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Research Article

Short-term variations of phytoplankton communities in response to *Noctiluca scintillans* bloom in the Chabahar Bay (Gulf of Oman)

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Abstract

The abundance, distribution, and species composition of phytoplankton were investigated in Chabahar Bay located in the Gulf of Oman during 2016-2017. The number of 114 phytoplankton species belong to 4 main phylum (Bacillariophyta, pyrrophyta, Cyanophyta and Chromophyta) were identified of which the most dominant phytoplankton group was pyrrophyta with a relative abundance of 94%. A significant difference of the density of phytoplankton between different sampling months was observed (non-parametric Kruskal-Wallis analysis, $p \leq 0.05$). Clear alignment between phytoplankton abundance and nutrient contents was observed during study period. The results showed that increasing the concentration of nutrients by the mid-autumn resulted in phytoplankton blooms. *Noctiluca scintillans* blooms were observed in October, January and February with the highest abundance in February while, disappeared in the rest of the sampling months. The maximum values of nutrients were observed in Oct (0.73, 5.59 and 3.66 µM of phosphate, nitrate and silicate, respectively) followed by a sharp decrease during Jan and Feb which is probably due to the phytoplankton blooms started from Oct. Diatoms (Bacillariophyta) with a relative abundance of 5.3%, were present in all sampling times with the minimum and maximum abundance in October and February, respectively.

Keywords: Abundance, Distribution, Biodiversity, *Noctiluca*, phytoplankton, Chabahar Bay

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Introduction

Chabahar Bay is a semi-enclosed bay located on the southeastern coasts of Iran (25°17'45"N, 60°37'45"E). The average depth of the bay is 12 m (maximum depth of 22 m in the mouth) (Fazeli, 2013). In the Gulf of Oman as an extension of the northwest of the Indian Ocean, monsoonal winds cause changes in the environmental conditions and physical parameters in the water column.

Bloom succession is mainly affected by physical factors, nutrient obtainability, mixotrophy, and predators. The first bloom of phytoplankton in the Gulf of Oman is reported in 1970s. Since then, there have been usual reports of red tide occurrences in this region (Al- Gheilani, 2011).

Annual bloom of the *Noctiluca scintillans* creates one of the major HABs in the area especially in cold months that has extended through the Indian Ocean, northern of the Oman Gulf, over the previous decades (Harrison *et al*., 2011). Phytoplankton blooms could damage to desalination plant and remove tap waters (In one occasion, a bloom of *Prorocentrum micans* cut off the city's tap water for a week), also forced damages to shrimp reproduction and fishing (Koochaknejad *et al*., 2016).

Due to annual HABs, their causes and effects have been studied to evaluate the succession of micro algal species on the Gulf of Oman, and bloom timing, which are related directly to species community, environmental conditions, and specific features.

Although, some studies have been conducted on taxonomy of phytoplankton, Chabahar Bay's bloom, little care has been paid to specific phytoplankton communities and dominated species during monsoon in the northern Gulf of Oman and Chabahar Bay (Balcerak, 2012; Al-Hashmi *et al*., 2012; Dorgham, 2013; Saraji, 2014; Mirzaei *et al*., 2017). In particular, the mentioned studies used limited data of seasonal or twice a year variations. In this study we investigated the variations in bloom species, *Noctiluca scintillans* and other species abundance, diversity and community structures in Chabahar Bay every 2 months in 2016 and 2017 including 2 samplings during the SW monsoon period.

Materials and methods

Study Area

The present study was carried out in the Gulf of Oman- Chabahar Bay. Samples were collected from nine fixed stations, covering the whole bay and a reference point outside the bay (Ref. station), from Jul. 2016 to May 2017 (Fig 1). These periods were classified according to the start and ending of the SW monsoon winds. Stations' depths were in the range of 4 to 15 m in the bay and 20 m at Ref. station (Table 1). Samples were taken from 1 m below the surface in all stations and from the near bottom layer in stations 3, 6 and 8 (in the main transect). In Ref. station, water sampling and measurements were performed in water levels of 1, 10 and 20 m.

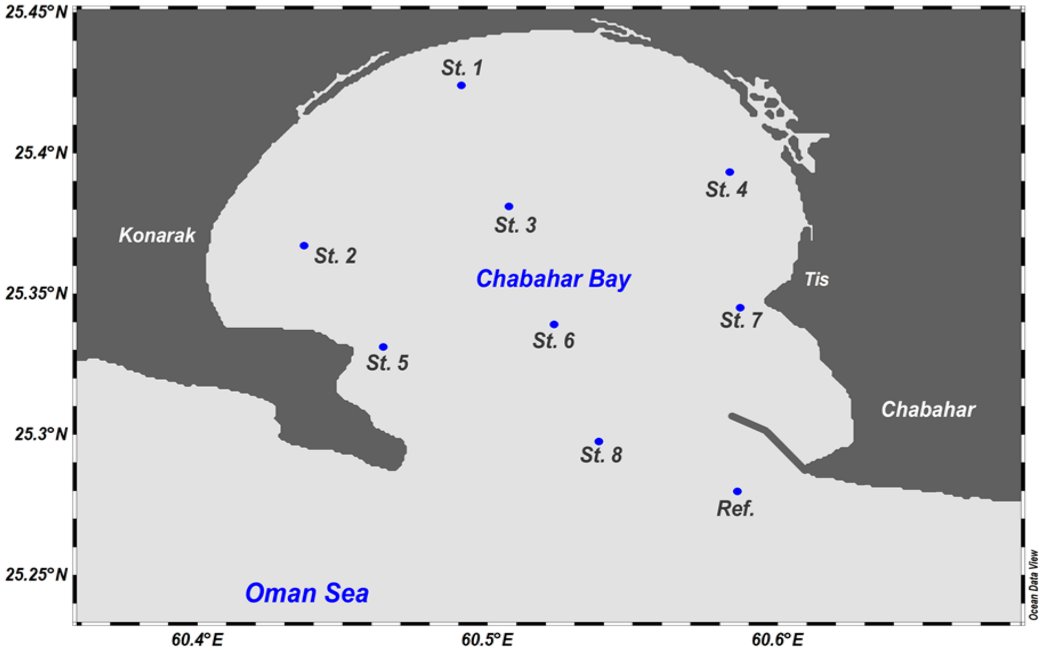

Figure 1: Map of study area located across the Chabahar Bay in the Gulf of Oman.

