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Phytoplankton and Nutrient Variations in the Iranian Waters of the Caspian Sea (Guilan region) during 2003–2004

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Abstract

This study concentrated on temporal distribution and species composition of phytoplankton connected with physicochemical variations between January 2003 and November 2004 in the South Western Caspian Sea. During the study, 75 phytoplankton were distinguished in total and average phytoplankton densities in 2003 and 2004 were $1.47\times10^5\pm6.05\times10^4$ and $1.97\times10^5\pm7.18\times10^4$ cells L^{-1}, respectively. Contributions of diatoms (66.0% in 2003; 57.0% in 2004) and cyanophytes to total phytoplankton (17.0 in 2003; 36.0% in 2004) were higher than any other group. Diatoms *Dactyliosolen fragilissimus* and *Thalassionema nitzschioides,* and cyanophytes *Oscillatoria* sp. and *Anabeanopsis raciborskii* provided the biggest contributions to the total phytoplankton. Average DIN concentration in 2003 was higher (3.86±1.65 µM) than the average in 2004 (3.37±1.13 µM). However, average DIP concentration in 2003 was lower (1.45±1.37 µM) than the average in 2004 (1.99±0.67 µM). Average DIS concentration was two-fold higher than average DIN concentration. Average DIN:DIP without NH_4 (2.66±1.66 in 2003; 1.69 ± 1.17 in 2004) and DIS:DIP ratios (5.61±3.44 in 2003; 3.93±2.49 in 2004) were clearly lower than Redfield ratios. Nutrient ratios and phytoplankton densities revealed that system was eutrophic

Keywords: Phytoplankton, checklist, cell density, nutrient, Caspian Sea.

2003–2004 Yıllarında Hazar Denizi'nin İran Sularında (Guilan Bölgesi) Fitoplankton ve Nütrient Değişimleri

Özet

Bu çalışmada, Güney Batı Hazar Denizinde fiziksel ve kimyasal değişimlerle ilişkili olarak Ocak 2003 – Kasım 2004 döneminde zamana bağlı fitoplankton değişimleri ve fitoplankton tür kompozisyonu incelenmiştir. Çalışma süresince, toplam 75 fitoplankton türü tanımlandı ve 2003 ve 2004'deki toplam fitoplankton yoğunlukları sırasıyla $1{,}47\times10^5\pm6{,}05\times10^4$ ve $1{,}97\times10^5\pm7{,}18\times10^4$ hücre L^{-1} olarak bulundu. Diyatomelerin toplam fitoplanktona olan katkıları (2003'de 66,0%; 2004'de 57.0%) ile siyanofitlerin toplam fitoplanktona olan katkıları (2003'de 17,0%; 2004'de 36,0%) diğer grupların katkılarından daha yüksekti. Diyatomelerden *Dactyliosolen fragilissimus* ve *Thalassionema nitzschioides*; siyanofitlerden *Oscillatoria* sp. ve *Anabeanopsis raciborskii* toplam fitoplanktona en büyük katkıyı sağladılar. 2003'deki ortalama DIN konsantrasyonu (3,86±1,65 µM) 2004'deki konsantrasyonundan (3,37±1,13 µM) daha yüksekti. Bununla birlikte, 2003'deki ortalama DIP konsantrasyonu (1,45±1,37 µM) 2004'deki ortalama DIP konsantrasyonundan (1,99±0,67 µM) daha düşüktü. Ortalama DIS konsantrasyonu ortalama DIN konsantrasyonundan iki kat daha yüksekti. NH_4 olmaksızın ortalama DIN:DIP (2003'de 2,66±1,66; 2004'de 1,69±1,17) ve DIS:DIP oranları (2003'de 5,61±3,44; 2004'de 3,93±2,49) açık bir şekilde Redfield oranlarından düşüktü. Nütrient oranları ve fitoplankton yoğunlukları ile ilgili sonuçlar sistemin ötrofik olduğunu göstermiştir.

Anahtar Kelimeler: Fitoplankton, tür listesi, hücre yoğunluğu, nütrient, Hazar Denizi.

Introduction

The Caspian Sea located between 36° N and 62° N is the largest inland body of water in the world with a drainage basin of roughly 3.70 million km^2 and accounts for 40.0 to 44.0% of the total lacustrine waters of the world (Marret *et al.*, 2004; Stolberg *et al.*, 2006; Mertens *et al.*, 2012). The basin is divided into three distinct physical regions: the Northern, Middle, and Southern Caspian. The northern Caspian only including the Caspian shelf is very shallow, and accounts for less than 1.00% of the total water volume (volume: 6,940 km^3; area: 80,000 km^2; average depth: 5 m; maximum depth: 20 m). The middle Caspian accounts for 33.0% of the total water volume (volume: 22,900 km^3; area: 138,000 km^2; average depth: 190 m; maximum depth: 790 m). The southern Caspian is the deepest, with oceanic depths of over 1000 m and accounts for 66.0% of the total water volume (volume: 45,800 km^3; area: 168,000 km^2; average depth: 325 m; maximum depth: 1025 m) (Kosarev and Yablonskaya, 1994; Aladin and Plotnikov, 2004).

