the Gulf of Oman in Pre-Monsoon Period

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Abstract

There is a need to increase our knowledge about phytoplankton diversity and distribution in the Iranian waters of the Persian Gulf and the Gulf of Oman. Phytoplankton samples along with environmental parameters of the Northeastern waters of the Gulf of Oman (Gordim Bay towards Gwadar Bay) were collected and recorded prior to summer monsoon (Mid of March 2013). Seven inshore and six offshore stations in two depth profile (0.5 m, 10 m) were sampled. A total of 26 genera were identified which comprised of 21 taxa from inshore and 17 taxa form offshore stations. Bacillariophyceae constituted the most dominant taxa, among which *Rhizosolenia* spp., *Chaetoceros* spp. and *Pseudo-nitzschia* spp. were more abundant diatoms. The dominant dinoflagellates were *Ceratium furca* and *C. breve*. The maximum and the minimum count of phytoplankton per station were 3975 and 53 cells/L. The difference in the species composition of inshore and offshore phytoplankton was significant, and the highest number of phytoplankton was recorded from the eastern coast of the study area. However, there was no significant difference between population numbers of surface water (0.5) and at 10m depth. Among the measured hydrological factors, silicate, chlorophyll a, and dissolved oxygen showed potential effect in spatial distribution of phytoplankton. Some toxic genera were observed but their occurrence was not at harmful bloom rate.

Keywords: *Phytoplankton, Distribution, Middle ROPME Sea Area, Inshore, Offshore*

1. Introduction

Phytoplankton communities play an important role in marine ecosystems and human life. Understanding of the aquatic ecosystem is not possible without knowledge of the species composition, productivity and biomass of these creatures. Phytoplankton species composition and distribution in the ROPME Sea Area (RSA) include the Persian Gulf (inner RSA), Gulf of Oman (middle RSA) and part of the Arabian Sea (outer RSA) with its very heterogeneous basin (ROPME/GC-14/7) has been investigated by many reserchers. The phytoplankton density in outer RSA based on satellite data were studied in the late 19th century (Barlow et al., 1999; Brock and McClain, 1992), but the knowledge about phytoplankton biodiversity and species composition in middle RSA was limited. Until 2013, 168 scientific articles including 94 articles on zooplankton and 74 articles on phytoplankton were

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published about the RSA, mostly from the Persian Gulf (Dorgham, 2013). Recently, Dorgham (2013) revealed several gaps on plankton research of the region including limited spatio-temporal sampling and discontinuity of spatial and temporal studies in the Indo-Pacific region, for example on the species entering the Persian Gulf from the Sea of Oman.

Among the 5,000 species of extant marine phytoplankton (Sournia et al., 1991), about 300 species at times are able to produce bloom somehow, they obviously discolor the surface of the sea (red tides), while only 80 or so species have the capacity to produce potent toxins (Hallegraeff, 2003). The previous records of harmful algal blooms (Richlen et al., 2010; Coles, 1996) in the RSA region emphasized studying on distribution and diversity of phytoplankton.

The present contribution aims to provide information on community structures and possible spatial pattern of phytoplankton in part of the Gulf of Oman in per-monsoon period.

2. Material and Methods

2.1. Study Area

Coastal waters of the Sea of Oman stretch from the Strait of Hormuz in the northwest to Ras Al-Hadd on the eastern tip of the Arabian Peninsula. It connects to the Persian Gulf via Strait of Hormoz as a shallow sea (Uchupi et al., 2002). The area strongly is influenced by the southwest monsoon (in July-September), so autumn and early winter considered as post monsoon situation and late winter (March), spring considered as pre-monsoon (Wilson, 2000). Sampling stations were located in the eastern parts of the Gulf of Oman from Gordim Bay toward Gowader Bay. Selected stations were geographically out of the ROPME cruise sampling stations. Thirteen stations were sampled prior to summer monsoon (March 2013) in two depth profiles of the inshore and offshore groups (0.5 m and 10 m, Fig. 1).

2.2. Field Methods and Sample Analysis

Water samples for chemical and biological analysis were collected on board (Nayband Navy Vessel) using Niskin samplers (1.7 L, HYDRO-BIOS) from two depth profiles (0.5 m and 10 m). Collected water samples were fixed and concentrated base on the methods described by Hallegraeff (2003).To precise calculation of phytoplankton abundances three replicates were considered.

