The relation between environmental parameters of Hormuzgan coastline in Persian Gulf and occurrence of the first harmful algal bloom of *Cochlodinium polykrikoides* (Gymnodiniaceae)

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Abstract

Cochlodinium polykrikoides was bloomed in the Persian Gulf for the first time in September 2008, started from the Strait of Hormuz and then spread out towards the northern parts covering most of the areas of the Gulf and lasted 8 months. In order to find out environmental conditions during the bloom, a monthly sampling program was carried out in seven surface stations in 2008-2009. At each station, three samples (triplicates) were collected for phytoplankton analysis and also one sample for environmental analyses, including salinity, chlorophyll a and nutrients. Blooms of *C. polykrikoides* were observed with a seawater temperature of 20.1 to 31.0 °C, salinity 37.0-40.1 ppt and nutrient concentration ranges during the bloom and red tide were 0.064-0.707 mg/l nitrate + nitrite and 0.001-1.66 mg/l phosphate, respectively. Maximum of *C. polykrikoides* abundance was measured 26×10^6 cells L^{-1} in October 2008. Kruscal wallis test demonstrated a significant difference in densities and chlorophyll-a in different months and seasons not in different stations. This study showed increase of temperature (>31.0 °C) stopped bloom and red tide due to *C. polykrikoides* in both the eastern and middle sampling stations but in the western stations was determined decrease in nutrient amounts as the major factor therefore increased nutrient of coastal waters, and environmental conditions could have efficacy the occurrence of this dinoflagellate.

Keywords: Red tide, *Cochlodinium polykrikoides*, Environmental conditions, Nutrients, Persian Gulf

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Introduction

Marine Phytoplankton including diatoms, dinoflagellates, blue-green algae, silicoflagellates and coccolithophores etc contributes about 95% of primary production in the ocean waters (Verlecar and Desai, 2004). Blooms of phytoplankton enhances the food chain and growth of marine organisms but when their numbers turns to become extremely high, red tide occurs and imposes great danger to the health of environment and marine creatures (Attaran-Fariman and Bolch, 2012).

In the late of twentieth century, a global increase in algae bloom has been occurred (Hallegraef, 1998) and many harmful species have bloomed (HABs) in different parts of the world. HABs have been increased in terms of number, density and geographical distribution and these blooms cause economic damages and various effects including threatening human health, missing marine resources or nourishing places or some effects on tourism (Zingone and Enevoldsen, 2000). Harmful algal blooms are serious threats to marine ecosystem and coastal economy. The intensity, duration and impacts of HABs can vary interannually, being influenced by changes climatic conditions and other factors such as nutrient and biochemical processes (Gobler et al., 2008). It is possible blooms in ocean may cover hundreds of square kilometers which could be traced by satellite images (Lindsey et al., 2010).

Different species of dinophyceae are responsible for the planktonic blooms and red tides in waters of Hormuzgan province amongst them, *Nauctiluca scintillans* (*miliaris*) is the main species and occurs repeatedly throughout the Persian Gulf and Oman Sea every year. But so far no record of *Cochlodinium polykrikoides* has been reported and identified from Iranian waters. It is one of the most important harmful dinoflagellate producing red tide and has fatal effects on of fish and other aquatics (Onoue and Nozawa, 1989a; Yuki and Yoshimatsu, 1989; Kim et al., 2000; Kim et al., 2002). The red tide forming dinoflagellate genus *Cochlodinium* appears to be expanding globally, as well as blooming and/or causing more economic losses within its previously reported geographic distribution (Kudela et al., 2008). This genus has become a cosmopolitan genus found in temperate and tropical waters of the globe (Steidinger and Tangen, 1997). *C. polykrikoides* is an unarmoured marine planktonic dinoflagellate species with a distinctive spiral-shaped cingulum and variable size (30-40 µm in length and 20-30 µm in width), Chains, rarely more than eight cells and it is also known as a red tide species associated with extensive fish kills and great economic loss (Steidinger and tangen, 1997). Its life cycle has two morphologically different stages: an armored and an unarmoured vegetative stage. The former easily develops into an unarmoured vegetative cell type also the cysts are generated by the armed vegetative cell (Kim et al., 2007). Other workers describe several other morphotypes of resting cysts (Matsuoka and Fukuyo, 2000). The cyst-motile stage relationship in *Cochlodinium* is thus not yet established (Richlen et al., 2010). The