Sampling

In each season, measurements of parameters including pH$_{NBS}$, temperature, dissolved oxygen (DO) and salinity at different stations were done by using a HACH portable meter HQ40d. Seawater pH and temperature measurements were performed using a combined glass/reference electrode (HACH, IntelliCAL PHC101) calibrated by NBS buffers (accuracy of ±0.02, precision of ±0.001). Salinity measured by conductivity probe (HACH, IntelliCAL CDC401 with the precision of ±0.1) calibrated by a certified reference seawater. Dissolved oxygen was measured by a calibrated dissolved oxygen optical sensor (HACH, IntelliCAL LDO101 luminescent/optical dissolved oxygen probe). A niskin bottle sampler was used for phytoplankton sampling by three replicates from each station. In order to examine the phytoplankton, water samples were collected in 1-L polyethylene bottles and fixed immediately on board by Lugol's Solution (ASTM D 4148–82, 2012). Water samples for determining dissolved inorganic nutrients were immediately filtered by syringe filters (0.45 µm, cellulose acetate), collected in 125 mL high-density polyethylene bottles and quickly frozen until analysis (Grasshoff *et al*., 2009).

Laboratory Analysis

In order to examine the phytoplankton, water samples were collected in 1-L polyethylene bottles and fixed immediately on board by Lugol's Solution (ASTM D 4148–82, 2012). Samples were used for quantitative and qualitative analysis. The phytoplankton species were counted with a Sedgwick rafter cell. Sedgwick rafter cell was filled with a preserved phytoplankton sample. When the algae settled to the bottom, the chamber was examined by an inverted microscope (Axiovert S100, Zeiss) with different magnifications. Those algal cells lying within the border of the ocular grid were identified and enumerated. Identification was carried out based on taxonomic and Identification guides (AL-Kandari *et al.*, 2009; Al Yamani *et al.*, 2010; Baker, 2012).

Water samples for determining dissolved inorganic nutrients were immediately filtered by syringe filters (0.45 µm, cellulose acetate), collected in 125 mL high-density polyethylene bottles and quickly frozen until analysis (Grasshoff *et al*., 2009). Dissolved inorganic nutrients were determined using spectrophotometric techniques (ROPME, 1999) with a UV–Vis spectrophotometer (Analytikjena, Specord 210). Repeatabilities of nutrients determination were checked by calculating the relative standard deviation (RSD) of the methods. RSDs for the determination of nitrate, phosphate, and silicate were less than 15, 5 and 10%, respectively.

Data Analysis

A Bray–Curtis similarity matrix was built in PRIMER 6 (Clarke and Gorley 2006). Data were fourth root transformed before calculation of Bray-Curtis coefficients. One-way analysis of similarity (ANOSIM; Clarke and Warwick (1999)) was used to compare significant differences in the structure assemblages among months. Cluster analysis, using group averages were also conducted on the data. The significance of obtained groupings was assessed using a similarity profile (SIMPROF) test (Clarke and Gorley , 2006). Species contributing the most to the average similarity within groups identified by the cluster analysis using the similarities percentage (SIMPER) routine. The diversity of species in sampling area was assessed by Shannon–Wiener index. Shannon, Simpson, evenness, margalef and richness indices were estimated using PAST software. Non-parametric Kruskal-Wallis test was conducted due to discover the differences in the abundance of the Phytoplankton communities in different periods and locations in accordance by the Bray–Curtis similarity index.

Canonical correspondence analysis (CCA) was used to examine the effects of environmental variables (explanatory variables) among different months on the transformed data (log X+1) of species abundance values (response variable). CCA was conducted using the vegan package (Oksanen *et al.,* 2013) available for use in R (R Core Team, 2013).

Results

Abundance and Community Structure

The total numbers of 114 phytoplankton species were identified which 35, 74, 3, and 2 taxa belong to Dinophyta, Bacillariophyta, Cyanophyta, and Chromophyta, respectively (Table 1). The relative abundances were 94.5, 5.3, 0.1, and 0.03% for Dinophyta, Bacillariophyta, Cyanophyta and Chromophyta, respectively (Fig. 2A).

The dominant species of phytoplankton were *Noctiluca scintillans, Gymnodinium spirale, Ceratium furca, Prorocentrum micans* of Dinophyta and *Nitzschia sigmoidea* of Bacillariophyta. A fairly bloom of *N. Scintillans* happened in late autumn and lasted for more than 3 months. At its peak in Feb, the abundance of *N. scintillans* reached to 1,084,381±14,501 Cell/L. Despite, the high abundance of phytoplankton during winter (Fig. 2B), some species of Dinophyceae (*Prorocentrum belizeanum, Scrippsiella stinii, Amphisolenia palmate, Cochlodinium polykriokoides*) and Bacillariophyta (*Chaetoceros atlanticum, C. dichaeta, Planktoniella sol, Nitzschia closterium, Rhizosolenia imbricate, Guinardia flaccida, Lioloma elongatum, Navicula membrane, Gyrosigma acuminatum*) were disappeared.