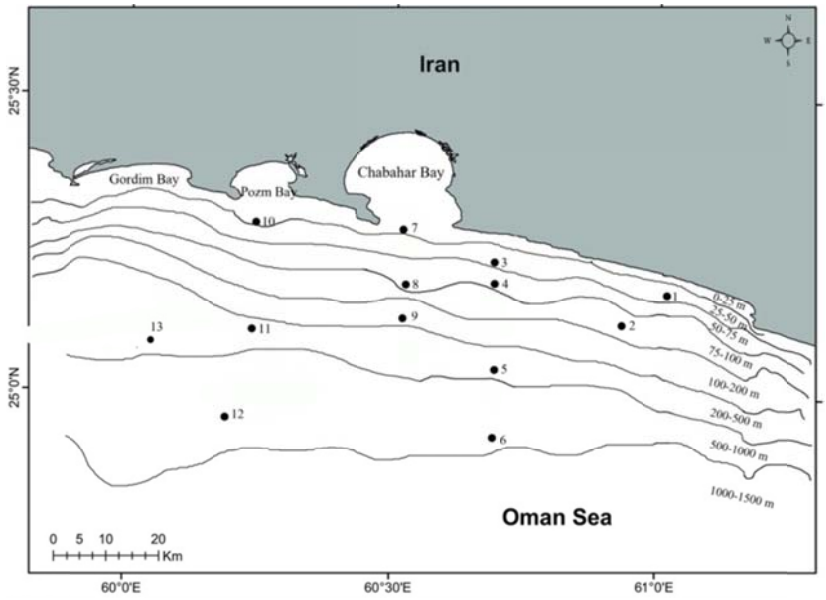

Fig. 1: Sampling stations of the present study (stations numbered from east to the west)

The collected samples for phytoplankton practices were examined under the light microscope (NIKON Eclipse 80i) to determine the general community composition of phytoplankton and to identify the different species at the genus and species levels. Different magnifications were used according to the size of the phytoplankton. Identification was carried out based on available taxonomic guides and descriptions (Baker et al., 2012, Tomas, 1997, Al-Yamani and Saburova, 2010, AL-Kandari et al., 2009). Among the above-mentioned keys AL-Kandari et al., 2009 prepared useful keys for the Persian Gulf, so that was more practical in this study due to proximity of their sampling locations to the Gulf of Oman.

Physicochemical water quality parameters including temperature; salinity, chlorophyll a (Chla) and dissolved oxygen were measured on board using a conductivity–temperature–depth (Idronaut-Ocean Seven 316 CTD probe) instrument (Table 1). Nutrients [nitrate, silicate and phosphate (µmol/L)] were also measured in the laboratory (Table 1). The water samples for nutrients analysis, filtered on board by 0.45µ Cellulose Acetate, were immediately frozen for storage and later thawed for the analysis of nitrate, nitrite, phosphate and silicate using a spectrophotometric method (MOOPAM, 2010).

2.3. Data Analysis and Statistics

The total numbers of phytoplankton/L were calculated according to the following equation:

$$N = \frac{n \times v}{V} \times 1000$$

Where: N, is the number of phytoplankton cells; n, refer to the mean of phytoplankton cells per 1 ml of sample; v, the volume of phytoplankton and V, is the volume of water was filtered (Karthik et al., 2014).

Non-metric Multi-dimensional scaling (nMDS) based on a Bray– Curtis similarity matrix of fourth-root-transformed data was used to depict two-dimensional ordination plots of assemblages. The similarity/permutation test ANOSIM (Warwick and Clarke, 1991) was used to compare statistical difference among stations, based on the Bray–Curtis of fourth-root-transformed data. PRIMER software (ver. 6, Primer-E Ltd, Plymouth, Clarke 1993; Clarke and Warwick 2001) was used for both nMDS and ANOSIM analyses. The software also provided us the Shannon biodiversity index (Table. 4). A manual forward selection process for Canonical Correspondence Analysis (CCA) in CANOCO software (ver. 4.5, Ter Braak & Smilauer 2002) was used to select the subset of environmental variables that best explained the variation in spatial patterns of phytoplankton abundance in the study area. The abundance data were down-weighted to rare species and squared root-transformed to reduce skewness and outliers and approximate normality. The logarithmic transformation is very common in environmental data due to different natures (units) of variables, so these data were log-transformed in the present study. The pattern of phytoplankton abundances was provided with GIS software (ver, 10.3.1).

Table 1: Raw environmental data measured in the present study

Station	Te	Sa	DO	pH	Chl a	Tu	PO_4	SiO_2	NO_3	NO_2
1	23.3	36.1	6.6	8.2	11.8	3.5	100.7	149.9	204.9	65.3
2	23.5	36.6	6.3	8.2	12.7	3.2	95.4	138.4	304.4	38.7
3	23.6	35.8	7.8	8.2	15.1	1.7	51.7	224.1	53.0	4.6
4	23.6	36.6	7.3	8.3	11.9	4.3	62.7	107.3	207.0	41.4
5	23.6	36.5	6.5	8.2	12.4	2.4	83.1	167.4	270.5	39.4
6	23.5	36.5	6.5	8.4	10.5	3.2	87.4	146.2	309.0	43.6
7	23.6	35.1	7.6	8.2	14.0	1.5	37.4	31.6	22.7	13.2
8	23.8	35.9	6.9	8.2	12.8	1.2	67.3	61.9	417.0	21.9
9	23.7	36.6	6.6	8.1	24.1	2.4	52.4	166.5	377.2	37.7
10	23.3	36.5	7.3	8.3	12.1	3.4	57.0	57.1	182.0	33.1
11	23.4	35.9	6.2	8.2	12.2	2.7	63.3	143.0	173.5	40.2
12	23.6	36.4	6.4	8.3	13.1	3.3	90.4	139.8	258.4	35.3
13	23.7	36.5	6.5	8.0	10.6	13.8	74.0	115.1	192.1	28.3