first identification of *C. polykrikoides* was by Margalef (1961) in coastal waters of Puerto Rico (Rhichlen, 2010). Then continued to be reported as blooms former species since late of 1990s particularly in the Pacific Ocean, in both the eastern and western margins, also in 2000 and 2001, large blooms were reported in Mexico in the eastern Pacific (Morales-Blake and Hernandez-Becerril, 2001; Gárrate-Lizárraga et al., 2004). It was recorded most tensely from different regions particularly from Korean waters (Kim, 1997), Japan, and Korea (Onoue and Nozawa, 1989b; Yuki and Yoshimatsu, 1989; Lee et al., 2001). Other reports include: southeastern Asia especially in Philippines (Vicente et al., 2002; Relox and Bajarias, 2003), Malaysia (Anton et al., 2008), China (Qi et al., 1993), in Chesapeake Bay (Mulholland et al., 2009). All these reports have been demonstrated great economic loss and damages to the environment.

Phytoplanktonic blooms and red tide occurrences are an ordinary phenomenon in Iranian waters in the northern Persian Gulf and Oman Sea. Since 1980s, blooms have been reported from the northern Persian Gulf indicating the most important bloomed species have been *Noctilluca scintillans*, *Trichodesmium* sp. and *Nitzschia* sp. (Bahri, 2009). The first bloom of *C. polykrikoides* was observed in September 2009.

The aim of this researh was to assess the role of climatological and physical-chemical parameters on the bloom dynamics of *C. polykrikoides* in the northern Persian Gulf.

Materials and methods

The field surveys were carried out monthly at 7 stations from October 2008 to November 2009 (Fig. 1). Sampling stations were allocated within geographical coordinates of 57˚ 02' 17.8" and 26˚ 31' 46.4" to 54˚ 32' 10" and 26˚ 34' 7.9" from east to the west of coastal waters of Hormuzgan province, north-west of Persian Gulf (Table 1).

These sampling were conducted during the morning using small boats. At each station, surface water samples for cell counts, chlorophyll a and nutrient analyses were collected manually by sampling bottles. Triplicate 1-5 L water samples, depending on the station and/or on apparent microalgal concentrations were fixed with formalin then centrifuged and concentrated to about 50 ml for subsequent *C.polykrikoides* cell counts.

For determinations of nutrient concentrations, water samples were collected in polyethylene bottles, fixed with HgCl2 and immediately refrigerated until further processing. A 4 L water sample for chlorophyll a determinations was also taken in an amber plastic bottle and refrigerated for immediate processing upon return to the laboratory. Triplicate water samples were used for quantitative determinations of *C. polykrikoides* cell. Prior to cell counts**,** sample volumes were adjusted depending on apparent cell concentrations. Samples were gently mixed to give a homogeneous distribution of cells and subsequently, three 1ml aliquot replicates were counted in a Sedgewick-Rafter counting chamber using an inverted microscope (model CK40,

Olympus, Inc.). Determinations of cell abundance were based on average cell counts calculated from the replicate samples.

Table1: Geographical coordinates of sampling stations

Stations	E	N
S_1	57˚ 02' 17.8"	26˚ 31' 46.4"
S_2	56˚ 50' 15.9"	26˚ 57' 31.6"
S_3	56˚ 23' 14.3"	27˚ 03' 41.6"
S_4	56˚ 17' 38.2"	27˚ 09' 51.3"
S_5	56˚ 11' 32.3"	27˚ 01' 20.7"
S_6	54˚ 56' 43.3"	26˚ 33' 50.3"
S_7	54˚ 32' 10.0"	26˚ 34' 7.9"

