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Effects of physicochemical factors on seasonal variations of phytoplankton in the Mond River Estuary of Bushehr Province, Persian Gulf, Iran

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Abstract. *Pouladi M, Qadermarzi A, Baharvand F, Vazirizadeh A, Hedayati A. 2017. Effects of physicochemical factors on seasonal variations of phytoplankton in the Mond River Estuary of Bushehr Province, Persian Gulf, Iran. Biodiversitas 18: 229-237.* The main purpose of present study was to investigate the abundance and biodiversity of phytoplankton from Mond estuary, Bushehr, Persian Gulf during different seasons and its relationships with environmental parameters and nutrients. Samples were taken in mid-season from spring 2012 to winter 2013 for oneyear period. The phytoplankton were contributed by the phyla Bacillariophyta, Dinophyta, Haptophyta, and Chlorophyta. The class Coscinodiscophyceae and Bacillariophyceae belonging to Bacillariophyta were the most diverse and dominant with 22 and 16 genera, respectively. The mean phytoplankton abundance were recorded in spring (12706.7±3586.9 cells L^{-1}), in summer (10173.3±2560.08 cells L^{-1}), in autumn (10600±2758.2 cells L^{-1}) and in winter (7000±2401.6 cells L^{-1}), respectively. Simpson and Shannon-Wiener biodiversity indices obtained showed in spring (0.93±0.007 and 3.8±0.2), in summer (0.92±0.008 and 3.64±0.2), in autumn (0.92±0.006 and 3.63±0.15) and in winter (0.89±0.013 and 3.07±0.24), respectively. The phytoplankton assemblages were most diverse and abundant at station-5 in all seasons. In addition, there were significant correlation ($P<0.01$) between phytoplankton abundance and diversity with pH, salinity, NO_3, PO_4 and temperature. Based on Principle Component Analysis (PCA), the most important factors that could describe most changes of abundance and diversity of phytoplankton in the Mond River estuary system were salinity, NO_3, pH, PO_4 and temperature, respectively. Results demonstrated that diatoms were the dominant population and salinity factor was more effective factor that affected the diversity and abundance of phytoplankton during study period in Mond River estuary.

Keywords: Abundance, Bushehr, diversity, Mond River Estuary, phytoplankton, Persian Gulf

INTRODUCTION

Estuaries are dynamic transition zones between the continental and the marine ecosystems that are characterized by their high primary and secondary levels and ecological complexity (Attrill and Rundle 2002; Lam-Hoai et al. 2006; Matos et al. 2011). In these transitional ecosystems, fluctuations in environmental variables have a direct effect on the dynamics of biological populations, in particular the plankton community (Marques et al. 2006; Matos et al. 2011). Estuaries provide nursery habitat for fish, birds and many other organisms (Calbet et al. 2001). These ecosystems encompass one of the most productive ecosystems around the world (Day et al. 1989). In the estuarine planktonic biota, the phytoplankton deserves special attention due to their fundamental role in the primary production of coastal environment (Gross and Gross 1996; Tiwari and Chauhan 2006; Tas and Gonulal 2007; Saravanakumar et al. 2008). Increased human activities, industrialization and urbanization have put lots of pressure on the estuarine habitat. These activities have direct effect on the water quality, quantity and quality of phytoplankton and other organisms. The abundance of phytoplankton are biological indicators for evaluating water quality and the degree of eutrophication (Chaturvedi et al. 1999; Ponmanickam et al. 2007; Shekhar et al. 2008).

There have been very few studies on the seasonal and annual variation of phytoplankton in Iranian estuaries, which indicate that the environmental management can be limited by the relating to how the physical and chemical factors influence the phytoplankton seasonal patterns in estuaries. In addition, few long-term observations on the phytoplankton assemblages have been carried out in the Iranian waters of the Persian Gulf (Seraji and Daghoughi 2000; Fallahi 2003; Fatemi et al. 2012; Isapour et al. 2012; Aein Jamshid et al. 2014; Shapoori and Golami 2014). Saraji and Daghoughi (2000) observed 35-40 phytoplankton genera in the coastal waters of west, central and east of Hormozgan; Fallahi (2003) observed diatoms were dominant with 97 species in the waters of Bushehr in Persian Gulf; Isapour et al (2012) showed that diatoms were more abundant and specious at Khouzestan when compared with other groups at Bushehr and Hormozgan areas; Shapoori and gholami (2014) observed that

Bacillariophyceae and Dinophyceae were the dominant groups of phytoplankton in the Kharg Island waters and AeinJamshid et al (2014) observed that the high risk toxin producing Dinophyceae and Bacillariophyceae dominated at contributing to about 29.3% and 61.7% of the total phytoplankton, respectively.