The Caspian Sea has been seriously modified by man-made activities, mostly as an outcome of modifications in the water flow and destruction of the water bodies in the system (Dumont, 1995; Kideys *et al.*, 2008; Bagheri *et al.*, 2013). Changes in the national surroundings have influenced local economies, mainly based on fish stocks (Stolberg *et al.*, 2006). Nutrients are introduced into the Caspian Sea mostly via northern basin due to the over discharge of the Volga River (85% of the total river input) (Rodionov, 1994; Dumont, 1998). Therefore, long-term changes in the evolution of phytoplankton in the northern Caspian are related to nutrient concentrations provided by Volga River.

The south western Caspian Sea is greatly influenced by fresh waters from the Anzali wetlands (catchment area: 3,740 km^2; fresh water discharge: 2,000,000 m^3 y^{-1}) (Sharifi, 2006; Bagheri *et al.*, 2012a), located in the west of the Sefidrood river delta (catchment area: 67,000 km^2, fresh water discharge: 4,000,000 m^3 y^{-1}) (Lahijani *et al.*, 2008; Bagheri *et al.*, 2011), and from the Lisar river (fresh water discharge: 1,200,000 m^3 y^{-1}) (IFGO, 2003; Bagheri *et al.*, 2012a). Average salinity dramatically increases (0.10-0.30 psu) from the surface to the bottom (Kosarev and Yablonskaya, 1994). The surface water temperature fluctuates from a minimum of 9.0 °C in winter and to a maximum of 29.0°C in summer (Bagheri *et al.*, 2010).

Due to the long-term separation from other marine systems, the Caspian Sea is distinguished by numerous common species. It is known that the Caspian Sea contains 54 endemic fish, 53 endemic mollusks, and 1 endemic mammal, known as the Caspian seal (*Pusa caspica* Gmelin, 1788) (Kosarev and Yablonskaya, 1994; Dumont 1998). After the Volga Don passage was established in 1960s, 7 diatoms, 2 dinoflagellates, 10 macrophytes, 7 invertebrates, 6 fouling, 2 fish, and 9 benthic invasive species broke in the Caspian Sea. However, system has been dominated by only a few invasive species belongs to phytoplankton, mesozooplankton and benthic communities (Karpinsky, 2010). Kasymov and Rogers (1996) reported 414 phytoplankton species between 1950s and 1980s. Due to the declining fresh water discharge, the phytoplankton species number in the southern Caspian Sea was lower (71 taxa) than in the northern Caspian (414 taxa) (Dumont, 1998).

Some researchers reported that the nutrients levels were low during 1990s in the Caspian Sea (Kosarev and Yablonskaya, 1994; Dumont, 1998; Kideys and Moghim, 2003; Kideys *et al.*, 2005a; Hosseini, 2011). Due to the extensive agricultural utilization and deforestation of woodlands, the nutrient loads of rivers have increased since the early 2000s (Kideys *et al.*, 2008; Bagheri *et al.*, 2014). The increased nutrient load in the south western of the Caspian Sea after 2000 caused a raise in primary production supported by high phytoplankton abundance (Bagheri *et al.*, 2012b, 2012c).

Recently, Khodaparast (2006), Bagheri *et al.* (2011) and Nasrollahzadeh *et al.* (2011) reported that the cyanophyte *Nodularia spumigena* Mertens ex Bornet and Flahault 1886 and dinoflagellate *Heterocapsa* sp. formed two abnormal phytoplankton blooms in the Iranian coasts of the Caspian Sea. Furthermore, Kideys *et al.* (2008), Roohi *et al.* (2010) and Bagheri *et al.* (2012b, c) reported that there were significant increases in phytoplankton blooms and their harmful effects in the southern Caspian Sea. In addition, phytoplankton studies conducted on the southern Caspian Sea in recent years (Kideys *et al.*, 2005b; Nasrollahzadeh *et al.*, 2008a; Khenari *et al.*, 2010; Roohi *et al.*, 2010) showed that there was a significant effect of invasive ctenophore *Mnemiopsis leidyi* A. Agassiz, 1865 on phytoplankton fluctuations in the Iranian waters of the Caspian Sea.

