

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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Received: December 2020 Accepted: January 2021

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, $p \le 0.05$). 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

DOR: 20.1001.1.15622916.2022.21.4.5.7

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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 physical factors, by nutrient obtainability, mixotrophy, and predators. The first bloom of phytoplankton in the Gulf of Oman is reported in 1970s. Since then, there have usual reports of red tide been 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 of on taxonomy phytoplankton, Chabahar Bay's bloom, little care has been paid to specific communities phytoplankton 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.

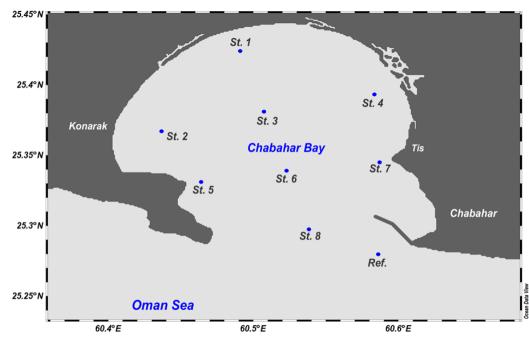


Figure 1: Map of study area located across the Chabahar Bay in the Gulf of Oman.

Sampling

In each season, measurements pH_{NBS}, parameters including temperature, dissolved oxygen (DO) and salinity at different stations were done by using a HACH portable meter HO40d. 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 optical sensor (HACH, oxygen 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 for determining samples 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 Repeatabilities 210). nutrients determination were checked by calculating the relative standard deviation (RSD) of the methods. RSDs 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).

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

Table 1 (continued):

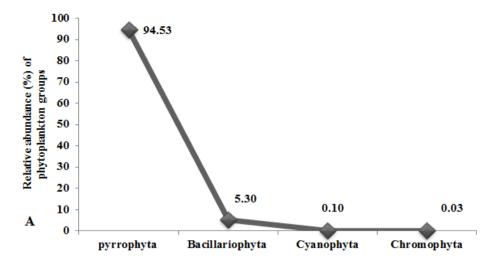
Family	Scientific name	Jul	Aug	Oct	Jan	Feb	May	Contribution by abundance (%)
	Alexandrium tamarens	*	*	*	*	*	*	0.009
Camiadamataaaa	A. leei	*	*	*	*	*	*	0.042
Goniodomataceae	A. insuetum	*	*	*	*	*	*	0.030
	A. minutum	*	*	*	*	*	*	0.009
D	Pyrophacus steinii	*	*	*	*	*	*	0.000
Pyrophacaceae	P. horologicum	*	*	*	*	*	*	0.061
Amphisoleniaceae	Amphisolenia palmata	*	*	-	-	*	*	0.002
Gymnodiniaceae	Cochlodinium polykriokoides	*	*	-	-	*	*	0.005
Noctilucaceae	Noctiluca scintillans	*	*	*	*	*	*	0.000
	Chaetoceros diversus	*	*	*	*	*	*	0.011
	C. pseudocurvisetum	*	*	*	*	*	*	0.005
Chaetocerotaceae	C. affnis	*	*	*	*	*	*	0.048
	C. atlanticum	*	*	_	_	*	*	0.014
	C. dichaeta	*	*	_	_	*	*	0.008
Licmophoraceae	Licmophora sp.	*	*	*	*	*	*	0.004
•	Thalassiosira oestrupii	*	*	*	*	*	*	0.006
Thalassiosiraceae	Planktoniella sol	*	*	_	_	*	*	0.004
	N. sigmoidea	*	*	*	*	*	*	0.043
	N. longissima	*	*	*	*	*	*	0.013
Bacillariaceae	N. closterium	*	*	_	_	*	*	0.006
Daemanaceae	N. Seriata	*	*	*	* * * * * * * * * * * * * * * * * * *	*	*	0.037
	Pseudo-nitzschia seriata	*	*	*		*	0.029	
		*	*	*			*	0.029
	Bacillaria paxillifera B. socialis	*	*	*			*	
		••	••			••		0.006
	Pseudosolenia calcar- avis	*	*	*	*	*	*	0.009
	R. cochlea	*	*	*	*	*	*	0.007
	R. robusta	*	*	*			*	0.007
	R. imbricata	*	*				*	0.008
Rhizosoleniaceae		*	*	*			*	
	R. bergonii	*	*				*	0.007
	Guinardia flaccida	*	*	- *			*	0.004
	Odontella aurita	*	*	*			*	0.009
	O. sinensis	*	*	*			*	0.014
m : .:	O. mobiliensis	*		*			*	0.005
Triceratiaceae	Triceratium reticulum Stephanopyxis	*	*	*			*	0.006 0.006
	palmeriana							0.000
stephanopyxidaceae	Haslea balearica	*	*	*	*	*	*	0.020
	Trachyneis antillarum	*	*	*	*	*	*	0.005
Naviculaceae	T. aspera	*	*	*	*	*	*	0.014
Naviculaceae	Meuniera membranacea	*	*	*	**** **** ** - * * - * * * * *	*	*	0.008
	Plagiotropis lepidoptera	*	*	*	*	*	*	0.004
Plagiotropidaceae	Leptocylindrus minimus	*	*	*	*	*	*	0.039
	L.s danicus	*	*	*	*	*	*	0.033
Leptocylindraceae	Cyclotella striata	*	*	*	*	*	*	0.010
ataulaan (1°)	C. stylorum	*	*	*	*	*	*	0.004
stephanodiscaceae	Thalassiosira eccentrica	*	*	*	*	*	*	0.013
771 1 · ·	Thalassiosira sp.	*	*	*	* - * * * * * * * * * * * * * * * * * *	*	*	0.003
Thalassiosiraceae			*				*	0.014