Mond estuary and river is the fifth river of Iran with 750 km estimated length. The Mond River (MR) originates from Fars Province and gets discharged in to the Persian Gulf, passing through Jahrom, Firuzabaad in the Fars province and Jam, Dashti and Dayyer in the Bushehr province (Ahmadi et al. 2013). The MR basin is ecologically important for migratory birds, wild life and aquatic organisms, especially fish. Therefore, studying on the phytoplankton abundance, composition and diversity of MR estuary is an important aspect for fishery management. The main objective of this study was to determine the phytoplankton abundance and diversity, and their ecological relationships with nutrients and water quality parameters in the MR estuary, Bushehr, the northern part of Persian Gulf, Iran.

MATERIALS AND METHODS

Study area

The study area was located in the Mond River estuary, the southeastern part of Bushehr province, and north of Persian Gulf, Iran (Figure 1). Along MR estuary, five sampling stations were determined based on environmental gradients of flow dynamics and mixing of fresh and coastal waters, depth, tides, river flow and geo-morphological features (Table 1).

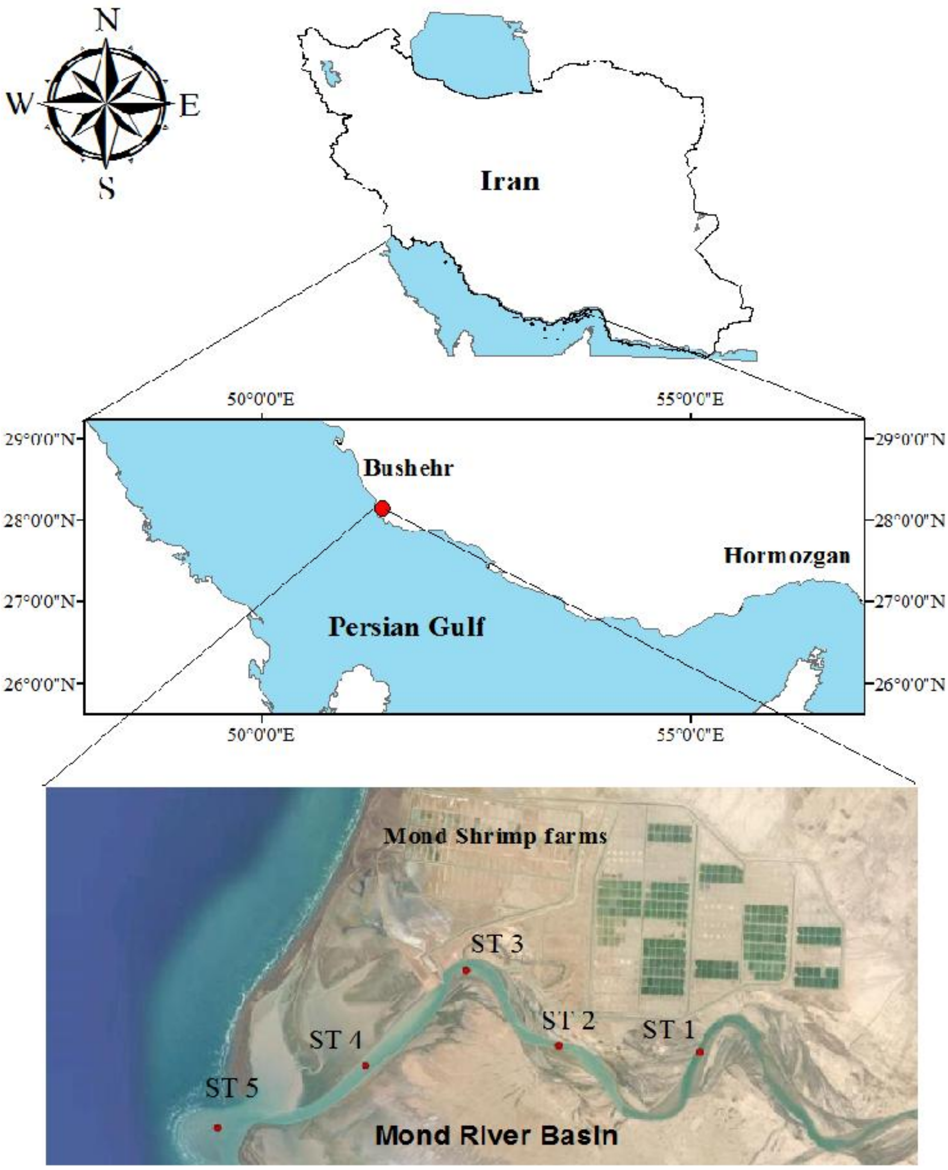

Figure 1. Sampling stations at the Mond River estuary, Persian Gulf, Iran

Procedures

Seasonal samplings were carried out in the middle of each season for one year period from May 2012 to February 2013.Water temperature and pH were recorded by Mercury thermometer and pH meter model WTW. Salinity was recorded with using Atago S/Mill refractometer. Dissolved oxygen was measured by YSI 51 Oxygenmeter (Model OH, USA) and transparency was obtained by Secchi depth plate .Water samples for measurement of nutrients were collected by Ruttner bottle (Hydro-Bios Model) and were measured using HACH spectrophotometer (Model DR 4000). To investigate the abundance and identification of phytoplankton assemblages, 3 liters of water were sampled with Ruttner bottles and were immediately fixed using Lugol's iodine solution (10 ml per 200 ml of sample). These bottles were stored in a cool and dark place for transportation to the laboratory survey. Enumeration of phytoplankton were carried out using Sedgwick rafter chamber with the aid of inverted microscope (Model: CETI Belgium) and were identified using standard publications(Faust and Gulledge 2002; Newell and Newell 2004).

The following formula was used to calculate the abundance of phytoplankton:

$$C\ [\text{cells } L^{-1}] = \frac{N \times 1000\ mm^3}{A \times D \times F}$$

N= number of cells or units counted, A= area of field (mm^2), D= depth of a field (Sedgwick-Rafter chamber depth) (mm), F= number of fields counted.

Taxonomic diversity indices were calculated using the phytoplankton database, for each station.. The Shannon-Wiener diversity index (H′) (Shannon and Weaver 1948) and Simpson index of diversity (D) (Simpson 1949) were used for species diversity as following:

$$H = -\sum_{i=1}^{s}(Pi)(\ln Pi) \quad (1)$$

$$D = 1 - \sum_{i=1}^{s}(Pi)^2 \quad (2)$$

Pi: the relative abundance of the i^{th} taxon, S: total number of taxa

Data analysis

One-way ANOVA was performed to test significant seasonal differences in phytoplankton abundance, diversity and water quality parameters. Data were presented as means ± standard error of means. Differences in means were compared by Duncan's Multiple Range Test. All data met the parametric test assumptions (normal distribution, homogeneity of variance, independence and randomness of the data). Data was transformed by Arcsin-square root to ensure a normal distribution (Zar 1984). All statistical analysis was carried out using SPSS, version 18.0. Pearson correlation was calculated for the abundance, diversity, water parameters and nutrients. Canonical correlation analysis was performed using CANOCO, version 4.5 and diversity indices were calculated using Ecological Methodology, version 6.0 (Krebs 2001).