Te, Temperature in °C; Sa, Salinity in ppt; DO, Dissolved Oxygen in mg/l; Chla, Chlorophyll a in µ/l; Tu, Turbidity in meter ; PO4, Phosphate in µ/l; SiO2, Silicate in µ/l; NO3, Nitrate in µ/l; NO2, Nitrite in µ/l.

3. Results

Twenty-six genera of phytoplankton were identified (Table 2). The most abundant genera were *Rhizosolenia* spp.(18.4 %), *Chaetoceros* spp. (16 %), *Cyclotella* spp. (11 %) and *Pseudo-nitzschia* spp. (10 %) (Fig. 2), among them *Rhizosolenia* spp. and *Pseudo-nitzschia* spp. were most frequent, while *Cyclotella* spp.was less frequent at study area. The lowest frequency of all genera belonged to: *Prorocentrum* spp., *Gymnodinium* spp., *Proboscia* spp., *Eucampia* spp. and Gonyaulax spp. Bacillariophyceae (diatoms) formed most dominant group (79%), followed by Dinophycae or dinoflagellates (20 %), and Prymnesiophyceae (coccolithophore) 1% (Table 3). Diatoms abundances were more than dinoflagellates in all stations (Fig.3), except in station No. 6 where dinoflagellates were more abundant in both depths and Prymnesiophyceae (Phaeocystis sp.) were observed (Table. 3).

Our results indicate that phytoplanktons of the study area have relatively heterogeneous distribution. Station No.10 has the highest calculated Shannon biodiversity index (H′=2.43) and station No. 9 the lowest diversity index (H′= 0.8) The same results were seen for number of species as stations No. 10 and No.3 showed the highest and station No. 9 the lowest species richness (S) (Table 4). Result of Mann–Whitney test showed non-significant differences between Shannon biodiversity index of inshore and offshore waters (P valve= 0.063).

Table 2. Observed phytoplankton taxa per station ("S" indicates the depth of 0.5 m, and "B" indicates the depth of 10 m)

Taxon / species	12S	12B	11S	11B	7S	7B	6S	6B	2S	2B	10S	10B	13S	13B	1S	1B	8S	8B	5S	5B	3S	3B	4S	4B	9S	9B
Coscinodiscus							+					+				+	+	+								
Guinardia					+					+		+		+		+					+	+	+	+		
Odontella					+						+	+						+			+	+	+	+		
Chaetoceros	+		+	+	+				+	+	+	+	+	+		+	+	+			+	+	+	+	+	+
Rhizosolenia	+				+	+	+		+	+		+	+	+		+	+	+	+	+	+	+	+	+	+	
Peudo-nitzschia seriata		+	+	+	+	+		+	+	+		+	+	+			+	+	+		+	+	+	+	+	
Lauderia					+				+	+		+									+			+		
Ceratium (C. furca & C. breve)	+	+	+		+		+		+	+	+	+		+	+	+				+	+	+	+			
Leptocylindrus					+							+														
Protoperidinium					+							+									+	+	+			
Thalassiosira										+	+	+											+			
Proboscia														+												
Noctiluca scintillans									+	+																
Dinophysis cudata	+	+							+	+	+	+				+	+				+	+	+			
Gonyaulax polygramma							+		+		+						+				+					
Lingulodinium		+					+																			
Prorocentrum												+														
Eucampia												+														
Gymnodinium breve								+																		
Bacteriastrum								+		+								+			+					
Phaeocystis								+																		
Cerataulina									+								+									
Stephanopyxis														+	+	+		+			+	+	+	+		
Cyclotella	+			+	+	+													+		+	+	+	+		
Planktoniella		+											+								+		+			
Thalassionema	+	+												+												

Table 3. Average number of phytoplankton community structure

Phytoplankton Community	**Mean ± SE (Cell / L) at each depth**		
	0.5 m	10 m	Total percentage
Diatoms	951.26 ±607.88	476.15 ± 228.07	79%
Dinoflagellates	212.54 ± 118.46	112.15 ± 76.17	20 %
Prymnesiophyceae	not observed	6.19 ± 11.46	1%