Table 1 (continued):

								Contribution
Family	Scientific name	Jul	Aug	Oct	Jan	Feb	May	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
F	Asterionellopsis						.1.	
Fragilariaceae	glacialis	*	*	*	*	*	*	0.012
	Grammatophora marina	*	*	*	*	*	*	0.003
striatellaceae	Lioloma elongatum	*	*	_	_	*	*	0.011
	Thalassionema						.1.	
	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
	N. membrane	*	*	_	_	*	*	0.032
Naviculaceae	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
cintomonorauceuc	A. proteus	*	*	*	*	*	*	0.003
Catenulaceae	A. obtusa	*	*	*	*	*	*	0.004
Cutchalaceae	Mastogloia sp.	*	*	*	*	*	*	0.002
	M. erythraea	*	*	*	*	*	*	0.002
Mastogloiaceae	M. mac-Donaldii	*	*	*	*	*	*	0.006
Musicgioidecae	Achnanthes brevipes	*	*	*	*	*	*	0.009
Achnanthaceae	Eucampia zodiacus	_	_	_	_	*	*	0.003
Biddulphiaceae	Oscillatoria thiebautii	*	*	*	_	*	*	0.008
-	Trichodesmium							
Oscillatoriaceae	erythraeum	*	*	*	*	*	*	0.005
Phormidiaceae	Spirulina sp.	*	*	*	*	*	*	0.004
Spirulinaceae	Dictyocha fibula	*	*	*	*	*	*	0.006
Dictyochaceae	Phaeocystis sp.	*	*	*	*	*	*	0.001
Phaeocystaceae	1cocysus sp.							0.001

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).



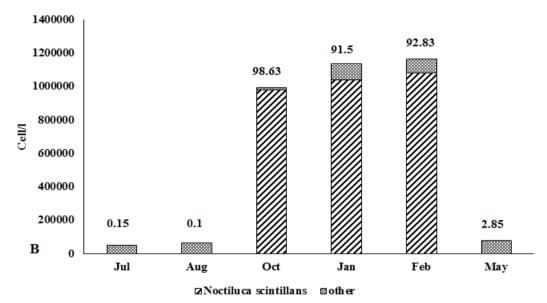


Figure 2: A: The relative abundance (%) of phytoplankton groups in the study B: Monthly variation of total abundance of phytoplankton species. The above number is the percentage of frequency of *N. scintillans* in those months (Cell/I).

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.

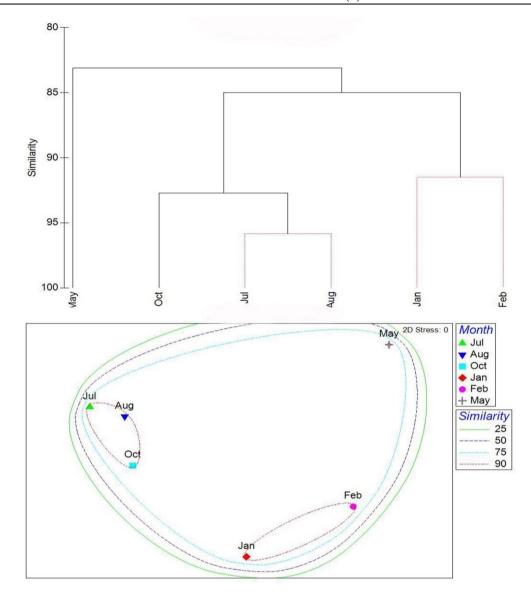


Figure 3: Dendrogram of hierarchical clustering (Above) and multidimensional scaling ordination plot (Below) of fourth root transformed abundance data of phytoplankton based on the similarity of the community composition at sampling months. Separated groups by SIMPROF are presented in different color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