This study aims to investigate the nutrient dynamic and to examine qualitative and quantitative state of the phytoplankton communities of the south western Caspian Sea during 2003-2004. In addition, eutrophication process of the system was discussed based on previous and current research findings.

Materials and Methods

Phytoplankton abundance and species composition were evaluated using samples collected from a total of 12 stations located along three transects; Lisar (L), Anzali (A) and Sefidrood (S). Since each transect extended from shallower coastal zone to deeper offshore zone, sampling stations were located at different depths (stations at 5 m: L1, A1, S1; stations at 10 m: L2, A2, S2; stations at 20 m: L3, A3, S3; stations at 50 m: L4, A4, S4) (Figure 1). The samplings were conducted periodically in 2003 (January, August, October, November and December) and 2004 (April, May, July, September, October and November).

Water samples were collected using a 1.71 L Nansen water sampler (Hydro–Bios, Germany; TPN; Transparent Plastic Nansen water sampler, No. 436201). Temperature was measured in situ by using a reverse thermometer (Hydro–Bios, TPN). Salinity was measured by a salinometer (Beckman; RS–7B, U.S. Patent, No. 2542057). Water transparency was measured with a Secchi disk. Water samples were frozen (-21.0°C) until analyses of inorganic nutrients. Dissolved inorganic phosphorus (DIP), dissolved inorganic nitrogen (DIN), and dissolved inorganic

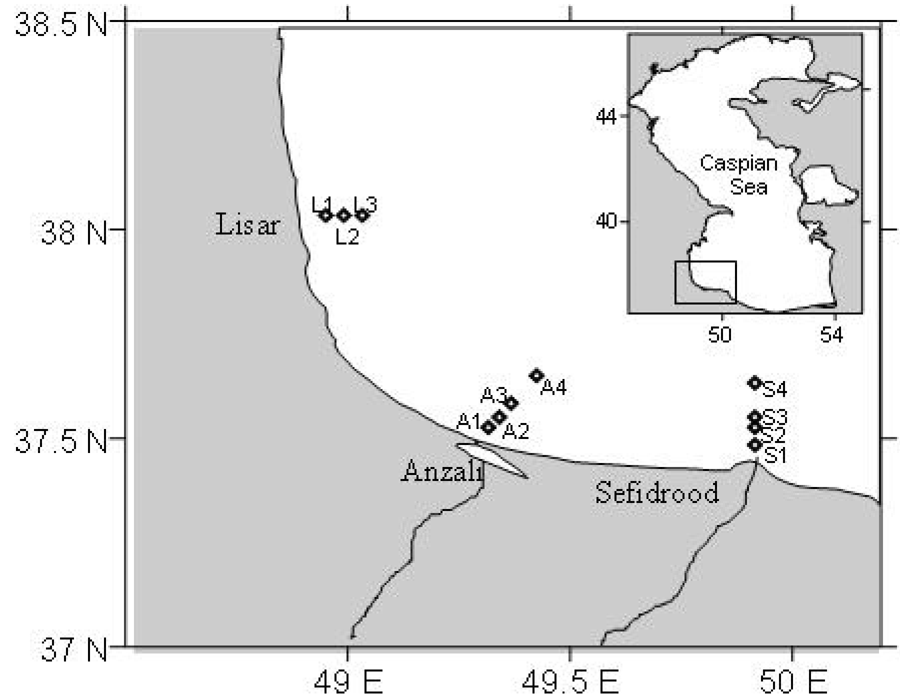

Figure 1. Sampling transects and their stations in the south western Caspian Sea.

silicate (DIS) were determined by a spectrophotometer (Hach DR/2000) using standard methods (Clesceri *et al.*, 2005).

Phytoplankton samples were collected from using a Nansen water sampler. The samples were kept in 500 ml bottles and preserved in 4.0% buffered formaldehyde. The samples were first allowed to settle for 10 days and then the sample volume was reduced to 250 ml by siphoning. The subsamples were further reduced to 30.0 ml using a centrifuge (5 min at 3000; ALC-PK131R; Germany, No. 30206372). For the enumeration of the phytoplankton, Sedgewick-Rafter counting slide was used and the samples were counted using a phase-contrast microscope (cover slip 24 × 24 mm; magnifications 10×, 20×, and 40×) (Prescott, 1962; Vollenweider, 1974; Newell and Newell 1977; Sournia 1978; Clesceri *et al.*, 2005). The enumerations of phytoplankton were repeated three times. Phytoplankton taxonomic classification was performed based on Tiffany and Britton (1971), Round *et al.* (1990) and Kasymov (2000).