RESULTS AND DISCUSSION

During the present study, 4 phyla of phytoplankton communities were identified: Bacillariophyta, Dinophyta, Haptophyta, and Chlorophyta (Tables 2). Higher diversity was observed from class Coscinodiscophyceae belonging to phylum Bacillariophyta with 22 genera and 37 species, and class Bacillariophyceae belong to phylum Bacillariophyta with 16 genera and 18 species. Phytoplankton species including *Coscinodiscus centralis*, *Donkinia* sp. and *Pleurosigma cuspidatum* belonging to the class *Coscinodiscophyceae* and phylum Bacillariophyta were observed during all seasons, but *Skeletonema costatum*, *Odontella mobiliensis*, *Odontella sinensis, Rhizosolenia bergonii*, *Rhizosoleina shurbsolei*, *Dactyliosolen fragilissimus*, *Chaetoceros compressus* and *Chaetoceros peruvianus* belonging to the class *Cosciodiscophyceae* and *Gyrosigma diminutum* belonging to the class *Bacillariophyceae* and phylum Bacillariophyta showed lowest dispersion in MR estuary during the study period (Tables 2). The mean seasonal abundances of phytoplankton are presented in Figure 2. Mean abundance of phytoplankton were 12706.7±3586.9 cells L^{-1} in spring, 10173.3±2560.08 cells L^{-1} in summer, 10600±2758.2 cells L^{-1} in autumn and 7000±2401.6 cells L^{-1} in winter, respectively. Station 5 at all seasons showed highest phytoplankton abundance i.e. in spring (25466.7±5205.55 cells L^{-1}), in summer (18933.3±3868.4 cells L^{-1}), in autumn (20666.7±4938.74 cells L^{-1}) and in winter (16066.7±1567.73 cells L^{-1}), respectively (Figure 2). The dominant species were observed to be *Palmeria hardmaniana* (with 2933.33±272.7 cells L^{-1}) in spring, *Coscinodiscus astermphalus* (with 3266.7±237.9 cells L^{-1}) in summer, *Pleurosigma cuspidatum* (with 2133.33±166.8 cells L^{-1}) in autumn and *Coscinodiscus centralis* (with 2133.33±256.9 cells L^{-1}) in winter. Between identified phytoplankton, diatoms (Coscinodiscophyceae and Bacillariophyceae) were dominant classes of phytoplankton in MR estuary. Where *Palmeria hardmaniana* (in spring), *Coscinodiscus astermphalus* (in summer), *Pleurosigma cuspidatum* (in autumn) and *Coscinodiscus centralis* (in winter) were the most abundant (Table 2). Phytoplankton communities are multispecies communities, which are highly multifaceted in terms of their diversity and dynamics. Succession shifts in phytoplankton community structure are mainly due to changes in environmental variables such as nutrients and other physicochemical variables which influence the distribution and abundance of plankton communities in estuaries (Ferreira et al. 2005; Madhu et al. 2007; Palleyi et al. 2011). Spatial distribution of diatoms in the estuary depends on the dispersion and mixing processes initiated by sea water and freshwater together. They always prefer to inhabit and dominates the phytoplankton community in shallow, turbulent and upwelling region, i.e. coastal region. Sufficiency of nutrients and radiant energy from the sun in this shallow and disturbed area facilitate these microscopic producing organisms to photosynthesize and reproduce strongly. In addition, dominance of diatoms indicated the physical inconsistency of the shallow coastal environments (Stowe 1996; Fernandez and Brandini 2004). Thus, dominance of diatoms, as observed during the present study is very common. The population size and relative abundance of each species within a planktonic assemblage was a function of the differential abilities to reproduce and survive in the estuary environment. Most diatoms were puissant of remaining in the estuarine environment despite their erratic salinities (Sarojini and Sarma 2001; Sahu et al. 2012).