Diversity Index

The temporal variation of all five calculated indices (Dominance, Shannon, Simpson, 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	64719	997926	1138628	1168112	80952				
marviduais	± 5798.07	$\pm\ 6723.33$	± 21344.13	± 13184.71	$\pm\ 13878.88$	± 1134.76				
Dominance	0.04 ± 0	0.04 ± 0	0.97 ± 0	$0.84 {\pm}~0.01$	$0.86 {\pm}~0.01$	0.02 ± 0				
Simpson	0.96 ± 0	0.96 ± 0	0.03 ± 0	$0.16 {\pm}~0.01$	$0.14{\pm}0.01$	0.98 ± 0				
Shannon	3.68 ± 0.06	3.69 ± 0.07	0.12 ± 0.01	0.60 ± 0.04	$0.53 {\pm}~0.05$	$4.14{\pm}0.08$				
Evenness	0.35 ± 0.01	$0.35{\pm}0.02$	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 PO₄, NO₃ and Si varied between 0.31-0.73 μ M, 0.88-5.59 μ M and 1.16-3.87 μ M, 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.

	Т	DO [mg/L]	pН	Salinity [psu]	ΡΟ ₄ (μΜ)	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** G. such as 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 the DO and nutrient considering gradients and species such as S. fastuosa prefer warm water with higher level of nutrients.

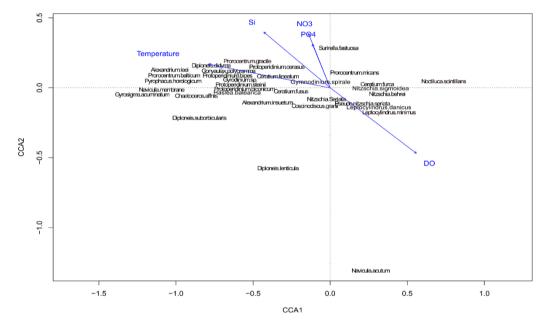


Figure 4: Canonical Correspondence Analysis (CCA) bi-plot showing the effect of environmental variables on the structure of phytoplankton assemblages (abundance data).

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 ended and the winter monsoon 2B) convective mixing (Fig. 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, limiting nutrient conditions may have 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 ofphytoplankton 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 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 monsooninduced 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 surface Noctiluca study, 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 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 CO₂fixation and heterotrophic feeding on a wide range of external prey including phytoplankton, and mesozooplankton microzooplankton 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 NO₃ 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 circulation pattern and seasonal cycles of organic nutrient. It was probable that high nutrient concentrations and watercolumn stratification in coastal waters are potential causes for this alteration (Corcoran and Shipe, 2011). It looks phytoplankton community 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 (Table 4). Some reportes 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 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.

Acknowledgments

We would like to thank the Iranian National Institute for Oceanography and Atmospheric Science (INIOAS) for supporting this project and special thanks to Koochaknejad for efficient and excellent assistance.

References

Al Gheilani, H.M., Matsuoka, K., AlKindi, A.Y., Amer, S. and Waring, C., 2011. Fish kill incidents and harmful algal blooms in Omani waters. *Journal of Agricultural and*