Table 1: List of phytoplankton species sampled in Chabahar Bay (*indicates presence).

Family	**Scientific name**	**Jul**	**Aug**	**Oct**	**Jan**	**Feb**	**May**	**Contribution by abundance (%)**
Prorocentraceae	*Prorocentrum gracile*	*	*	*	*	*	*	0.041
	P. micans	*	*	*	*	*	*	0.045
	P. balticum	*	*	*	*	*	*	0.034
	P. belizeanum	*	*	*	*	*	*	0.004
Kolkwitziellaceae	*Diplopsalis orbicularis*	*	*	*	*	*	*	0.002
	D. lenticula	*	*	*	*	*	*	0.004
Gonyaulacaceae	*Protoceratium reticulatum*	*	*	*	*	*	*	0.006
	Gonyaulax polygramma	*	*	*	*	*	*	0.049
Goniodomataceae	*Pyrodinium bahamense*	*	*	*	*	*	*	0.003
Gymnodiniaceae	*Akashiwo sanguinea*	*	*	*	*	*	*	0.007
	Gyrodinium sp.	*	*	*	*	*	*	0.028
Protoperidiniaceae	*Protoperidinium cerasus*	*	*	*	*	*	*	0.019
	P. bipes	*	*	*	*	*	*	0.030
	P. claudicans	*	*	*	*	*	*	0.004
	P. divergens	*	*	*	*	*	*	0.006
	P. biconicum	*	*	*	*	*	*	0.028
	P. steinii	*	*	*	*	*	*	0.032
Ceratiaceae	*Ceratium fusus*	*	*	*	*	*	*	0.041
	C. furca	*	*	*	*	*	*	0.097
	C. lineatum	*	*	*	*	*	*	0.050
	C. breve	*	*	*	*	*	*	0.008
Dinophysiaceae	*Dinophysis mitra*	*	*	*	*	*	*	0.006
	D. rotundata	*	*	*	*	*	*	0.022
Gymnodiniaceae	*Gymnodinium spirale*	*	*	*	*	*	*	0.196
Calciodinellaceae	*Scrippsiella stinii*	*	*	*	*	*	*	0.014
	S. trochoidea	*	*	*	*	*	*	0.010

Table 1 (continued):

Family	Scientific name	Jul	Aug	Oct	Jan	Feb	May	Contribution by abundance (%)
Goniodomataceae	*Alexandrium tamarens*	*	*	*	*	*	*	0.009
	A. leei	*	*	*	*	*	*	0.042
	A. insuetum	*	*	*	*	*	*	0.030
	A. minutum	*	*	*	*	*	*	0.009
Pyrophacaceae	*Pyrophacus steinii*	*	*	*	*	*	*	0.000
	P. horologicum	*	*	*	*	*	*	0.061
Amphisoleniaceae	*Amphisolenia palmata*	*	*	-	-	*	*	0.002
Gymnodiniaceae	*Cochlodinium polykriokoides*	*	*	-	-	*	*	0.005
Noctilucaceae	*Noctiluca scintillans*	*	*	*	*	*	*	0.000
Chaetocerotaceae	*Chaetoceros diversus*	*	*	*	*	*	*	0.011
	C. pseudocurvisetum	*	*	*	*	*	*	0.005
	C. affnis	*	*	*	*	*	*	0.048
	C. atlanticum	*	*	-	-	*	*	0.014
	C. dichaeta	*	*	-	-	*	*	0.008
Licmophoraceae	*Licmophora sp.*	*	*	*	*	*	*	0.004
Thalassiosiraceae	*Thalassiosira oestrupii*	*	*	*	*	*	*	0.006
	Planktoniella sol	*	*	-	-	*	*	0.004
Bacillariaceae	*N. sigmoidea*	*	*	*	*	*	*	0.043
	N. longissima	*	*	*	*	*	*	0.013
	N. closterium	*	*	-	-	*	*	0.006
	N. Seriata	*	*	*	*	*	*	0.037
	Pseudo-nitzschia seriata	*	*	*	*	*	*	0.029
	Bacillaria paxillifera	*	*	*	*	*	*	0.006
	B. socialis	*	*	*	*	*	*	0.006
	Pseudosolenia calcar-avis	*	*	*	*	*	*	0.009
	R. cochlea	*	*	*	*	*	*	0.007
	R. robusta	*	*	*	*	*	*	0.008
Rhizosoleniaceae	*R. imbricata*	*	*	-	-	*	*	0.002
	R. bergonii	*	*	*	*	*	*	0.007
	Guinardia flaccida	*	*	-	-	*	*	0.004
	Odontella aurita	*	*	*	*	*	*	0.009
	O. sinensis	*	*	*	*	*	*	0.014
	O. mobiliensis	*	*	*	*	*	*	0.005
Triceratiaceae	*Triceratium reticulum*	*	*	*	*	*	*	0.006
	Stephanopyxis palmeriana	*	*	*	*	*	*	0.006
stephanopyxidaceae	*Haslea balearica*	*	*	*	*	*	*	0.020
	Trachyneis antillarum	*	*	*	*	*	*	0.005
Naviculaceae	*T. aspera*	*	*	*	*	*	*	0.014
	Meuniera membranacea	*	*	*	*	*	*	0.008
	Plagiotropis lepidoptera	*	*	*	*	*	*	0.004
Plagiotropidaceae	*Leptocylindrus minimus*	*	*	*	*	*	*	0.039
Leptocylindraceae	*L.s danicus*	*	*	*	*	*	*	0.033
	Cyclotella striata	*	*	*	*	*	*	0.010
stephanodiscaceae	*C. stylorum*	*	*	*	*	*	*	0.004
	Thalassiosira eccentrica	*	*	*	*	*	*	0.013
Thalassiosiraceae	*Thalassiosira* sp.	*	*	*	*	*	*	0.003
	Coscinodiscus radiatus	*	*	*	*	*	*	0.014