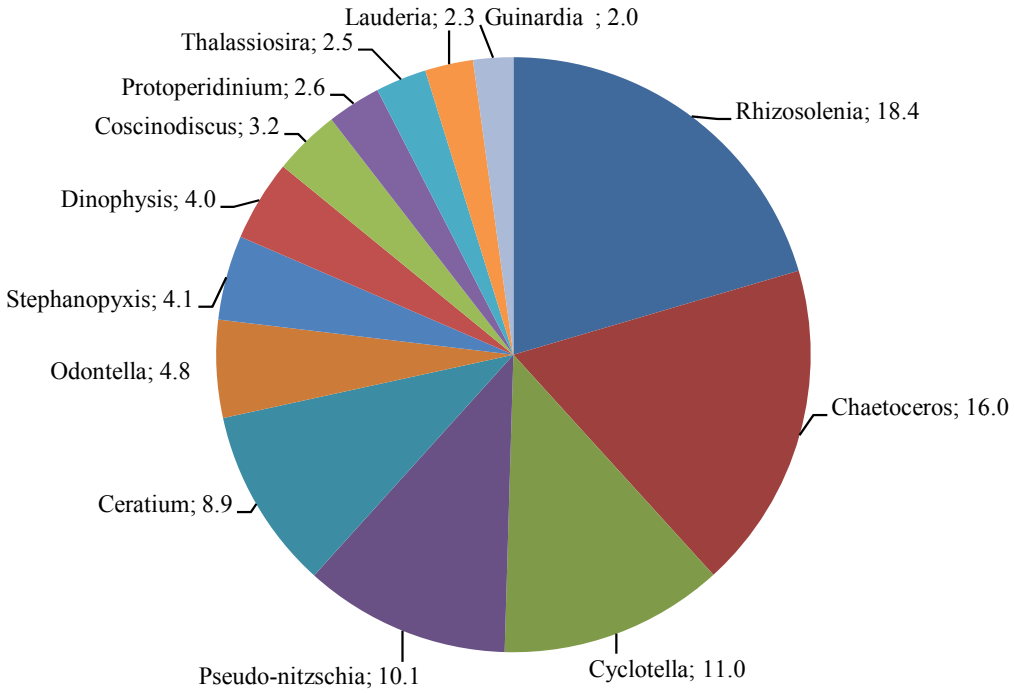

Fig. 2: Percentage of the phytoplankton groups with more than 2% composition at studied area

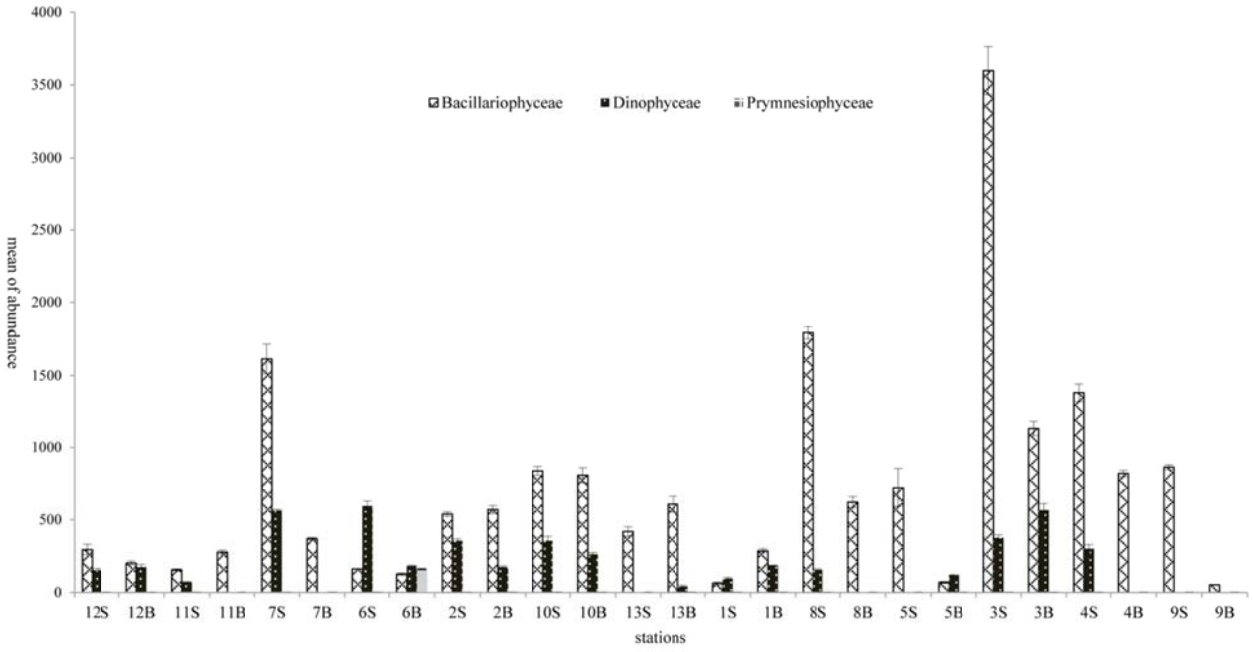

Fig. 3: Mean abundance of phytoplankton groups per station, Bacillariophyceae constitute dominant phytoplankton in most stations.