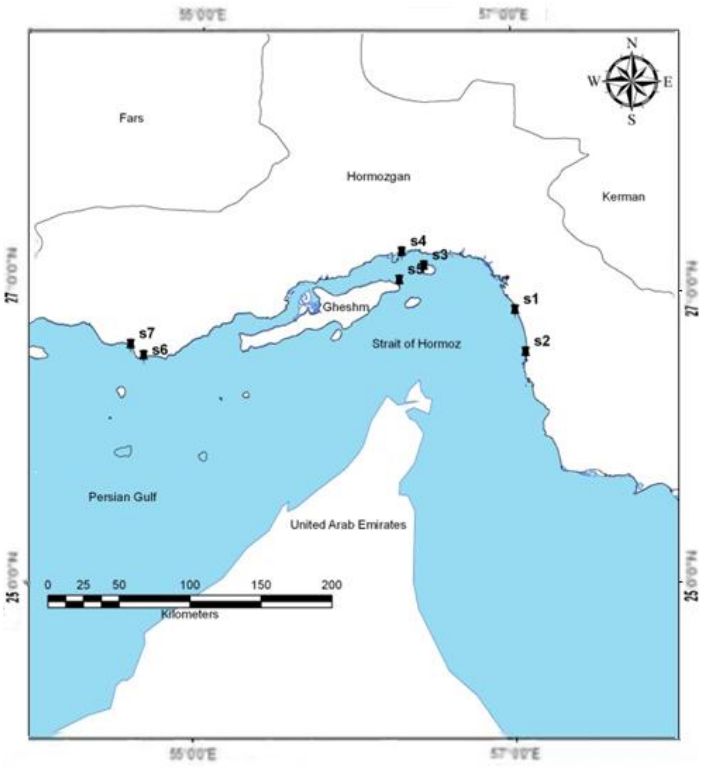

Figure1: Sampling stations of *Cochlodinium polykrikoides* bloom in the northern Persian Gulf coastal waters (2008-2009)

Meanwhile, on each sampling site, some water measurements including sea surface temperature, pH, salinity, dissolved oxygen, TDS and conductivity were also measured by Hack multi- analyzer model 156. Phosphate was measured by Vanadomolybdo phosphoric Acid colorimetric method and nitrite, nitrate and chlorophyll a were also measured by spectrophotometer UV/visible (Varian-carry 100) according to Manual of Oceanographic Observations and Pollutant Analysis Methods procedures (Marine

environment assessment marine meteorology, 1999) at the DOE lab.

For statistical purposes, by using Shapiro-Wilk test, it was shown that density and chlorophyll a samples distribution curves does not follow the normal distribution, therefore, one-way ANOVA Kruscal-Wallis test was used to compare the means according to space and time. Mann-Whitney test was also used for pair comparison between the samples and in order to obtain the relationship between physical and chemical parameters and the density and chlorophyll a, combined with Pearson correlation coefficient and regression analysis. All data were analyzed using Statistica soft ware version6 (StatSoft).

Results

All samples were thoroughly examined and *Cochlodinium polykrikoides* dinoflagellate was identified and density counted.

Abundance of C. polykrikoides

The cell counts showed in the first occurrence month a range of maximum 26×10^6cells L^{-1} at station 4 to minimum of 6.02×10^5 cells L^{-1} at station 7. The density trend showed an increase from east (station 1) towards the middle stations (3, 4 and 5) and then showing a descending trend to the west. The chlorophyll a measurements also showed exactly the same pattern of density fluctuations (Fig. 2).

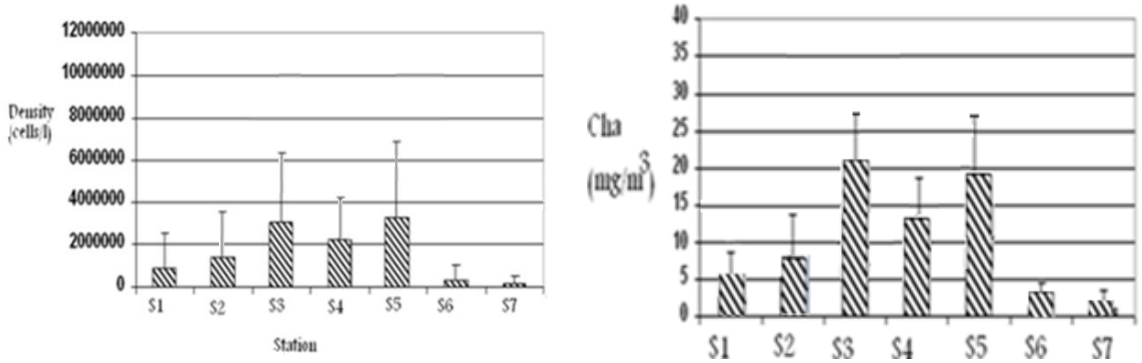

Figure2: *C. polykrikoides* abundance and chlorophyll a concentration in sampling stations (2008-2009).Error bars indicate SD

Kruscal-Wallis test demonstrated no significant differences for cell density (Chi-Square = 5.476, df = 6, Sig. = 0.484) and chlorophyll a (Chi-Square= 4.117, df = 6, Sig. = 0.661) at the level of $P<0.05$ amongst all stations.