Table 1 (continued):

Family	**Scientific name**	**Jul**	**Aug**	**Oct**	**Jan**	**Feb**	**May**	**Contribution by abundance (%)**
	C. granii	*	*	*	*	*	*	0.021
	C. wailesii	*	*	*	*	*	*	0.004
	C. centralis	*	*	*	*	*	*	0.005
Coscinodiscaceae	*C. oculus- irridis*	*	*	*	*	*	*	0.002
	C. marginatus	*	*	*	*	*	*	0.004
	Palmeria hardmaniana	*	*	*	*	*	*	0.004
	Actinocyclus octonarius	*	*	*	*	*	*	0.004
Hemidiscaceae	*Lauderia annulata*	*	*	*	*	*	*	0.007
Lauderiaceae	*Paralia sulcata*	*	*	*	*	*	*	0.001
Paraliaceae	*Fragilaria sp.*	*	*	*	*	*	*	0.011
	Synedra sp.	*	*	*	*	*	*	0.006
Fragilariaceae	*Asterionellopsis glacialis*	*	*	*	*	*	*	0.012
	Grammatophora marina	*	*	*	*	*	*	0.003
striatellaceae	*Lioloma elongatum*	*	*	-	-	*	*	0.011
	Thalassionema frauenfeldii	*	*	*	*	*	*	0.002
Thalassionemataceae	*T. nitzschioides*	*	*	*	*	*	*	0.005
	Pleurosigma strigosum	*	*	*	*	*	*	0.006
	P. diverse-striatum	*	*	*	*	*	*	0.005
	Navicula elegans	*	*	*	*	*	*	0.017
	N. acutum	*	*	-	-	*	*	0.039
Naviculaceae	*N. membrane*	*	*	-	-	*	*	0.032
	Gyrosigma acuminatum	*	*	-	-	*	*	0.053
	Diploneis suborbicularis	*	*	*	*	*	*	0.031
	D. didyma	*	*	*	*	*	*	0.024
Diploneidaceae	*D. lenticula*	*	*	*	*	*	*	0.021
	Surirella fastuosa	*	*	*	*	*	*	0.018
surirellaceae	*Entomoneis sulcata*	*	*	*	*	*	*	0.002
entomoneidaceae	*Amphora spectablis*	*	*	*	*	*	*	0.002
	A. proteus	*	*	*	*	*	*	0.003
Catenulaceae	*A. obtusa*	*	*	*	*	*	*	0.004
	Mastogloia sp.	*	*	*	*	*	*	0.002
	M. erythraea	*	*	*	*	*	*	0.002
Mastogloiaceae	*M. mac-Donaldii*	*	*	*	*	*	*	0.006
	Achnanthes brevipes	*	*	*	*	*	*	0.009
Achnanthaceae	*Eucampia zodiacus*	-	-	-	-	*	*	0.003
Biddulphiaceae	*Oscillatoria thiebautii*	*	*	*	-	*	*	0.008
Oscillatoriaceae	*Trichodesmium erythraeum*	*	*	*	*	*	*	0.005
Phormidiaceae	*Spirulina* sp.	*	*	*	*	*	*	0.004
Spirulinaceae	*Dictyocha fibula*	*	*	*	*	*	*	0.006
Dictyochaceae	*Phaeocystis sp.*	*	*	*	*	*	*	0.001
Phaeocystaceae								

Kruskal-Wallis showed significant differences in phytoplankton abundance among different months ($p<0.05$) but not among different sites ($p>0.05$). The ANOSIM showed that significant differences in the assemblage structure occurred among months ($R=0.721$, $p<0.001$). Cluster analysis of the Bray-Curtis similarity matrix based on phytoplankton species delineated four groups (SIMPROF test $p<0.05$).