The mean seasonal Simpson and Shannon-Weiner biodiversity indices were presented in (Table.6). Mean diversity of Simpson and Shannon-Weiner were 0.93±0.007 and 3.8±0.2 in spring; 0.92±0.008and 3.64±0.2 in summer; 0.92±0.006 and 3.63±0.15 in autumn and 0.89±0.013and 3.07±0.24 in winter, respectively. Highest Simpson and Shannon-Weiner diversity indices were observed at station 5 during all the seasons with 0.95±0.004 and 4.37±0.14 in spring; 0.94±0.005 and 4.25±0.13 in summer; 0.94±0.012 and 4.13±0.28 in autumn and 0.92±0.01 and 3.75±0.2 in winter, respectively (Figure 2; Figure 3). Plankton communities in the estuary can serve as a biological indicator for studying / understanding any change in an ecosystem under pollution stress. In ecology, a diversity index is a statistic, which is applied to measure the species biodiversity in an ecosystem (Gao and Song 2005). In comparison of seasonal variation, the highest amounts of phytoplankton diversity were in the spring and lowest during winter. The nature of species diversity in relation to species composition and phytoplankton abundance is a significant feature in aquatic environments. Commonly, species diversity increases with an increase in their numerical abundance. Similarly, low species diversity happens, when some particular species or one species dominates the phytoplankton population (Chandran 1985; Kulshreshta et al. 1989; Sahu et al. 2012).

Seasonal average of temperature and dissolved oxygen were 23.92 °C and 8.28 mg L^{-1} in spring; 33.4 °C and 6.87 mg L^{-1} in summer; 19.54°C and 7.39 mg L^{-1} in autumn, and 14.8 °C and 9.46 mg L^{-1} in winter, respectively. Seasonal average of water transparency, salinity and pH were 43.6 cm, 28.2 ppt and 8.2 in spring; 44.8 cm, 38.8 ppt and 8.1 in summer;4 6 cm, 35.8 ppt and 8.1 in autumn and 49.8 cm, 25.2 ppt and 8.15 in winter, respectively, where the seasonal average of nutrients PO_4 and NO_3 were 190 and 40 µg L^{-1} in spring, 190 and 34 µg L^{-1} in summer, 200 and 33 µg L^{-1} in autumn and 120 and 23 µg L^{-1} in winter, respectively (Table 7).

Correlation among water parameters with phytoplankton abundance and diversity indices are presented in (Table 7). The results showed that there were positive correlation between phytoplankton abundance and salinity (0.01> P and r=0.679);Simpson diversity and salinity (0.01> P and r=0.77); Shannon-Wiener diversity and salinity (0.01> P and r=0.779); phytoplankton abundance and pH (0.01> P and r=0.682);Simpson diversity and pH (0.05> P and r=0.453); Shannon-Wiener diversity and pH (0.05> P and r=0.556); phytoplankton abundance and PO_4 (0.05> P and r=0.473); Shannon-Wiener diversity and PO_4 (0.05> P and r=0.463); phytoplankton abundance and NO_3 (0.01> P and r=0.603);Simpson diversity and NO_3 (0.01> P and r=0.805); Shannon-Wiener diversity and NO_3 (0.01> P and r=0.779); Simpson diversity and Temperature (0.05> P and r=0.532) and Shannon-Wiener diversity and Temperature (0.05> P and r=0.448) (Table 8).