On the other hand, the monthly variations of cell counts had a maximum mean value of 1.189×10^7 in October 2008 and a minimum of 163 cells L^{-1} during June 2009 (Table 2).

Kruscal-Wallis test showed a significant difference in densities (Chi-Square =65.069, df = 11, Sig. = 0.000) and chlorophyll a (Chi-Square = 64.072, df = 10, Sig. = 0.000) in different months at the level of $P<0.05$. Also this test showed a significant difference in densities (Chi-Square = 32.092, df = 3, Sig. = 0.000) and chlorophyll a (Chi-Square = 48.641, df = 3, Sig. = 0.000) in different seasons at the level of $P<0.05$.

Seasonal changes of *C.polykrikoides* density were presented in table 3. The maximum mean value of density was in autumn.

Mann-Whitney test demonstrated significant differences between different seasons spring/summer (0.035), spring/winter (0.002), summer/autumn (0.004), summer/winter (0.002) at the level of $P<0.05$.

Meanwhile, the relationship between the cell density (Y) and the chlorophyll a concentration(X) was calculated as $Y=7.4282X + 0.7686$ with $R^2=0.9489$.

Table 2: Comparison of *C. polykrikoides* abundance and chlorophyll a in sampling months (2008-2009)

Month	Cell Density Mean ±S.D	Min	Max	Chlorophyll α Mean ±SD	Min	Max
April 2009	96075 ± 84895	25	201000	0.7654 ± 0.6514	0.0171	1.7232
May 2009	158573 ± 101011	12	288000	0.7584 ± 0.6882	0.0185	1.9747
June 2009	163 ±159	72	500	0.0132 ± 0.0002	0.0130	0.0135
July 2009	176 ± 68	31	250	0.0129 ± 0.0014	0.0010	0.0138
August 2009	500 ± 487	31	1200	0.0180 ± .0010	0.0161	0.0192
September 2009	658 ± 483	62	1820	0.0233 ± 0.0038	0.0192	0.0310
October 2009	188 ± 105	63	325	0.0262 ± 0.0019	0.0231	0.0291
October 2008	11890000 ± 9718600	602000	26000000	-	-	-
November 2008	4295143 ± 3565400	970000	9145000	32.4261±25.7250	7.7250	68.7121
December 2008	996571 ± 688955	174000	2125000	7.5150 ± 5.4579	1.3123	17.5067
January 2009	1136625 ± 969120	15000	2922000	8.7446 ± 6.6910	0.0925	24.7892
February 2009	471371 ± 458052	1500	1205000	4.2614 ± 4.0342	0.0182	11.7551

-Data not available.

Table 3: Seasonal changes in density of *C. polykrikoides* (2008 -2009)

Seasons	Density Mean ±SD	Min	MAX	Chlorophyll α Mean ±S.D.	MIN	MAX
Spring	115479 ± 100324	12	288000	0.7619 ± 0.6438	0.0171	1.9747
Summer	336 ± 257	0	1200	0.0147 ± 0.0025	0.0100	0.0192
Autumn	6947120 ±	62	26000000	21.0595 ± 10.8252	0.0192	68.712
Winter	815314 ± 662992	1500	2125000	6.7646 ± 5.6564	0.0182	17.506

Physicochemical characteristics of seawater

In Tables 4 and 5 are shown physicochemical parameters of sea water in sampling stations and months respectively. For the red tide and bloom period in all stations, the temperature range was 20.1-29.6 °C, salinity 37-40.1 ppt and nutrient concentration ranges were 0.064-0.707 mg/l nitrate + nitrite and 0.001-1.66 mg/l phosphate, respectively. N/P ratio was also determined that at the time of bloom, this ratio was less than 7. The relation and regression of the cell density (Y) and temperature (X) were calculated as : $Y= -2E +0.7X^2 +9E +0.8X -1E +10$; ($R^2= 0.775$). Also the relation for nitrate (X), phosphate (X') and the summation of these (X") were orderly $Y= 7E+ 0.7X – 7E +0.6$, $R^2 = 0.6403$ and $Y= 3E+ 0.7X' +755222$, $R^2 = 0.9347$, $Y= 3E+ 0.7X" – 3E + 0.6$, $R^2 = 0.9891$.