Analysis of variance (One-way ANOVA) followed by the Duncan test for water parameters and nonparametric test (Kruskal–Wallis) for phytoplankton density were used to identify the importance of variables between different sampling periods. Spearman rank correlation coefficients (r) were calculated to estimate the relationships between phytoplankton density and other hydrological parameters. A statistical software (Statsoft; SPSS version 15) was used for comparisons between different sampling periods. Descriptive statistics such as minimum, maximum, mean, standard deviation were conducted using Biodiversity Professional Version 2 (McAleece *et al.*, 1999). Means and standard deviations were given as "mean±SD". Moreover, cluster analysis (Bray–Curtis similarity index; UPGMA; log10 transformed; MVSP version 3.13d) was used to detect temporal changes in the phytoplankton structure.

Results

Physical Characteristics

Descriptive statistical results of the monthly variations of the surface temperature, salinity and Secchi disk depths in the south western Caspian Sea are shown in Table 1. The average surface salinity variations from inshore (St. A1) to offshore (St. A4) on the Anzali transect are given in Figure 2.

Temporal surface temperature values in 2003 varied between 8.80 (January 2003) and 28.6°C (August 2003) and the annual average temperature was 18.1±7.07 °C in 2003. However, due to lack of data in winter, the temporal surface temperature was between 11.2 (April 2004) and 28.1°C (July 2004). Therefore, the annual average temperature in 2004 was higher (20.3±5.42°C) than that in 2003 (18.1±7.07°C) (Table 1). These variations in temperature were significant ($P<0.01$).

Regarding salinity variations, while the temporal surface salinity in 2003 varied between 7.33 and 12.7 psu, the annual average surface salinity in 2003 was 11.3±0.63 psu (Table 1). Contrary to temperature variations, temporal salinity variations in 2003 (min-max: 7.33-12.7; mean: 11.3±0.63 psu) were more similar to variations in 2004 (min-max: 8.02-12.6; mean: 11.1±0.63 psu) and temporal salinity variations were not meaningful ($P>0.05$). However, Figure 2

Table 1. Descriptive statistical results of hydro-physical parameters in the south western Caspian Sea

Parameters	Temperature (°C)			Salinity (psu)			Secchi Depth (m)		
	Min	Max	Mean±SD	Min	Max	Mean±SD	Min	Max	Mean±SD
January-03	8.80	12.4	10.8±1.46	7.33	12.4	10.4±1.87	1.10	4.20	2.03±0.87
August-03	26.2	28.6	27.4±1.10	10.4	12.2	12.0±0.39	1.20	5.50	3.05±1.05
October-03	22.9	24.3	23.4±0.51	8.82	12.7	11.8±1.67	0.80	7.50	3.06±1.81
November-03	15.8	17.5	16.5±0.68	9.66	12.5	10.9±1.39	1.30	6.50	3.07±1.83
December-03	11.8	14.3	12.7±1.10	9.01	12.3	11.5±1.13	0.60	5.40	2.77±2.08
Average (2003)	17.11	19.4	18.1±7.07	9.05	12.4	11.3±0.63	1.00	5.82	2.80±0.44
April-04	11.2	14.8	13.0±1.10	8.16	12.1	10.8±1.38	1.30	7.20	3.00±0.87
May-04	17.4	20.8	19.1±1.21	11.56	12.2	11.4±1.01	1.90	9.00	4.50±2.00
July-04	25.9	28.1	27.0±0.83	9.81	12.2	12.0±0.19	1.25	5.20	2.62± 0.8
September-04	23.9	25.0	24.5±0.41	11.16	12.6	11.5±0.50	1.50	4.20	2.81±0.40
October-04	21.2	23.3	22.8±0.63	8.02	11.8	10.1±0.45	0.90	3.70	1.60±0.60
November-04	14.2	17.3	15.4±1.27	8.58	12.1	10.9±1.69	1.10	4.00	2.10±1.30
Average (2004)	19.0	21.6	20.3±5.42	9.55	12.2	11.1±0.63	1.32	5.55	2.77±0.99