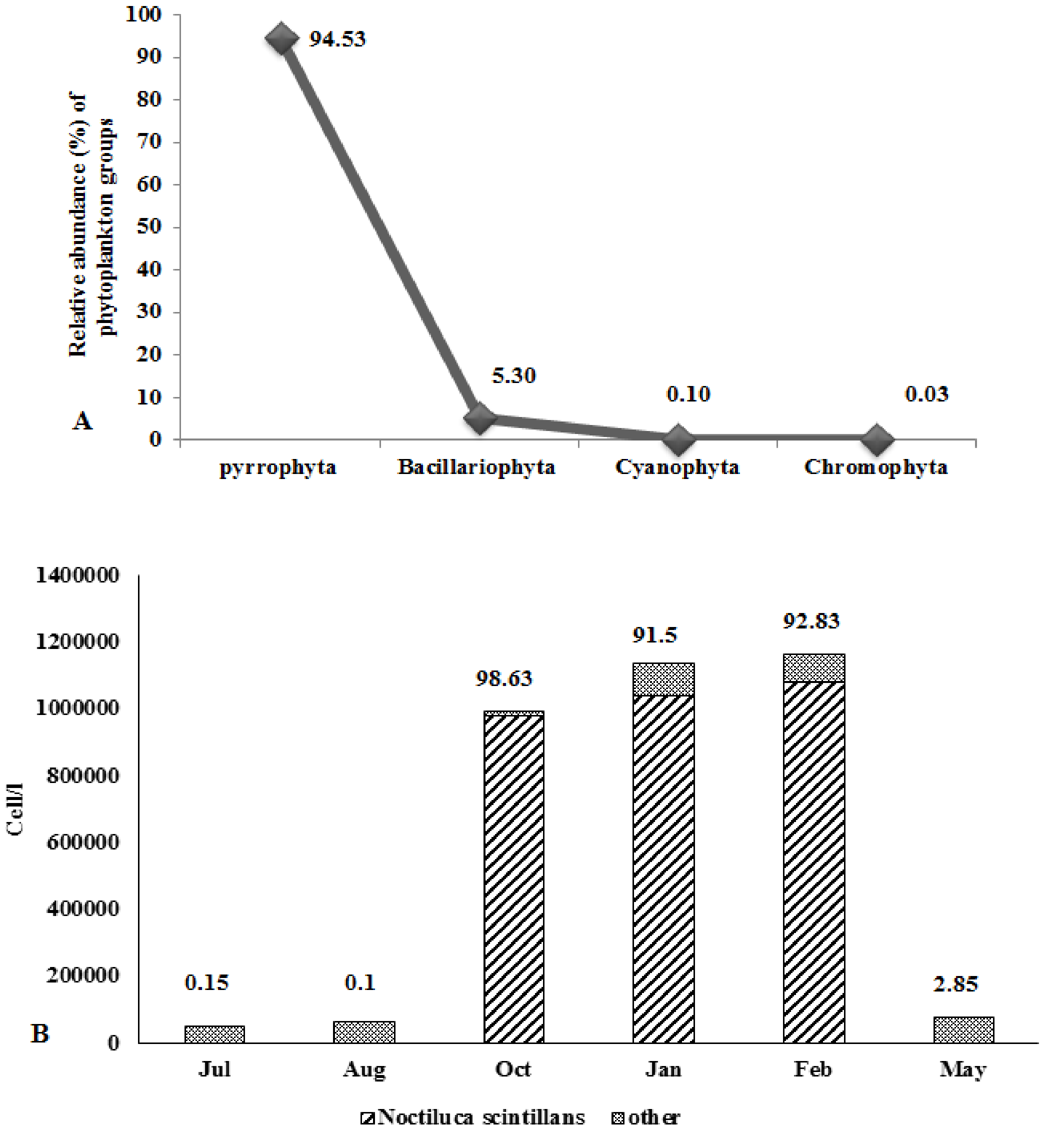

Figure 2: A: The relative abundance (%) of phytoplankton groups in the study B: Monthly variation of total abundance of phytoplankton species. The above number is the percentage of frequency of *N. scintillans* in those months (Cell/l).

NMDS plot based on phytoplankton abundance data for all months showed a certain grouping of months (Fig. 3). SIMPROF analysis distinguished the months into four main groups at a significance level of 0.05 using Bray–Curtis similarity: May, Oct, Jan-Feb and Jul-Aug. SIMPER analysis indicated *Noctiluca scintillans* is the most contributed species in the formation of following groups Oct (23.25%), Jan-Feb (21.14%) and July-Aug (9.46%). *Pyrophacus horologicum and Prorocentrum balticum* contributed 4.19% and 3.70% correspondingly in the formation of May.