During the study period, based on PCA, stations 4 and 5 in spring, stations 4 and 5 in summer, stations 4 and 5 in autumn, and station 5 in winter were most contributed by abundance, diversity, salinity, NO_3, pH, PO_4 and Temperature, while least by Transparency and dissolved oxygen (Figure 5; Table 8).

In this study, salinity varied from its maximum 38.8 ppt in August to its minimum 25.2 ppt in February and the ANOVA result confirm these findings. Based on Pearson correlation and PCA, salinity is a major factor that affects the abundance and diversity in our study area. The salinity in Bushehr coastal waters is affected by the general trend of salinity variation in Persian Gulf which is depended on the current entering from Indian Ocean and Oman Sea in to the Persian Gulf, and mixing of low saline freshwater of Mond and Helleh Rivers with high saline seawater (Kamp and Sadrinasab 2006; AeinJamshid al. 2014). Salinity is a dynamic indicator of the nature of the exchange system. Phytoplankton abundance in the MR estuary increases towards the sea via the salinity gradient. Salinity influences the distribution and diversity of many living marine species. The rate of cell division on this microflora, as well as their occurrence, distribution and productivity is influenced by salinity (Lionard et al. 2005; Putland et al. 2007; Palleyi et al. 2011; Sahu et al. 2012; Farhadian et al. 2015). There are many other factors, other than salinity that can influence the distribution of phytoplankton, such as turbidity, freshwater influx volume, water column stratification and grazing rate of zooplankton (Burns and Beardall 1987).

Seawater pH may have a main performance on phytoplankton growth with a number of possible mechanisms at high pH, carbon limits occur for organisms that cannot use of bicarbonate (Burns and Beardall 1987; Nimer and Merrett 1992), so pH affects on primary production (Chen and Durbin 1994). We observed that the pH was in alkaline range and its impacts on the stations with most phytoplankton abundance at the mouth of the estuary.Even a slight change or deviation from the optimum pH level leads to change in the ionic equilibrium in estuaries, whereby the cells will have to use more energy to maintain internal conditions and the rate of cellular enzymatic reaction gets impaired (Nimer et al. 1997).

Available data indicate that phytoplankton production and biomass in most benthic systems is controlled by nutrients (Wehr and Sheath 2003; Onyema and Emmanuel 2009). Among the nutrients, Phosphate and nitrogen compounds are the limiting nutrients, whose concentrations in water influence phytoplankton growth (Ambasht and Ambasht 2005). According to PCA analysis, NO_3 and PO_4 were other effective factors in stations with most

Table 2. Comparison of phytoplankton presence (*) during different seasons at the Mond River estuary, Persian Gulf, Iran