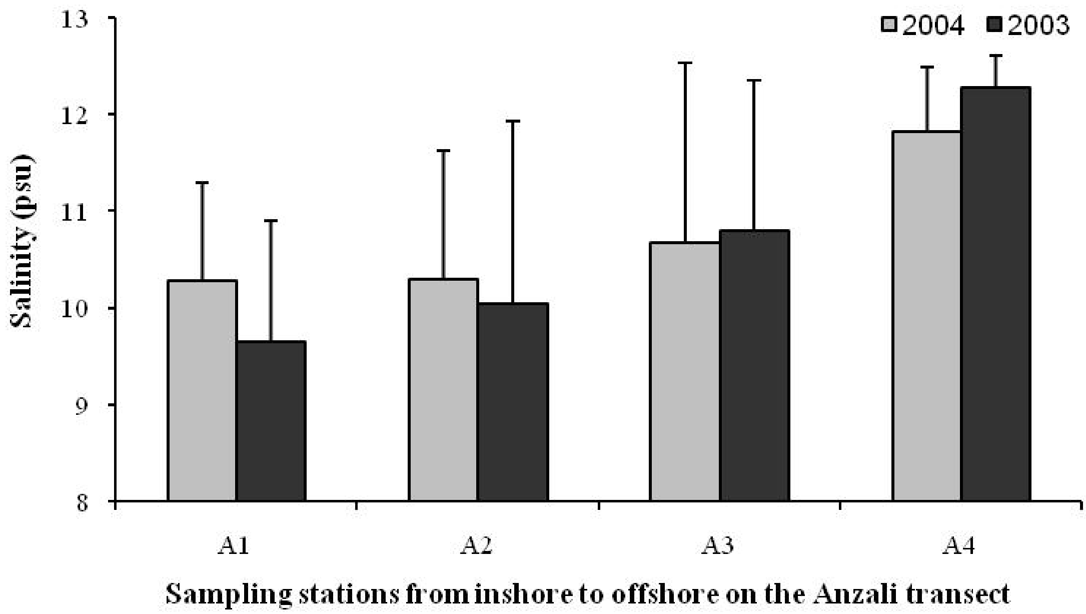

Figure 2. The variations of the average and standard deviation (SD) of surface salinity from inshore (St. A1) to offshore (St. A4) on Anzali transect in the south western Caspian Sea.

revealed that during the sampling period, especially during 2003, there was a gradually increase in salinity from inshore (9.60 psu) to offshore (12.3 psu) in the south western Caspian Sea.

Temporal Secchi disk depths varied between 0.60 and 7.50 m with an average depth of 2.80±0.44 m in 2003, whereas they varied between 0.90 and 9.00 m with an average 2.77±0.99 m in 2004 (Table 1). The Secchi disk depths were not significantly different between sampling periods ($P>0.05$) and were negatively correlated with phytoplankton densities ($r = – 0.478$; $P<0.01$).

Nutrients

Descriptive statistical results of nutrient concentrations in the south western Caspian Sea in the study period are shown in Table 2.

While DIN concentrations in 2003 varied between 0.10 and 11.7 µM (mean: 3.86±1.65 µM), the concentrations in 2004 fluctuated between 0.16 and 20.1 µM (mean: 3.37±1.13 µM). However, variations in DIP were smaller than DIN and DIS variations during the study and varied between 0.03 and 5.22 µM (mean: 1.45±1.37 µM) in 2003 and between 0.15 and 4.90 µM (mean: 1.99±0.67 µM) in 2004 (Table 2). On the other hand, variations of DIS were higher than other nutrient variations and the concentrations varied between 0.71 and 39.9 µM (mean: 8.14±6.35 µM) in 2003 and between 1.17 and 34.2 µM (mean: 7.83±5.00 µM) in 2004.

Findings on nutrients also revealed that there was a wide monthly nutrient variation, especially in 2003 (Table 2). Except DIN, nutrient concentrations in January 2003 were higher than any other sampling period. However, not only in January 2003, but also in October 2004 nutrient concentrations were higher due to the high river discharges in these periods (Table 2).

While average DIN concentrations varied between 2.50 µM (May and November 2004) and 6.38 µM (October 2004), average DIP concentrations varied between 0.70 µM (December 2003) and 3.18 µM (January 2003). Average DIS concentration varied between 3.95 µM (May 2004) and 12.4 µM (January 2003) (Table 2). Although there were important variations in nutrient concentrations in the sampling periods, annual average nutrient concentrations in 2003 and 2004 were nearly similar to each other (Table 2). However, DIN and DIP concentrations were significantly different during 2003 and 2004 ($P<0.05$) in view of statistics, whereas DIS was not significantly different ($P>0.05$). On the other hand, there were important positive correlations between river discharges with DIP concentrations ($r = 0.697$), and DIN concentrations ($r = 0.520$). However, the positive correlation between river discharges and DIS was lower ($r = 0.357$).

Nutrient Ratios

Descriptive statistical results of nutrient ratios such as DIN:DIP, DIS:DIN and DIS:DIP without ammonium (NH_4) in the south-western Caspian Sea in the study period are shown in Table 3.