- *Marine Sciences*, 16, 23-33. DOI:10.24200/jams.vol16iss0pp23-33
- Al-Hashmi, K., Sarma, Y.V.B.. Claereboudt, M., Al-Azri, A.R., Piontkovski, S.A. and Al-Habsi, H., **2012.** Phytoplankton community structure in the Bay of Bandar Khyran, Sea of Oman with special reference harmful to algae. International Journal of Marine Science. 2(5). 31-42. DOI: 10.5376/ijms.2012.02.0005
- Al-Hashmi, K., Claereboudt, M., Piontkovski, S., Al Azri, A. and Amin, S.M.N., 2015. Seasonal variability of size-classes of phytoplankton biomass in a subtropical embayment, Muscat, Sea of Oman. *Iranian Journal of Fisheries Sciences*, 14(1), 136-149.
- Al-Kandari, M., Al-Yamani F.Y. and Al-Rifaie K., 2009. Marine Phytoplankton Atlas of Kuwait's Waters, Kuwait Institute for Scientific Research.
- **Al-Saadi, H.A., and Hadi, R.A.M.,** 1987. Ecological and taxonomical studies on phytoplankton in the RSA. *Research Journal of Biological Sciences*, 18(3), 7-31.
- Al-Yamani, F.Y., Bishop, J., Al-Rifaie, K., Ismail, W., Al-Yaqout, A., Al-Omran, L., Kwarteng, A., Al-Ghadban, A. and Sheppard, C., 1997. Assessment of the effects of the Shatt Al-Arab's altered discharge regimes on the ecology of the northern Arabian Gulf. Kuwait Institute for Scientific Research, Report No. KISR, 5174.
- Al-Yamani, F.Y., Khvorov, S.A. and Khvorov, A.S., 2010. Interactive Guide of Planktonic Decapod Larvae

- of Kuwait's Waters. Kuwait Institute for Scientific Researches. Electronic resource. Registry, (2010/009), 4.
- ASTM 4148-82, 2012. Standard Test Method for Analysis of Phytoplankton in Surface Water by the Sedgwick-Rafter Method. ASTM Committee E47 on Biological Effects and Environmental Fate and is the direct responsibility of Subcommittee E47.01 on Aquatic Assessment and Toxicology, United States.
- Attaran- Fariman, G., 2010.

 Dispersion of potentially HABs former species along the south- east coast of the Oman Sea. Final Report of the project to Iran's Marine environment.
- Baker, A.L., 2012. Phycokey- an image based key to Algae (PS Protista), Cyanobacteria, and other aquatic objects. University of New Hampshire Center for Freshwater Biology.
- **Balcerak, E., 2012.** Arabian Sea eddies promote seasonal phytoplankton blooms. Eos, *Transactions American Geophysical Union*, 93(2), 28-28. DOI:10.1029/2012EO020026
- Clarke, K.R. and Warwick, R.M., 1999. The taxonomic distinctness measure of biodiversity: weighting of step lengths between hierarchical levels. Marine Ecology Progress Series, 184, 21-29.
- Clarke, K.R. and Gorley, R.N., 2006. PRIMER v5: User Manual/Tutorial. Primer-E Limited. Plymouth, UK.
- Corcoran, A. A., and Shipe, R. F. 2011. Inshore–offshore and vertical patterns of phytoplankton biomass and community composition in Santa Monica Bay, CA (USA). Estuarine,

- Coastal and Shelf Science, 94(1), 24-35. DOI:10.1016/j.ecss.2011.05.007
- Dorgham, M.M., 2013. Plankton research in the ROPME Sea Area, achievements and gaps, International Journal of Environmental Research, 7(3), 767-778. https://www.sid.ir/en/journal/ViewPaper.aspx?id=369404
- Dorgham, M.M. and Moftah, A., 1989.
 Environmental conditions and phytoplankton distribution in the Arabian Gulf and Gulf of Oman, September 1986. *Journal of the Marine Biological Association of India. Cochin*, 31(1), 36-53.
- **Fatemi, A.R., Vosughi, G.H. and Nikoueian, A.R., 2005.** Diatoms diversity and abundance in Iranian waters of theRSA, Bushehr area. *Iranian Scientific Fisheries Journal*, 13(4), 111-124.DOI??
- Fazeli, N., Savari, A., Nabavi, S.M.B. and Zare, R., 2013. Seasonal variation of zooplankton abundance, composition and biomass in the Chabahar Bay. *International Journal of Aquatic Biology*, 1(6), 294-305. https://doi.org/10.22034/ijab.v1i6.14
- Goes, J.I. and Gomes, H.D.R., 2016.

 An ecosystem in transition: the emergence of mixotrophy in the Arabian Sea. In *Aquatic Microbial Ecology and Biogeochemistry: A Dual Perspective* (pp. 155-170). Springer, Cham.
- Goes, J.I., Tian, H., do Rosario Gomes, H., Anderson, O.R., Al-Hashmi, K., deRada, S., Luo, H., Al-Kharusi, L., Al-Azri, A. and Martinson, D.G., 2020. Ecosystem state change in the Arabian Sea fuelled by the recent loss of snow