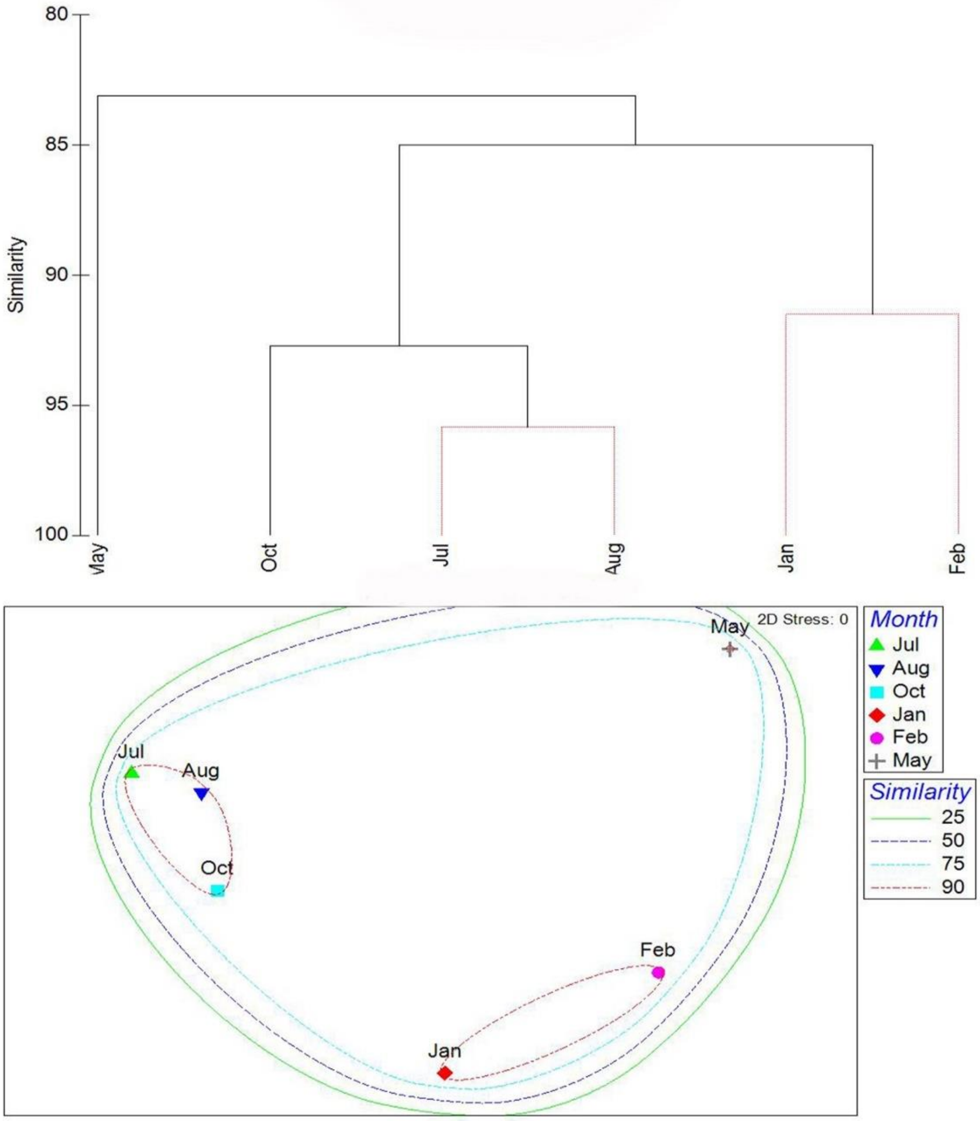

Figure 3: Dendrogram of hierarchical clustering (Above) and multidimensional scaling ordination plot (Below) of fourth root transformed abundance data of phytoplankton based on the similarity of the community composition at sampling months. Separated groups by SIMPROF are presented in different color lines.

Diversity Index

The temporal variation of all five calculated indices (Dominance, Simpson, Shannon, Evenness, and Margalef) was significant (Kruskal-Wallis (KW) test, $p<0.001$). In the months that Bloom *N. scintillans* has been observed, the lowest Shannon and Simpson diversity index of phytoplankton (0.12/0.03) were observed, while in other months the values of Shannon and Simpson were higher (4.14/0.98) (Table 2). Such pattern of high Dominance of phytoplankton and low Evenness were observed presence and absence of *N. scintillans* bloom respectively (Oct, Jan, and Feb).

Table 2-Diversity indices of phytoplankton.

	Jul± SE	Aug± SE	Oct± SE	Jan± SE	Feb± SE	May± SE
Taxa	113±1.76	113± 3.58	113± 2.09	111± 3.27	114± 2.97	114± 5.11
Individuals	51979 ± 5798.07	64719 ± 6723.33	997926 ± 21344.13	1138628 ± 13184.71	1168112 ± 13878.88	80952 ± 1134.76
Dominance	0.04± 0	0.04± 0	0.97± 0	0.84± 0.01	0.86± 0.01	0.02± 0
Simpson	0.96± 0	0.96± 0	0.03± 0	0.16± 0.01	0.14± 0.01	0.98± 0
Shannon	3.68± 0.06	3.69± 0.07	0.12± 0.01	0.60± 0.04	0.53± 0.05	4.14± 0.08
Evenness	0.35± 0.01	0.35± 0.02	0.01± 0	0.02± 0	0.01± 0	0.55± 0.01
Margalef	10.31± 0.15	10.11± 0.3	8.11± 0.15	7.89± 0.23	8.09± 0.21	10.00± 0.41

Environmental parameters and Nutrients

At all sampling times, the average temperature, salinity and pH were obtained to be in the ranges of 24.1 to 31.9°C (27.8±3.3°C), 36.75 to 37.31 psu (37.0±0.2 psu) and 8.08 to 8.21 (8.14±0.05), respectively. The average concentrations of PO_4, NO_3 and Si varied between 0.31-0.73 µM, 0.88-5.59 µM and 1.16-3.87 µM, respectively (Table 3). The maximum values of nutrients were observed in Oct (0.73, 5.59 and 3.66 µM of phosphate, nitrate and silicate, respectively) followed by a sharp decrease during Jan and Feb which is probably due to the phytoplankton blooms started from Oct. In Jul and Aug, low levels of dissolved nutrients were observed compared to values obtained in Oct.

Table 3: Mean and standard deviation values of chemical parameters measured; temperature, dissolved Oxygen (DO), pH, salinity, nitrite (NO2), nitrate (NO3), phosphate (PO4) and silicate (Si) in sampling stations.

	T	DO [mg/L]	pH	Salinity [psu]	PO_4 (µM)	NO_3 (µM)	Si (µM)	NO_2 (µM)
Jul	31.88	5.69	8.08	37.13	0.34	3.61	3.12	0.00
Aug	30.90	5.81	8.13	37.31	0.43	4.48	2.93	0.01
Oct	26.41	5.86	8.13	37.05	0.73	5.59	3.66	0.03
Jan	24.11	6.99	8.21	36.91	0.24	0.98	1.13	0.00
Feb	24.35	7.32	8.21	36.75	0.31	0.88	1.16	0.00
May	29.34	5.64	8.08	36.87	0.73	1.37	3.87	0.02

Phytoplankton community responses to environmental parameters

The relationships between environmental variables and structures of the phytoplankton assemblage are depicted in Figure 4. Only species with more than 0.1 frequencies were included in the final Canonical Correspondence Analysis (CCA) bi-plot (Fig. 4). The first two axes of CCA explained 84.2% and 6% of the variation in phytoplankton assemblages, respectively (total cumulative explained variation=90.2%) and the eigenvalues of axes 1 and 2 were 0.432 and 0.0316, respectively. It is clear that *N. scintillans* are in a different position from other species in terms of their relationship to environmental variables. Species such as *G. polygramma* and *A. leei*, which are dinoflagellates capable of forming red tides, are located opposite *N. scintillans*, indicating that their occurrence requires conditions that are different from each other. Reactions of some taxa to the temperature gradients are quite clear. *N. acutum*, and species from *L. danicus and L. minimus* which are observed in the cold months of the year, are located at the negative temperature gradient and *P.gracile* and *G. acuminatum* are located at the positive temperature gradient. We can conclude that species such as *L. danicus* and *L. minimus* prefer cold water with lower level nutrients considering the DO and nutrient gradients and species such as *S. fastuosa* prefer warm water with higher level of nutrients.