Without NH_4 as a nitrogen source, while DIN:DIP, DIS:DIP and DIS:DIN ratios varied between 0.15 and 6.16 (mean: 2.66±1.66), between 0.73 and 30.9 (mean: 5.61±3.44) and between 0.98 and 12.4 (mean: 2.11±0.55), respectively in 2003, they varied between 0.27 and 4.10 (mean: 1.69±1.17), between 1.15 and 11.4 (mean: 3.93±2.49), and

Table 2. Descriptive statistical results of hydro-chemical parameters in the south western Caspian Sea (Rivers discharge data are provided by GWRO, 2010)

Parameters	DIN (µM)			DIP (µM)			DIS (µM)			Discharge (million m^3)
	Min	Max	Mean±SD	Min	Max	Mean±SD	Min	Max	Mean±SD	Mean
January-03	1.14	11.7	5.19±2.94^b	1.12	5.22	3.18±2.86^c	1.12	39.9	12.4±8.66^a	133.0
August-03	0.10	5.71	3.05±0.90^a	0.03	1.41	0.80±0.20^a	0.99	17.1	5.21± 4.12^a	32.0
October-03	0.15	8.14	4.40±1.07^{ab}	0.97	3.22	1.61±0.23^{abc}	0.71	26.0	6.14±4.19^a	62.2
November-03	0.23	7.14	3.66±0.60^{ab}	0.32	1.16	0.98±0.01^a	2.84	27.1	8.70±5.94^a	68.7
December-03	0.17	7.86	3.02±1.23^a	0.28	1.55	0.70±0.17^a	1.35	30.7	8.30±6.84^a	87.2
Average 2003	0.36	8.11	3.86±1.65	0.54	2.51	1.45±1.37	1.40	28.1	8.14±6.35	76.6
April-04	0.21	8.20	2.82±0.83^a	0.35	2.22	1.65±0.34^{abc}	2.38	25.3	8.44±3.89^a	120.0
May-04	0.16	7.14	2.50±1.19^a	0.15	2.40	1.41±0.37^{abc}	1.24	7.11	3.95±1.80^a	111.0
July-04	0.28	4.10	2.67±0.56^a	1.03	3.38	2.10±0.72^{abc}	3. 38	23.8	8.01±4.70^a	63.9
September-04	--	--	--	--	--	--	--	--	--	77.6
October-04	0.71	20.1	6.38±1.43^b	1.25	4.90	2.94±0.33^b	1.44	26.3	8.18±6.82^a	142.0
November-04	0.20	8.45	2.50±1.64^a	0.42	3.97	1.21±0.58^{ab}	1.17	34.2	10.6±7.80^a	74.0
Average 2004	0.31	9.60	3.37±1.13	0.64	3.37	1.99±0.67	1.55	23.4	7.83±5.00	98.1

*Averages with dissimilar letters (a, b, c) specify significant difference ($P<0.01$).
DIN: Dissolved inorganic nitrogen; DIP: Dissolved inorganic phosphate; DIS: Dissolved inorganic silicate.

Table 3. Descriptive statistical results of nutrient ratios without amonium (NH_4) in the south western Caspian Sea.

Parameters	DIN:DIP(µM)			DIS:DIN(µM)			DIS:DIP(µM)		
	Min	Max	Mean±SD	Min	Max	Mean±SD	Min	Max	Mean±SD
January-03	1.02	2.24	1.63	0.98	3.40	2.38	1.00	7.64	3.89
August-03	3.13	4.05	3.81	2.99	9.90	1.71	12.1	30.9	6.50
October-03	0.15	2.53	2.73	3.19	4.73	1.40	0.73	8.07	3.81
November-03	0.72	6.16	3.73	3.79	12.4	2.38	8.88	23.3	8.88
December-03	0.61	5.07	3.02	3.91	7.94	2.75	4.82	19.8	11.9
Average (2003)	1.12	4.01	2.66±1.66	2.97	7.67	2.11± 0.55	5.50	18.0	5.61±3.44
April-04	0.60	3.69	1.71	3.09	11.3	2.99	6.80	11.4	5.12
May-04	1.07	2.98	1.77	1.00	7.75	1.58	2.96	8.27	2.80
July-04	0.27	1.21	1.27	5.81	12.1	3.00	3.28	7.05	3.81
September-04	--	--	--	--	--	--	--	--	--
October-04	0.57	4.10	2.17	1.31	2.03	1.28	1.15	5.38	2.78
November-04	0.48	2.13	2.07	4.04	5.85	4.24	2.79	8.60	8.76
Average (2004)	0.59	2.82	1.69 ±1.17	3.05	7.80	2.32±1.20	3.39	8.14	3.93±2.49

DIN: Dissolved inorganic nitrogen; DIP: Dissolved inorganic phosphate; DIS: Dissolved inorganic silicate between 1.00 and 12.1 (mean: 2.32±1.20), respectively in 2004 in the coastal surface water of the south western Caspian Sea. On the other hand, while annual average ratio of DIS to DIN (DIS:DIN) in 2003 (2.11±0.55) and 2004 (2.32±1.20) was substantially uniform, the ratio of DIS to DIP (DIS:DIP) in 2003 (5.61±3.44) was different than in 2004 (3.93±2.49) (Table 3).