- over the Himalayan-Tibetan plateau region. *Scientific Reports*, 10, 7422. https://doi.org/10.1038/s41598-020-64360-2.
- Gomes, H.do R., Goes, J.I., Matondkar, S.P., Buskey, E.J., Basu, S., Parab, S. and Thoppil, P., 2014. Massive outbreaks of Noctiluca scintillans blooms in the Arabian Sea due to spread of hypoxia. *Nature Communications*, 5(1), pp.1-8. DOI: 10.1038/ncomms5862
- Gomes, H.D.R., McKee, K., Mile, A., Thandapu, S., Al-Hashmi, K., Jiang, X. and Goes, J.I., 2018. Influence of light availability and prey type on the growth and photophysiological rates of the mixotroph Noctiluca scintillans. *Frontiers in Marine Science*, 5, 374 P.
- Grasshoff, K., Kremling, K. and Ehrhardt, M. eds., 2009. Methods of seawater analysis. John Wiley and Sons.
- Harrison, P., Furuya, K., Glibert, P., Xu, J., Liu, H., Yin, K. D., Lee, J. H. W., Anderson, D., Gowen, R., Al-Azri, A. and Ho, A., 2011. Geographical distribution of red and green *Noctiluca scintillans*. *Chinese Journal of Oceanology and Limnology*. 29(4), 807-831 DOI: 10.1007/s00343-011-0510-z
- Hassan, F.M., Taylor, W.D., Al-Taee, M.M. and Al-Fatlawi, H.J., 2010. Phytoplankton composition of Euphrates River in Al-Hindiya barrage and kifil city region of Iraq. *Journal of Environmental Biology*, 31(3), 343. www. jeb.co.in
- Issa, A.A., Abd-Alla, M.H. and Ohyama, T., 2014. Nitrogen fixing cyanobacteria: future prospect. Advances in biology and ecology of

- *nitrogen fixation*, 2, 24-48. DOI: 10.5772/56995
- Koochaknejad, E., Ghazilou, A., Ershadifar, H., Kor, K. and Maghsoudlou, A., 2016. A three-year record of red tides in Chabahar coastal waters (north of the Gulf of Oman). *Journal of the Persian Gulf*, 7(25), 61-66. jpg.inio.ac.ir
- Lotliker, A.A., Baliarsingh, S.K., Trainer, V.L., Wells, M.L., Wilson, C., Bhaskar, T.U., Samanta, A. and Shahimol, S.R., 2018. Characterization of oceanic *Noctiluca* blooms not associated with hypoxia in the Northeastern Arabian Sea. *Harmful algae*, 74, 46-57. https://www.elsevier.com/open-access/userlicense/1.0/
- Mirzaei, M.R., seraji, F., Erfanifar, E., Aminirad, T., Aminikhoei, Z. and Azhang, B., 2017. Assessing phytoplankton community structure in relation to hydrographic parameters and seasonal variation (Pre and Post Monsoon). *Journal of Biological Diversity*, 18, 507-513. DOI: 10.13057/biodiv/d180209
- Nowrouzi, S. and Valavi, H., 2011. Effects of environmental factors on phytoplankton abundance and diversity in Kaftar Lake. *Journal of Fisheries and Aquatic Science*, 6(2), 130. DOI: 10.3923/jfas.2011.130.140
- Oksanen, J., Blanchet, F.G. and Lindt, R., 2013. Vegan: Community Ecology
 Package. R package version 2.0-7.

- R Core Team, 2013. R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. Retrieved from http://www.R-project.org/.
- **ROPME, 1999.** The Regional Organization for the Protection of Marine Environment.
- Saraji, F., Wan Maznah, W. O., Ebrahimi, M., Jokar, K. and Akbarzadeh, G.A., 2014. Seasonal Variation of Phytoplankton Community in the Northern of Oman Sea (Part of Iranian Waters). International Journal of Botany and Research, 4, 19-28. DOI:10.17265/2162-5298/2015.02.005
- Vajravelu, M., Martin, Y., Ayyappan, S. and Mayakrishnan, M., 2018. influence of Seasonal physicochemical parameters phytoplankton diversity, community and abundance structure Parangipettai coastal waters, Bay of Bengal, South East Coast of India. Oceanologia, 60(2), 114-127. https://doi.org/10.1016/j.oceano.201 7.08.003
- Xiang, C., Tan, Y., Zhang, H., Liu, J., Ke, Z. and Li, G., 2019. The key to dinoflagellate (*Noctiluca scintillans*) blooming and outcompeting diatoms in winter off Pakistan, northern Arabian Sea. *Science of the Total Environment*, 694, 133396. https://doi.org/10.1016/j.scitotenv.20 19.07.202