Table 4. The biodiversity indices in studied stations

Index	**12**	**11**	**7**	**6**	**2**	**10**	**13**	**1**	**8**	**5**	**3**	**4**	**9**
Taxa_S*	9	4	10	9	12	15	9	7	10	4	15	13	3
Individuals	830	523	2560	1238	1685	2389	1118	638	2550	823	5999	2527	937
Shannon_H	2.14	1.34	2.01	2.08	2.33	2.43	1.96	1.80	1.78	1.01	2.30	2.40	0.80

*Species richness

Some of the reported phytoplankton in the present study are toxic including *Dinophysis caudate, Peudo-nitzschia seriata*. and *Gonyaulax* polygramma.

Primary cluster results based on Bray Curtis similarity revealed that there was similarity in community structure between stations with lower depth of 100 m and stations with higher depth of 100 m. Then the stations with more than 100 m depth were considered as offshore and stations with lower depth were specified as inshore stations.

The results of nMDS and ANOSIM analyses were consistent with the above hierarchy (Fig. 4). One way ANOSIM analysis demonstrated a significant difference between inshore and offshore phytoplankton communities (Global R_{total}: 0.258, P value $_{total}$= 0.001).

ANOSIM analyses revealed no significant difference between community structure at 0.5 m and 10 m depth of inshore stations (Global R total: 0.079, P value $_{total}$ = 0.153). The same results were found for community structure at 0.5 and 10 depth of offshore stations (Global R_{total}: -0.123, P value $_{total}$= 0.879). Therefore, for each station the average frequency of both 0.5m and 10 m was used in CCA analysis.

The CCA analysis based on manual forward testing was used to reveal the relationship between phytoplankton assemblages and environmental factors (Fig. 5). The uncorrelated environmental factors were excluded from CCA analysis (i.e. phosphate, nitrate, nitrite, pH. and turbidity). None of the environmental factors showed a significant effect on the spatial distribution of phytoplankton communities. Dissolved oxygen, silicate and chlorophyll a, have more effective on phytoplankton community. By increasing the amount of dissolve oxygen DO, phytoplankton community change and decreased. Instead, silicate and chlorophyll a have an additive effect on the communities (Fig. 5). Results also were revealed that *Thalassionema* spp. *followed by Stephanopyxis* spp, *Rhizosolenia* spp *Lingulodinium* spp. and *Pseudo-nitzschia* spp. are positively associated with silicate. *Gonyaulax* spp. followed by *Coscinodiscus* spp. positively associated with temperature and salinity. The presence of *Guinardia* spp. is correlated with dissolved oxygen.

GIS mapping of phytoplankton abundance (Fig.6) relatively showed more plankton distribution around inshore stations than to the offshore stations. Also Eastern inshore stations of Chabahar Bay revealed more phytoplankton abundances than stations at the western part.

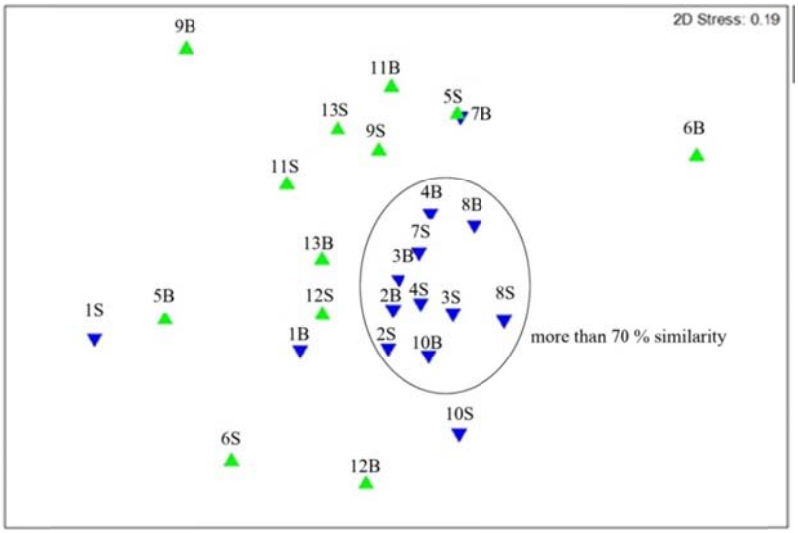

Fig. 4: Similarity between phytoplankton assemblage of inshore (blue triangle) and offshore (green inversion triangle) stations based on MDS analysis (Stress value: 0.19, fourth root). Overlying similarity contours derived from the cluster analysis highlighted stations with more the 70 % similarity (Stations within the ellipse).