Qualitative Phytoplankton

The phytoplankton checklist, along with annual presence (+) or absence (-) indexes and contributions of different taxonomic groups to the total phytoplankton in the south western Caspian Sea are presented in Table 4. Total 51 and 46 species were annually distinguished in 2003 and 2004, respectively, in phytoplankton community structure. In 2003, of the total 51 phytoplankton species, 25 taxa (49.0%) diatoms (15 genera, 25 species), 8 taxa (15.7%) dinoflagellates (7 genera, 8 species), 7 taxa (13.7%) chlorophytes (6 genera, 7 species), 8 taxa (15.7%) cyanophytes (6 genera, 8 species), and 3 taxa (5.90%) euglenoids (3 genera, 3 species) were distinguished. In 2004, of the total of 46 phytoplankton species, 21 taxa (45.7%) diatoms (16 genera, 21 species), 5 taxa (10.9%) dinoflagellates (3 genera, 5 species), 11 taxa (23.9%) chlorophytes (9 genera, 11species), 7 taxa (15.2%) cyanophytes (7 genera, 7 species), and 2 taxa (4.3%) euglenoids (2 genus, 2 species) were distinguished (Table 4).

On the other hand, according to the community structure constructed in study period of January 2003 and November 2004, 75 taxa phytoplankton was distinguished in total (Table 4). Of this total phytoplankton, 11 taxa (14.7%) cyanophytes (8 genera, 11 species), 10 taxa (13.3%) dinoflagellates (7 genera, 10 species), 33 taxa (44.0%) diatoms (19 genera, 33 species), 18 taxa (24.0%) chlorophytes (12 genera, 18 species) and 3 taxa (4.00%) euglenoids (3 genera, 3 species) were distinguished in the sampling area (Table 4).

Quantitative Phytoplankton

The contributions of different phytoplankton groups to the total phytoplankton density during the sampling period are presented in Figures 3 and 4. On the other hand, Figure 5 shows the vertical variation of phytoplankton cell density along with vertical temperature variations in thermocline and water mixture periods. Bray–Curtis similarity index (UPGMA; log10 transformed) results of total phytoplankton density in different time periods has been revealed in Figure 6.

The annual average phytoplankton densities in 2003 and 2004 were $1.46\times10^5\pm6.0\times10^4$ and $1.97\times10^5\pm7.2\times10^4$ cells L^{-1}, respectively. Among the phytoplankton groups, not only qualitatively (44.0%), but quantitatively as well diatoms were the first important group and formed more than half of the total cell density (66.0% in 2003 and 57.0% in 2004) in phytoplankton community structure. After the diatoms, while cyanophytes were the second important group (17.0% in 2003 and 36.0% in 2004), dinoflagellates (2.60% in 2003 and 5.30% in 2004) and euglenoids (>0.20% in both years) were other contributors (Figure 3). In 2003, diatoms *Dactyliosolen fragilissimus* (Bergon) G. R. Hasle, 1997 and cyanophyte *Oscillatoria* sp. were two important representative phytoplankton species and their contributions to the total phytoplankton density reached to 52.2% and 75.3%, respectively. In 2004, among diatom *Thalassionema nitzschioides* (Grunow) Mereschkowsky 1902, cyanophytes *Oscillatoria* sp. and *Anabeanopsis raciborskii* Wolos, 1912 were three important representative phytoplankton species and their contributions reached, respectively, to 62.8, 43.3 and 37.2% of total phytoplankton cell density (Figure 3). Therefore, during the study there were important blooms formed by above four phytoplankton species occurred in different periods in the south western Caspian Sea.

Although diatoms were generally species living in cold waters, average their cell density in October 2004 (6.30×10^5 cell L^{-1}) were higher than the density in January 2003 (4.80×10^5 cell L^{-1}). The diatom cell density in October 2004 was the highest average value of the sampling period. On the other hand, cyanophytes were the second important group and their concentrations (4.50×10^5 cell L^{-1}) were fundamentally near to the average diatom concentration in October 2004 (6.30×10^5 cell L^{-1}), whereas their concentration in early winter period (December 2003) were substantially lower (2.50×10^2 cell L^{-1}) (Figure 4). Otherwise, statistical test showed that phytoplankton taxa were significantly different from each other in different sampling time periods ($P<0.05$), and there were strongly positive correlation ($P=0.05$ level; Spearman rank correlation; 2–tailed) between cell densities of diatoms and cyanophytes, and nutrient levels (DIN and DIP) during the sampling period. Otherwise, cyanophyte densities were strongly positive correlated with the water temperature values ($P=0.05$ level; Spearman rank correlation; 2-tailed).