Species	Spring	Summer	Autumn	Winter
Cosciodiscophyceae				
Actinocyclus octonarius	*	*		
Bacterastrum delicatulum	*	*		
Bacterastrum hyalinum		*	*	
Cerataulina pelagica	*		*	*
Chaetoceros coarctatus	*		*	*
Chaetoceros compressus				*
Chaetoceros decipiens		*	*	*
Chaetoceros peruvianus		*		
Climacodium frauenfeldianum				*
Coscinodiscus astermphalus	*	*	*	
Coscinodiscus centralis	*	*	*	*
Coscinodiscus granii	*	*	*	
Coscinodiscus oculus-iridis	*	*	*	
Coscinodiscus radiates	*	*		*
Coscinodiscus wailesii		*		*
Cyclotella stylorum		*	*	
Dactyliosolen fragilissimus				*
Dentonula pumila	*	*		
Ditylum brightwelli			*	*
Guinardia flaccida			*	
Guinardia striata	*		*	*
Helicotheca thamensis	*	*		
Hemiaulus sinensis	*	*	*	*
Lampriscus broeckii	*	*	*	
Lampriscuss hadboltianum		*		*
Lauderia annulata		*	*	*
Odontella mobiliensis			*	
Odontella sinensis				*
Palmeria hardmaniana	*	*	*	
Proboscia alata	*	*	*	
Rhizosoleina shurbsolei				*
Rhizosolenia bergonii	*			
Rhizosolenia imbricate	*	*	*	
Skeletonema costatum		*		
Stephanopyxis palmeriana	*		*	*
Thalassiosira eccentric	*	*		
Thalassiosira oestrupii	*		*	*
Fragilariophyceae				
Asterionellopsis glacialis	*	*		
Fragilaria sp.		*	*	
Grammatophora oceanica			*	*
Thalassionama nitzchioides		*	*	
Thalassiothrix cf. longissima	*	*		
Trachysphenia australis	*		*	*
Bacillariophyceae				
Achnanthes brevipes		*	*	*
Amphora sp.	*		*	
Cylindrotheca sp.		*	*	*
Diploneis smithii	*		*	
Donkinia sp.	*	*	*	*
Entomoneis sulcata		*	*	*
Gyrosigma diminutum		*		
Haslea cf. balearica		*	*	
Mastogloia linearis	*		*	
Navicula cf. erifuga	*	*		*
Nitzschia lorenziana	*			*
Nitzschia panduriformis	*	*	*	*
Nitzschia sp.		*	*	
Plagiotropis lepidoptera		*	*	*
Planothidium sp.	*	*	*	
Pleurosigma cuspidatum	*	*	*	*
Surirella fastuosa		*	*	
Trachyneis antillarum			*	*
Raphidophyceae				
Heterosigma sp.	*	*	*	*
Dinophyceae				
Alexandrium insuetum	*	*	*	
Amphidinium sp.		*	*	
Ceratium breve	*			*
Ceratium Furca		*	*	*
Ceratium massiliense	*	*		
Dinoflagellate spp.	*	*		
Dinophysis caudate	*	*		
Dinophysis mitra	*		*	*
Prorocentrum gracile	*			*
Prorocentrum lima		*	*	
Prorocentrum micans	*			*
Protoperidinium elegans	*		*	
Protoperidinium sp.		*	*	*
Protoperidinium spiniferum		*		*
Noctilucophyceae				
Noctiluca scintillas	*	*	*	
Coccolithophyceae				
Phaeocystis sp.	*		*	
Pyramimonadophyceae				
Pterosperma undulatum		*		*

abundance and diversity. Distribution of nutrients and chemical composition in an estuary represents the mixing of two dissimilar waters bodies, those of rivers, streams and the sea, which are associated with fluctuating stream flood seasons and the flow of large quantities of freshwater, or with dry seasons when tidal flow of seawater dominates (John 1986). The natural nutrient cycle can be disrupted however, by excessive nutrient loading from human sources such as wastewater or agricultural run offs can lead to harmful algal blooms. Thus, total primary production will not necessarily change, but changes in the concentration and ratio of nutrients can affect phytoplankton communities and their ecological impact is profound (Caljon 1987; Day et al. 1989; Jiyalalram 1991; Sahu et al. 2012; Farhadian et al. 2015). Phosphate plays an important role in proliferation and increasing phytoplankton abundance, i.e. when abundant phosphate is stored by phytoplankton as polyphosphate granules and when phosphate is low, is secreted by alkaline phosphatase activity, by the hydrolysis of a chemical bond between the phosphates and are used is the form of phosphates (Barnes and Hughes 1999; Castro and Huber 2000). Different forms of nitrogen compounds (especially NO_3 form) and ammonia excreted by zooplankton and some animals are quickly absorbed by algae and some phytoplankton. Also decomposition of fauna and flora by bacteria in the nitrogen supply is involved. In open areas, with increasing of light intensity, day length and phytoplankton bloom, the amount of nitrogenous compounds is greatly reduced. So it can be an important factor in the growth and proliferation of phytoplankton (Castro and Huber 2000; Barnes 2003).

Temperature was another effective factor that has significant correlation with phytoplankton assemblage. Ecological effects of sea temperature due to metabolism and increasing heat is very important and in many cases phytoplankton maximum growth associated with this index is predictable (Dorgham and Moftah 1989). Also PCA analysis showed that the water transparency is another effective factor in relation to other factors and nutrients at stations. Water turbidity reduces light penetration and photosynthetic activity, which in our study has changed the absorption of radiant energy, where high suspended material and sediments concentration were observed. In such circumstances, the population of phytoplankton, particularly diatoms are reduced which in turn could reduce the population of zooplankton and macrobenthic invertebrates (Barnes and Hughes 1999; Barnes 2003).