Table4: Annual average of physical and chemical parameters at different stations (2008-2009)

Station		pH	T ^{O}c	Salinity ppt	DO mg/l	Conductivity ms/cm	T.D.S. mg/l	Nitrate mg/l	Nitrite mg/l	Phosphate mg/l
S1	During red tide	8.20	27.35	38.71	5.96	58.10	29.07	0.134	0.0054	0.382
	Red tide	8.35	25.37	38.40	6.64	57.68	28.95	0.154	0.0057	0.550
	Non red tide	7.93	30.80	39.22	4.02	58.85	29.27	0.098	0.0050	0.087
S2	During red tide	8.32	27.06	38.54	5.68	57.94	29.28	0.190	0.0172	0.031
	Red tide	8.45	25.01	38.42	6.68	57.75	28.95	0.247	0.0270	0.481
	Non red tide	8.10	30.65	38.75	3.93	58.28	29.85	0.091	0.0025	0.108
S3	During red tide	8.44	27.10	38.50	5.80	57.80	29.02	0.163	0.0075	0.180
	Red tide	8.55	24.80	38.30	6.80	57.50	28.80	0.200	0.0100	0.248
	Non red tide	8.25	31.15	38.90	4.07	58.50	29.40	0.090	0.0037	0.060
S4	During red tide	8.31	26.70	38.30	5.96	57.50	28.60	0.185	0.0043	0.127
	Red tide	8.38	24.10	38.01	7.02	57.10	28.40	0.236	0.0031	0.175
	Non red tide	8.19	31.27	38.80	4.10	58.20	28.90	0.097	0.0030	0.045
S5	During red tide	8.33	26.79	38.21	6.05	57.51	28.68	0.195	0.0033	0.179
	Red tide	8.41	24.34	37.90	7.21	57.15	28.54	0.250	0.0045	0.256
	Non red tide	8.20	31.07	38.77	4.02	58.15	28.92	0.093	0.0025	0.046
S6	During red	8.37	26.30	38.60	5.78	58.16	29.05	0.136	0.0040	0.007
	Red tide	8.40	22.50	39.00	7.27	58.80	29.30	0.196	0.0030	0.003
	Non red tide	8.36	28.50	38.40	4.90	57.78	28.90	0.103	0.0050	0.008
S7	During red	8.43	26.20	38.70	5.50	58.30	29.00	0.107	0.0040	0.007
	Red tide	8.48	22.30	39.20	6.75	59.00	29.45	0.140	0.0030	0.004
	Non red tide	8.41	28.40	38.40	4.80	57.80	28.70	0.084	0.0050	0.008
Mean		8.33	27.04	38.57	5.66	57.99	29.00	0.150	0.0100	0.143

Table 5: Annual average of physical and chemical parameters of sea water (2008-2009)

Months	**pH**	**T** c^o	**salinity** **(ppt)**	**DO** **mg/l**	**NO_3** **mg/l**	**NO_2** **mg/l**	**PO_4** **mg/l**	**Density** **(cells/l)**
October 2008	8.52	28.9	39.2	8.8	0.378	-	0.561	11.888430
November	8.65	21.8	38.7	7.9	0.196	0.017	0.347	4.152286
December	8.43	21.0	38.4	7.0	0.157	0.010	0.273	1.100286
January 2009	8.30	20.6	38.3	7.0	0.168	0.005	0.360	1.186429
Febuary	8.41	22.1	38.3	6.6	0.168	0.005	0.170	0.471371
March	8.38	28.1	37.6	5.1	0.144	0.006	0.040	0.096075
May	8.31	29.0	38.0	4.7	0.142	0.007	0.039	0.143311
June	8.22	32.1	38.5	4.2	0.098	0.005	0.058	0.000159
July	8.16	33.1	38.9	4.0	0.116	0.003	0.065	0.000108
August	8.24	30.7	38.7	4.2	0.090	0.003	0.048	0.000500
September	8.20	27.5	38.9	4.2	0.080	0.004	0.042	0.000483
October	8.21	27.4	39.0	4.3	0.070	0.004	0.045	0.000187
Mean ±S.E	8.34±0.040	26.9±1.270	38.5±0.130	5.6±0.490	0.151±0.236	0.006±0.001	0.171±0.050	1.586635±0.997

- Data not available.