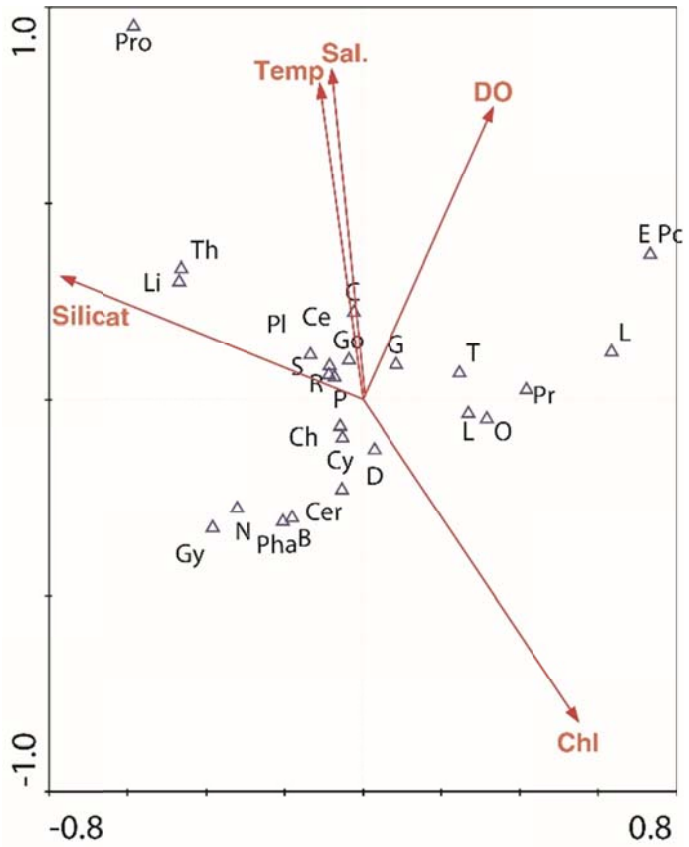

Fig. 5: Canonical correspondence analysis (CCA) ordination diagram showing associations between environmental variables and spatial patterns in macroinvertebrate assemblages in the study area. The environmental variables are Chlorophyll a (F=1.29 , P=0.21); Silicate (F=1.32 , P=0.22); Temperature (F=0.86, P=0.20); Salinity (F=0.81, P=0.6) and Dissolved oxygen (F = 0.92, P = 0.5). C; *Coscinodiscus*, G; *Guinardia*, O; *Odontella*, C; *Chaetoceros*, R; *Rhizosolenia*, P; *Pseudo-nitzschia*, L; *Lauderia*, Ce; *Ceratium*, Le; *Leptocylindrus*, Pr; *Protoperidinium*, T; *Thalassiosira*, Pro; *Proboscia*, N; *Noctiluca*, D; *Dinophysis*, Go; *Gonyaulax*, Li; *Lingulodinium*, Pc; *Prorocentrum*, E; *Eucampia*, Gy; *Gymnodinium*, B; *Bacteriastrum*, Ph; *Phaeocystis*, Cer; *Cerataulina*, S; *Stephanopyxis*, Cy; *Cyclotella*, Pl; *Planktoniella*, Th; *Thalassionema*.

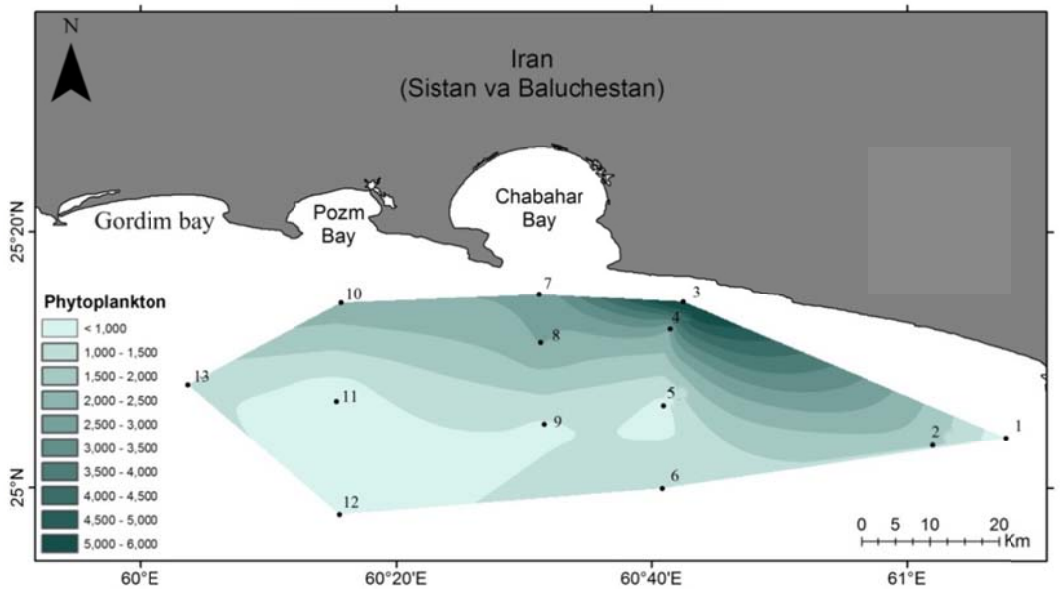

Fig. 6: spatial changes mean of phytoplankton biomass (mg/m3) at different stations in the studied areas.