Table 5. Seasonal abundance (Mean ±SE) of phytoplankton classes at different stations of the Mond River estuary, Persian Gulf, Iran

Class	Spring	Summer	Autumn	Winter
Bacillariophyceae	11733.3±940.56	10666.7±895	16200±1236.62	8466.67±833
Coccolithophyceae	800±49.9	-	600±24.94	-
Coscinodiscophyceae	34600±2904.02	27666.6±2221.76	24066.7±2404.5	18400±1672.1
Dinophyceae	10800±801.17	7066.7±580.72	7600±680.44	4733.33±542.38
Fragilariophyceae	3866.7±295.9	3733.33±333.5	3600±110.16	2400±221.58
Noctilucophyceae	1200±16.33	533.33±42.22	333.33±42.16	-
Pyramimondophyceae	-	666.67±36.51	-	600±57.35
Raphidophyceae	533.33±34	533.33±34	600±74.23	400±38.87

Table 6. Mean (±SE) of phytoplankton abundance and diversity indices in Mond River estuary, Persian Gulf, Iran (P<0.05)

Index	Spring	Summer	Autumn	Winter
Abundance	12706.7±3586.9 ^{a}	10173.3±2560.08 ^{a}	10600±2758.2 ^{a}	7000±2401.6 ^{b}
Simpson	0.93±0.007 ^{a}	0.92±0.008 ^{a}	0.92±0.006 ^{a}	0.89±0.013 ^{b}
Shannon-Weiner	3.8±0.2 ^{a}	3.64±0.2 ^{ab}	3.63±0.15 ^{ab}	3.07±0.24 ^{b}

Table 7. Average of water quality parameters in different seasons at Mond River estuary

Parameters	Spring	Summer	Autumn	Winter
Salinity (ppt)	28.2±4.21^{bc}	38.8±1.68^{a}	35.8±1.53^{ab}	25.2±4.19^{c}
Dissolved Oxygen (Mg L^{-1})	8.28±0.15^{b}	6.87±0.22^{c}	7.39±0.11^{c}	9.46±0.38^{a}
pH	8.2±0.025^{a}	8.1±0.013^{b}	8.1±0.06^{b}	8.15±0.045^{ab}
Temperature (^{O}C)	23.92±0.16^{b}	33.4±0.5^{a}	19.54±0.2^{c}	14.8±0.33^{d}
Transparency (cm)	43.6±0.68^{b}	44.8±1.16^{b}	46±1.05^{b}	49.8±1.5^{a}
PO_4 (µg L^{-1})	190±30^{a}	190±33^{a}	200±50^{a}	120±30^{b}
NO_3 (µg L^{-1})	40±2^{a}	34±1^{b}	33±4^{b}	23±2^{c}

Note: Values with different letters indicate significant mean differences

Table 8. Pearson correlation between some of the properties of water with abundance and biodiversity indices in Mond River estuary, Persian Gulf, Iran

Correlation		Abundance	Simpson Index	Shannon-Weiner Index
Salinity	Pearson Correlation	0.679**	0.770**	0.779**
	Sig. (2-tailed)	0.001	0.001	0.001
Dissolved Oxygen	Pearson Correlation	0.090	-0.215	-0.119
	Sig. (2-tailed)	0.705	0.363	0.616
pH	Pearson Correlation	0.682**	0.453*	0.556*
	Sig. (2-tailed)	0.001	0.045	0.011
Temperature	Pearson Correlation	0.239	0.532*	0.448*
	Sig. (2-tailed)	0.309	0.016	0.047
Transparency	Pearson Correlation	0.223	-0.092	0.016
	Sig. (2-tailed)	0.346	0.700	0.948
PO_4	Pearson Correlation	0.473*	0.402	0.463*
	Sig. (2-tailed)	0.035	0.079	0.040
NO_3	Pearson Correlation	0.603**	0.805**	0.779**
	Sig. (2-tailed)	0.005	0.001	0.001

Note: *: Significant correlation in 0.05 level, **: Significant correlation in 0.01 level

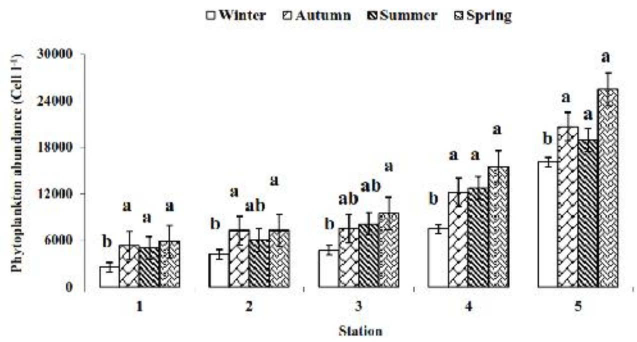

Figure 2. Seasonal abundance (Mean ±SE) of phytoplankton at different stations in the Mond River estuary, Persian Gulf, Iran (P<0.05).