Pearson correlation coefficient showed that the cell density had a negative correlation with temperature (-0.445) and salinity (-0.126) at the level of $P<0.05$ and a positive correlation with nitrate (0.306), nitrite (0.375), phosphate (0.390), DO (0.691) and pH (0.411) at the level $P<0.01$.

Pearson correlation coefficient also demonstrated that relation between the cell density and nitrate in S1(0.435), S2(0.695), S6(0.936) and S7(0.797) had a greater role than phosphate in this stations S1(0.084), S2(0.096), S6(0.369) and S7(0.102) but relation between cell density and phosphate in stations S3(0.952), S4(0.998) and S5(0.984) was the more important than nitrate S3(0.540), S4(0.912) and S5(0.962) at the level $P<0.05$.

Discussion

Red tide is a frequent phenomenon which occurs in marine waters every year causing by a variety of phytoplankton species including *C. polykrikoides*. But the extensive bloom of this species in recent years has been very pronounced because of its great damage to the marine environment and commercial industries such as mariculture. Red tide resulting from this species has been extended worldwide (Kudela et al., 2008) mainly in warm temperate and tropical waters (Steidinger and Tangen, 1997) from which, and Persian Gulf has not been an exception. The bloom started from Hormuzgan province in the Strait of Hormuz in October 2008 and then extended westward to the inner Persian Gulf within a few months. It covered most of the area mainly inshore and partly offshore. In the south it had the same trend and started from Omani coasts and then to UAE. The first efforts to identify the cause of this unusual bloom which turned the color of water into a stinky dark red blanket showed that this had been caused by *C.polykrikoides* which was a new species to appear and to bloom in the area (Matsuoka et al., 2010b). Using molecular phylogenetic technique, Matsuoka et al. (2010b) also found that the origin of this species belong to the American/Malaysian ribo-type which is distributed worldwide.

Interesting things about this bloom was three aspects. First, it started at the beginning of autumn and lasted for the winter and spring seasons while the usual blooms for this area which is mainly caused by *Noctiluca scintillans*, usually occurs in autumn (and spring) but never had occurred during the cold periods. Second, usual blooms last only for only a few days or weeks while this bloom lasted for about 7 months in the area continuously. Third, the cell density was unexpectedly very high to magnitudes which have never been reported from this region, reaching a maximum of 26×10^6 cells per liter. But, according to different reports, these kinds of cell number seem to be normal for this species; from Chesapeake Gulf for example, a density of more than 10 million cells per liter

(Mulholland et al., 2009), in Philippines between 2.5 $\times 10^5$ – 3.2 $\times$ 10^6 (Azanza et al., 2008), in California, up to 7.05×10^6 (Gárrate-Lizárraga et al., 2004), in Costa Rico coasts, 1.7×10^5 (Vargas – Montero et al., 2006) and from Malaysia 6×10^6 cells per liter (Anton et al., 2008) had been reported. The high from Iranian waters comparing to mentioned reports indicates a much appropriate conditions prevailed in the Persian Gulf during the red tide occurred.

Kulis (2009) suggested reasons such as decrease of temperature, nutrient depletion and effects of grazers on the reduction of cell density may stop this red tide. Bloom started in October 2008 during which sea water temperature was measured between 28.4 - 29.6 °C with a cell density of about 1.2×10^6 cells L^{-1}. In the following month in Nov. 2009, density increased sharply to its average maximum of about 4.1×10^6 cell L^{-1} while sea temperature dropped to 20.5 ^oC. The same rang of temperature more or less like November in the following months with bloom still nourished but with a decreasing trend reaching about 1.43×10^5 cells L^{-1}. It seems that favorable temperature for this creature to bloom is favored when temperature drops and water become cooler below 30 ^oC. For this reason, as soon as temperature went above 30 ^oC in June 2009, cell density dropped to about zero (only163 cells/l). For the rest of summer times it was the case and bloom stopped. This clearly shows that this species could not tolerate warm conditions and favors lower temperatures. That is why there was a negative correlation between cell densities and temperature (-0.445 at the level of $P<0.05$). Similar conditions have been observed in other parts of the world. For instance, in western Japan and southern Korea, the temperature was reported between 10–27 ^oC during the bloom (Matsuoka et al., 2010a) and in California Gulf between 29-31 ^oC (Garrate-Lizarraga et al., 2004). Some researchers have found a relationship between morphological appearance of this species and temperature fluctuations. In this regard, Kim et al. (2004) has reported that *C. polykrikoides* reacts morphologically to low temperature and salinity. We found the same situation, so that in October with a temperature of higher than 28 ^oC, chains were appeared as eight cells while they were seen as short and single chains during colder months.