4. Discussion

Phytoplankton community structures vary spatially and temporally around the world's oceans (Prabhahar et al., 2011). Physico-chemical factors (i.e. oceanic currents, seasonal monsoon, thermal stratification, NO3 concentration) affects plankton dynamics in marine environments (Nowrouzi and Valavi, 2011; Hassan et al., 2004, Al-Hashmi et al., 2012). Currents and seasonal winds (i.e. southwest or summer monsoon and winter or northeast monsoon) are two main environmental factors that affected plankton density and community in the Western Indian Ocean (Wilson, 2000). The studied area in the present contribution geographically is located out of the range covered by ROPME oceanographic cruises. The area strongly is influenced by the southwest monsoons that occur in July-September, so autumn and early winter considered as post-monsoon situation and the late of winter (March) and spring considered as pre-monsoon (Wilson, 2000; Walters and Sjoberg, 1988).

Al-Hashmi et al., (2012) observed large fluctuations in overall phytoplankton abundances per station ranging from 96 cells / L to 17495 cells /L. For the present contribution the maximum count of phytoplankton per station was 3975 and the minimum count of 53 cells/L. Less phytoplankton diversity of the present study (28 genera) compared to the high diversity of Al-Hashmi et al., (2012) study (248 taxa) is stated as a reason for this difference. Saraji et al., (2014) investigated phytoplankton composition of the Gulf of Oman during pre and post monsoon. They reported that Dinophyceae was the most abundant group (91.74%), followed by Bacillariophyceae (5.90%) in the pre-monsoon, while in the post-monsoon season, Bacillariophyceae was dominant (86.36%), followed by Dinophyceae (13.15%). Considering the sampling time in the present study (March), our results (Bacillariophyceae, 79%; Dinophyceae, 20 %) differ from Saraji et al., (2014). Instead, our results are consistent with findings of Gouda and Panigrahy (1996) for the east coast of India and Al-Hashmi et al., (2012) for the Oman Sea. They stated that diatoms dominated during winter when the temperature dropped below 26°C, while dinoflagellates dominated during summer when the water temperature increased above 28°C (Al-Hashmi et al., 2012). Sea surface temperature (SST) in the present sampling areas ranged between 23.3-23.8°C (Table. 1). The dominance of dinoflagellate over diatoms during summer is reported by Al-Azri et al (2010) for the Oman Sea. Dinoflagellates expressed that better adapted than diatoms to dominate the phytoplankton communities under low nutrient concentration (Lalli and Parson, 1997) as well as higher temperatures (Boney, 1989).

Based on our results *Rhizosolenia* spp., *Chaetoceros* spp. and *Pseudo-nitzschia* spp. were the most abundant phytoplankton. Al-Hashmi et al., (2012) reported Rhizosolenia and Coscinodiscus as the most abundant diatoms in their study. However, Saraji et al., (2014) reported Rhizosolenia imbricate, *Chaetoceros dichaeta* and *Chaetoceros atlanticum* only in the post-monsoon season.

In the present contribution, Bacillariophyceae, with 17genera, is more diverse than to the Dinophyceae, with 8 genera. Our findings disagree with Al-Hashmi et al., (2012) those who observed 248 phytoplankton taxa, where Dinophyceae was more diverse (131 species) than the Bacillariophyceae (120 species). Dinophyceae was also more diverse than Bacillariophyceae in Saraji et al., (2014) study. The main reason for this difference is the multiplicity of time and depths sampled in two mentioned study compared to the present study. In addition different hydrography of the sampling areas, in Al-Hashmi et al., (2012) study (i.e. the upwelling tends during the late-summer in Khyran Bay) that increase the concentration of nutrients and as a result phytoplankton abundances and diversitis may be the reason for this discrepancy.

Salinity is the main environmental variable

responsible for spatial community distribution in the Eastern Indian Ocean (Achary et al., 2010). Al-Hashmi et al., (2012) stated that the phytoplankton abundance, its seasonal and spatial variability are strongly associated with thermal stratification and NO_3 concentration in the waters in Bandar Khyran (Oman Sea).