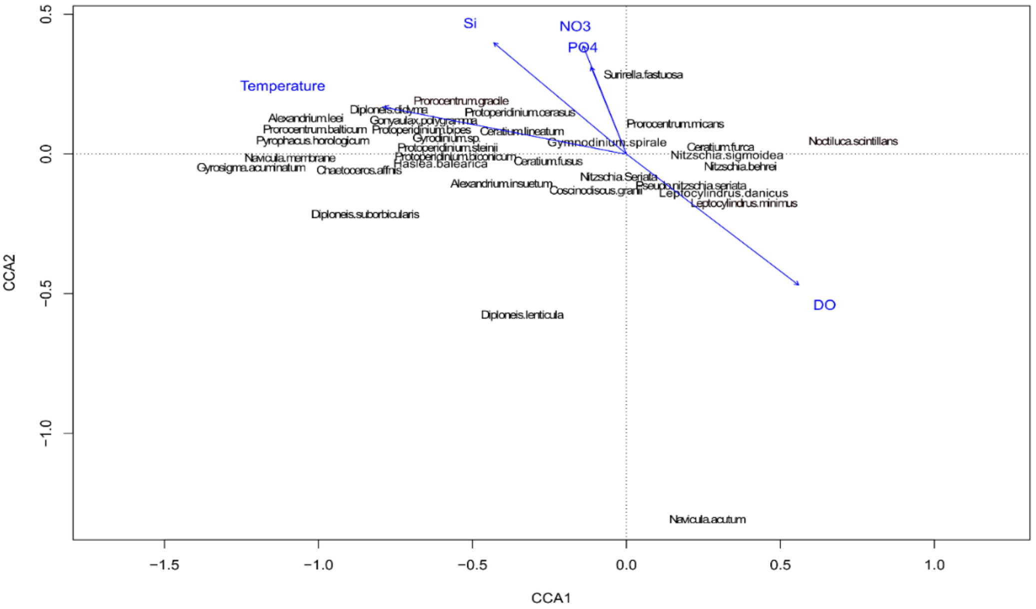

Figure 4: Canonical Correspondence Analysis (CCA) bi-plot showing the effect of environmental variables on the structure of phytoplankton assemblages (abundance data).

Discussion

The phytoplankton abundance showed a significant variation among different sampling times. The phytoplankton density increased from July (southwest monsoon) to Feb (northeast monsoon) and decreased again, when the northeast monsoon ended and the winter convective mixing (Fig. 2B) disappeared. The highest phytoplankton abundance was observed in northeast monsoon (1,168,112±136,189 Cell/L) when the vertical mixing of water column due to evaporative cooling resulted in high concentration of nutrients in the euphotic layer.

Plankton density fluctuations can be influenced by various factors depending on the study area (Al-Yamani *et al*., 2010). Other study, in line with our results, observed lower phytoplankton density during southwest monsoon (Hassan *et al*., 2010). Temperature drop, strong currents, turbulences, and limiting nutrient conditions may have been the cause of phytoplankton stagnation during southwest monsoon period. No significant correlation was perceived between environmental features and phytoplankton abundance (p>0.05), however, clear alignment between phytoplankton abundance and nutrient contents was observed. Our results showed that nutrients have substantial role in phytoplankton diversity and abundance in this region. With increase of the nutrient load, phytoplankton abundance was sharply increased in Oct. The seasonal abundance variation pattern of phytoplankton was similar to those reported in past studies (Dorgham, 2013; Saraji *et al*., 2014; Mirzaei *et al*., 2017). Phytoplankton abundance, distribution, and biodiversity of species in the Gulf of Oman and Chabahar Bay are mainly influenced by oceanic currents, monsoon winds, concentration of nutrients and temperature (Nowrouzi and Valavi, 2011, Al-Hashmi *et al.*, 2012).