Salinity also affects the phytoplankton bloom. Salinity range during the bloom of this species has been observed between 32 and 33 ppt in western Japan (Kim et al., 2004) and between 30 and 34 ppt in California (Kudela et al., 2008). In this study, salinity range was between 37.0-40.1 ppt which is a much higher in comparison. This difference indicates that this species could bloom in a wide range of salinities but Pearson correlation coefficient showed a very low negative correlation between salinity and cell density (-0.126) at the level of $P<0.05$ that means the more salinity the less bloom. Morales-Blake and Hernández-

Becerril (2001) have expressed that this species is a eurytherm and euryhaline species. This explains that why high salinities in the Persian Gulf, which is one of the most saline marine environment in the world, did not prevent *C. polykrikoides* to bloom with a period of about 7 months of red tide with salinities above 38 ppt in the area also it tolerances temperature until 31 °C. To examine the relation between bloom density and nutrients, a correlation test was carried out. The results show a positive correlation with nitrate (0.306), nitrite (0.375), phosphate (0.390), at the level of $P<0.01$. In this regard, similar results obtained from other parts of the world including Malaysia (Anton et al., 2008), California (Garrate-Lizarraga et al., 2004) and Philippines (Vicente et al., 2002) are agreeable to the results of this study that nutrients play a major role in enhancing the red tide. Among these nutrients, using Pearson correlation coefficient with cell density, it was shown that in all sampling periods, there was very high correlation especially during Oct 2008 with phosphate (0.912) and nitrate (0.705). But Pearson correlation coefficients for all bloom months showed a higher correlation with nitrate. By using satellite images, Morrison (2000 cited in Herring and Scott, 2002) showed that there is a strong upwelling alongside of the coasts of Oman Sea bringing rich-nutrient waters to the surface. Kudela et al. (2008) has also expressed that this species uses both organic and inorganic nitrogen as a mixotroph organism. Even though these results confirm the relation between the bloom of this species and nitrate in some stations; but in stations 3, 4 and 5, the high correlation was due to the phosphate and not to nitrate. To add to these results, we found that 4 months after the onset of bloom in stations 6 and 7 (Western stations away from the Strait of Hormuz), bloom disappeared with a decrease in nutrient amounts. The main source of nutrient flux into the Persian Gulf from the east is nutrient-rich waters of Oman Sea.

Until today, the cause of *C.polykrikoides* bloom in this region is not known yet and from previous records this is the first HAB event associated with this species in the Persian Gulf and Oman Sea. It appeared so fast that no one expected and could explain it but it coincides with an appearance global expansion of this taxon, as well as a recent increase in HAB impacts observed in the region. The mechanisms underlying this event are not known yet and different reasons can cause it for example the algae was first introduced to the area via discharged ballast water from transport ships coming mainly from Far East and India or cells of this species were transferred to the region by a strong cyclone called Gonu which hit the coast of Oman first and then Iran in June 2007 coming from east of north Indian ocean and then bloomed in the consequent months because of appropriate conditions which surprisingly increased the cell densities to figures more than

25×10^6 cells/l. Moreover, comparing to other countries like South Korea and Japan, it is likely that this species would return and starts to bloom again. Richlen et al. (2010) believe that a pattern of subsequent recurrence of *C. polykrikoides* blooms following an initial outbreak has been observed in other parts of the world, suggesting that this species may become a persistence HAB problem in this region. Therefore, we recommend here that a monitoring program regarding the periodic sampling on water and sediment (for cyst stage) should be carried out until the life stages and cycles of this species in Iranian waters is completely known.

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