In the present study, chlorophyll a, silicate, temperature, salinity and dissolved oxygen seemed that affect phytoplankton community distribution, however there is no significant correlation between community structure and environmental factors. Decoupling of phytoplankton community and environmental conditions even for long term environmental data (Corcoran and Shipe, 2011; Kim et al., 2009). Cluster analysis to find out similarity of phytoplankton composition among stations showed two distinct sampling station groups: offshore stations (triangle in Fig. 4) and inshore stations (inverted triangle in Fig. 4). Inshore and offshore gradients in phytoplankton community composition also is reported by Durairatnam et al., (1969) in Gulf of Mannar, Burford et al., (1995) in Australia, Estrada et al., (1999), Varela et al., (2001) in Mediterranean Sea and by Corcoran and Shipe (2011) in Santa Monica Bay. The results of MDS and ANOSIM analysis confirmed the significant difference between inshore and offshore surface phytoplankton assemblages. However this difference was not observed in the Persian Gulf, (Rabaniha, 2012). It was expected that high organic nutrient concentrations and water-column stratification in near shore waters are possible reasons for this change (Corcoran and Shipe, 2011). Because of limitations of our knowledge about currents and other hydrological parameters affecting phytoplankton community in the Gulf of Oman, a more detailed future studies will reveal why this difference exists. In spite of significant differences between inshore and offshore stations, there is no significant difference between phytoplankton community in surface water (0.5 m) and 10 m depth. Therefore, the layer 0-10 m in the studied area could be considered as surface layer when sampling is designed in phytoplankton monitoring program.

Inshore stations showed higher taxa than to the offshore stations (Table. 4). Twenty one taxa were recorded for inshore stations, and 17 taxa were observed for offshore stations, some of them restricted to inshore or offshore waters. Malone, (1980) mentioned that continental shelf areas generally have higher proportion of large phytoplankton than small species. Also Eastern inshore stations of Chabahar Bay revealed more phytoplankton abundances than western part stations; it seems upwelling currents of the eastern parts (Reynolds, 1993) of the Oman Sea near to Chabahar Bay may be affecting phytoplankton abundances. In the present contribution *Noctiluca scintillans* was only observed at station 2 (Table. 2). The *N. scintillans* often bloom in the Indian Ocean region, including the Sea of Oman (Al-Azri et al., 2007). Temperatures ranging from (22~24) °C and (20~24) °C were also expressed to be optimum for Noctiluca at various regions (Uhlig and Shaling, 1985). Al-Hashmi et al., (2012) reported blooms of the *Noctiluca scintillans* during the months of January and September. Although water temperature in the present study ranged between 23.3-23.8°C (Table. 1), *N. scintillans* was observed with low abundance (110 cell/L). The increase in optimum biological and hydrographic factors play major role in the bloom formation of *Noctiluca scintillans* and its spatial distribution (Al-Hashmi et al., 2012).

Different criteria clearly are being used to define bloom occurrence of toxic vs nontoxic phytoplankton. For harmful species, mere presence or measurable toxin levels are increasingly defined as a bloom occurrence. In other words, one or more species are in a state of bloom even though they may not achieve high biomass or high population density (Smayda, 1997). Depending on environmental conditions, potential bloom levels differ intrinsically among

species (Agusti et al. 1987). For the RSA region, Richlen et al., (2010) reported bloom of Cochlodinium polykrikoides, an ichthyotoxic dinoflagellate, in the Persian Gulf and Gulf of Oman during 2008-2009. We did not observe presence of *C. polykrikoides*, in our sampling stations, instead we recorded some toxic genera include *Dinophysis* caudate, *Peudo-nitzschia seriata and Gonyaulax polygramma*. Al Hashemi et al (2012) also observed Dinophysis and Pseudo-nitzschia in their sampling stations. Smayda (1997) stated that Dinophysis at very low densities, generally less than 1,000 cells/ L can be considered as harmful bloom. In the present study, the maximum counted Dinophysis 153 cells/L. Fish kills can occur, at concentrations of ~0.5 million cells/ L for *Gymnodinium breve* before water is visibly discolored (Bushaw-Newton & Sellner 1999). The Maximum number of *G. breve* of the present study was 181 cells/L (Station No. 6 B).

Conclusion and Recommendations

The dynamics of phytoplankton communities are linked to annual fluctuations of temperature, water column stratification, resource availability, and consumption. Climate can modify these environmental factors and strongly affects the diversity, community structure, and temporal dynamics of phytoplankton. Changes in phytoplankton communities provide a sensitive early warning for climate-driven perturbations to marine ecosystems (Hallegraeff, 2010). Regular phytoplankton monitoring programs is recommended for the Gulf of Oman and the Persian Gulf to identify future changes in marine ecosystems. In spite of significant differences of phytoplankton compositions between inshore and offshore stations, there is no significant difference between phytoplankton community in surface water (0.5 m) and 10 m depth. We recommend the layer 0-10 m in the studied area can be considered as surface layer in monitoring program. Even though the concentration of harmful algae reported in the present study was low, there is always the threat of increasing bloom from industrial and domestic effluents that could enhance the growth of these species.

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