Dinoflagellates, the functional group that *Noctiluca* belongs to, prefer less turbulent waters and typically reach their greatest abundance at the surface during relatively stable periods (Goes *et al.*, 2020). Therefore, Low abundance of *N. Scintillans* during the summer was probably due to the southwest monsoon-induced turbulence. At this time, *Noctiluca* could be found at depth, often close to the oxycline and where photo synthetically available radiation is still enough (Goes and Gomes, 2016). In our study, surface *Noctiluca* blooms appeared by late autumn (Nov), when northeast monsoon winds lowered the sea surface temperature (from 31 to 26°C, Table 3) and transferred deep water with high concentration of nutrients and *Noctiluca* to the surface. Then, in the presence of extraneous prey (diatoms), *Noctiluca* switches a higher dependence on heterotrophy to reach the high growth rates necessary for the bloom (Gomes *et al*., 2014). This could be the reason for a significant decrease of diatom abundance in Nov. Detailed study of historic taxonomic records available for the winter monsoons of 1965, 1972 and 1990 averaged over an area in the north of Gulf of Oman by Gomes *et al*. (2014), showed no indication of *N. scintillans* as a component of the winter phytoplankton community. Instead, diatoms were the dominant bloom-forming group fueled by the transfer of nutrients into the euphotic zone during winter convective mixing of pre-2000s. Their field data on the distribution of phytoplankton species (Gomes *et al*., 2014) and several other studies (Lotliker *et al*., 2018; Xiang *et al*., 2019; Goes *et al*., 2020) show that the switchover from diatoms to *N. scintillans* in winter occurred in the early 2000s. *Noctiluca*'s ecological success and range expansion in the northwest Indian Ocean and the Gulf of Oman including Chabahar Bay appear to be tied to the lack of predatory pressure (Gomes *et al*., 2014), its mixotrophic characteristic (Goes and Gomes, 2016) (autotrophic CO_2 fixation and heterotrophic feeding on a wide range of external prey including phytoplankton, micro- and mesozooplankton and zooplankton eggs), the ability of its endosymbionts to photosynthesize more efficiently under suboxic conditions compared to other phytoplankton species (Gomes *et al*., 2018) and alleviated dependence on extraneous NO_3 in a nitrate-limited environment (i.e. northwest Indian Ocean) (Goes *et al*., 2020).

Cyanophyceae were more abundant in summer, while their abundance decreased during post-monsoon and northeast monsoon in winter. Cyanophyceae can stabilize nitrogen and are thermophile (Issa *et al*., 2014) so the abundance and diversity of this group's species in summer were higher than other seasons. Samples which were taken during May showed the highest number of phytoplankton taxa (114) therefore, the peak value of phytoplankton diversity was occurred in pre-monsoon (May). However, with Mirzaei *et al*. (2017) and Saraji *et al.* (2014) the diversity and abundance of Dinophyceae was high in the pre monsoon. Shannon index (H) was the highest in the pre- monsoon.

The concentration of nutrients increased significantly from Feb to May when the bloom of *N. scintillans* ended. In Oct high density of *N. scintillans* was observed which related to water circulation pattern and seasonal cycles of organic nutrient. It was probable that high nutrient concentrations and water-column stratification in coastal waters are potential causes for this alteration (Corcoran and Shipe, 2011). It looks phytoplankton community and composition of the Gulf of Oman, close to Chabahar Bay, could be affected by upwelling streams. Al-Hashmi *et al*, reported blooms of the *N. scintillans* during Jan and Sep. The rise in finest biological and hydrographic features play main role in the species bloom and its distribution (Al-Hashmi *et al.*, 2012) that are in fair agreement by the results of present survey. An extensive growth in phytoplankton species has been perceived as compared to some earlier reports from the similar locality. The numbers of Diatoms and Dinoflagellates taxa were compared with previous reportes (Table 4). Some usual phytoplankton species, which were not noted from the bay before (Mirzaei *et al.*, 2017), were recorded during this study such as *Prorocentrum micans*, *P. balticum, Diplopsalis orbicularis, Protoceratium reticulatum, Gonyaulax polygramma* and *Akashiwo sanguine*.

Table 4: Comparison of the number of taxa of diatoms and dinoflagellates in this study with previous reported data in the Persian Gulf and Gulf of Oman

Study Area (study period)	Dinoflagellates	Diatom	References
West Indian Ocean- Persian Gulf (1986)	62	17	Dorgham and Mofta (1989)
Western Indian Ocean- Qatar waters	54	12	Al-Saadi and Hadi (1987)
Western Indian Ocean-N.W. Persian Gulf	34	8	Al-Yamani *et al.* (1997)
Str. Hormuz- Persian Gulf (1986)	10	11	Dorgham and Mofta (1989)
Gulf of Oman- Persian Gulf (1986)	47	61	Dorgham and Mofta (1989)
Limited to Persian Gulf (1986)	56	16	Dorgham and Mofta (1989)
ROPME sea area	416	68	Al-Saadi and Hadi (1987)
Bushehr area (Iran)	97	-	Fatemi *et al.* (2005)
Western part of Persian Gulf (2013)	16	39	INIOAS (PG- GOOS)
Bushehr area (Iran) (2013) (Winter)	14	20	INIOAS (PG- GOOS)
Bushehr area (Iran) (2013) (Summer)	12	18	INIOAS (PG-GOOS)
Sothern west of coastal (Iran)	22	32	Attaran (2010)
South East Coast of India (2015-2016)	9	92	Vajravelu (2018)
North coast of Oman Gulf (2014)	76	85	Mirzaei *et al* (2017)
Chabahar Bay (2016-2017)	35	74	Present study

The results confirm that green *Noctiluca* has become a major player in the planktonic food web of the northern of the Gulf of Oman, during the winter monsoon. However, *Noctiluca* has recently been reported during the summer monsoon (Al-Hashmi *et al.*, 2015) showing that it may also be expanding its temporal range to include the highly productive summer period of the northeast Indian Ocean when the blooms of diatoms form, and become the main driving force for large coastal fisheries (Gomes *et al*., 2018). As green *Noctiluca* is a voracious predator of diatoms, and competes with zooplankton (e.g. copepods) it may show adverse impacts on the food chain and fisheries in this region. Due to the importance of the role of phytoplankton and recent observed transition in the marine ecosystem of the region, detailed studies on plankton (phyto and zoo) and a revision of earlier understanding of the food chain in the Chabahar Bay seems to be necessary. Additionally, tentative investigations are required to determine other physical and chemical aspects, which may have significant role for the ecological success and distribution of the phytoplankton density and their biodiversity along the northern part of the Gulf of Oman including Chabahar Bay.

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