Table 8. Seasonal PCA analysis of phytoplankton abundance, diversity indices and water quality parameters at Mond River estuary, Persian Gulf, Iran

Parameters	**Component**	
	1	**2**
Abundance	0.204	0.137
Simpson	0.194	-0.007
Shannon-Weiner	0.208	0.043
Salinity	0.157	-0.027
Dissolved Oxygen	0.008	0.346
Ph	0.150	0.252
Temperature	0.075	-0.246
Transparency	0.034	0.302
Po_4	0.108	-0.035
No_3	0.151	-0.131
Percent of Variance	49.55	26.01

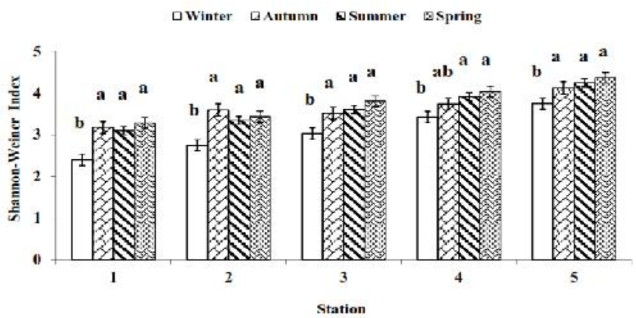

Figure 3. Shannon-Weiner diversity (Mean ±SE) of phytoplankton at different stations in the Mond River estuary, Persian Gulf, Iran (P<0.05)

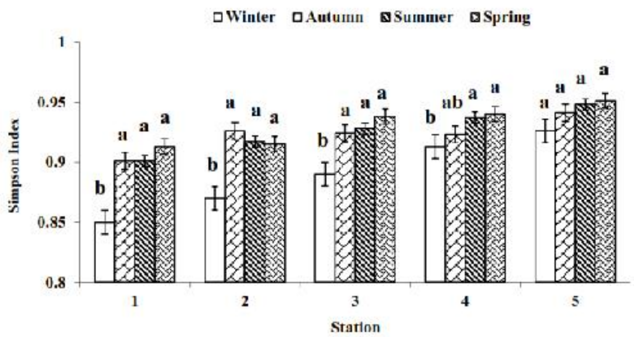

Figure 4. Simpson diversity (Mean ±SE) of phytoplankton at different stations in the Mond River estuary, Persian Gulf, Iran (P<0.05)

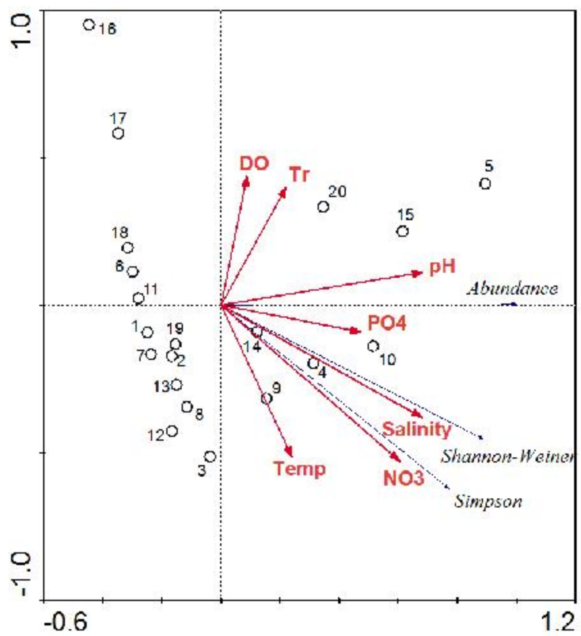

Figure 5. Stations-parameters biplot diagram of PCA analysis summarizing the contribution of dominant factors during the study period at different stations. DO (Dissolved oxygen), (pH), Tr (Transparency), Temp (Temperature), (1-5) spring stations, (6-10) summer stations, (11-15) autumn stations, (16-20) winter stations

Dissolved oxygen is the other critical variable in evaluating the water quality in estuaries. The low dissolved oxygen concentration of a water body directly affects the survival of aquatic organisms, and thus alters the ecological balance of a healthy estuary (Zheng et al. 2004). Frequent occurrences of hypoxia due to sudden decrease of dissolved oxygen has caused significant reduction of fishery harvests, toxic algal blooms and loss of biotic diversity (Pearl 1988; Howarth et al. 2000). The variances of dissolved oxygen in estuaries are controlled by physical and biochemical processes (Ambrose et al. 1993; Chen 2003) and for this area we need more studies and researches specially sediment biogeochemistry and water body biochemistry.

To conclude, our study showed that the highest abundance and diversity of phytoplankton communities were observed at the mouth area of the estuary during all seasons and had a positive significant correlation with salinity, NO3, pH, PO4 and Temperature. Since few studies have been conducted in the estuaries of the Persian Gulf, therefore, it is recommended to investigate zooplankton and Benthos communities for understanding the relationships between communities in estuaries.

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