The thermocline structure formed between the different depths in thermocline warm periods (Figure 5A). The thermocline started to occur in May 2004 and reached to the maximum in July 2004. This strong thermocline occurred between 20 and 40 m and continued to the end of September 2004 (Figure 5A). Although the average temperature values in the interval of thermocline varied between 24.5 and 8.90°C, they varied between 8.90 and 28.2°C in all water column (Figure 5A). In the thermocline warm

Table 4. Phytoplankton checklist and contributions of different taxonomic groups to the total phytoplankton in south western Caspian Sea

Phytoplankton	Sampling Period	
Taxonomic Groups and Species	2003	2004
Chlorophytes	13.7%	23.9%
Actinastrum hantzschii Lagerheim, 1882	-	+
Acutodesmus acuminatus (Lagerheim) Tsarenko in Tsarenko & Petlovanny 2001	-	+
Ankistrodesmus falcatus (Corda) Ralfs, 1848	-	+
Binuclearia sp.	+	-
Binuclearia lauterbornii (Schmidle) Proschkina-Lavrenko, 1966	+	-
Chlamydomonas olifaniae Korshikov 1932	-	+
Coelastrum microporum Nägeli in A.Braun 1855	-	+
Coelastrum sphaericum Nageli, 1849	+	-
Desmodesmus communis (Hegewald) Hegewald 2000	-	+
Golenkinia sp.	-	+
Krichneriella sp.	-	+
Monoraphidium convolutum (Corda) Komárková-Legnerová 1969	-	+
Monoraphidium griffithii (Berkeley) Komárková-Legnerová 1969	+	-
Mougeotia sp.	+	-
Mucidosphaerium pulchellum (Wood)Bock, Proschold & Krienitz 2011	+	-
Scenedesmus sp.	+	-
Schroederia sp.	-	+
Tetraselmis sp.	-	+
Cyanophytes	15.7%	15.2%
Anabaena kisselevii Proshkina-Lavrenko, 1961	+	-
Anabaenopsis sp.	+	-
Anabeanopsis raciborskii Wolos, 1923	+	+
Cuspidothrix ussaczevii (Lavrenko) Rajaniem, *et. al.*, 2005	-	+
Lyngbya sp.	+	+
Merismopedia minima Beck, 1897	+	-
Merismopedia punctata Meyen, 1839	-	+
Oscillatoria sp.	+	+
Pandorina sp.	+	-
Sphaerospermopsis aphanizomenoides (Forti) Zapomelová, *et. al.*, 2010	+	+
Spirulina sp.	-	+
Diatoms	49.0%	45.7%
Actinocyclus paradoxus Ehrenberg, 1854	-	+
Aulacoseira granulata (Ehrenberg) Simonsen, 1979	+	+
Chaetoceros sp.	+	+
Chaetoceros mirabilis I.V. Makarova, 1959	+	-
Chaetoceros subtilis Cleve, 1896	-	+
Cocconeis scutellum Ehrenberg, 1838	+	-
Coscinodiscus sp.	+	-
Coscinodiscus granii Gough, 1905	+	+
Cyclotella choctawhatcheeana Prasad in Prasad,*et. al.*, 1990	+	-
Cyclotella meneghiniana Kutzing, 1844	+	+
Dactyliosolen fragilissimus (Bergon) Hasle in Hasle & Syvertsen, 1996	+	+
Diploneis interrupta (Kutzing) Cleve, 1894	-	+
Fragilaria acus (Kützing) Lange-Bertalot in Krammer & Lange-Bertalot, 2000	+	-
Gyrosigma sp.	+	-
Gyrosigma acuminatum (Kutzing) Rabenhorst, 1853	-	+
Gyrosigma attenuatum (Kutzing) Rabenhorst, 1853	+	+
Gyrosigma strigilis (W. Smith) Cleve, 1894	+	-
Melosira varians C. A. Agardh, 1827	+	+
Navicula sp.	+	+
Nitzschia sp.	+	+
Nitzschia acicularis (Kutzing) W. Smith, 1853	+	+
Nitzschia distans W. Gregory, 1857	+	-
Nitzschia lorenziana Grunow in Cleve & Möller 1879	-	+
Nitzschia palea (Kutzing) W. Smith, 1856	+	-
Nitzschia sigma (Kutzing) W. Smith, 1853	+	-
Nitzschia tenuirostris Manguin, 1952	-	+
Pseudosolenia calcar-avis (Schultze) B.G. Sundström, 1986	+	+
Skeletonema costatum (Greville) Cleve, 1873	+	+
Skeletonema subsalsum (Cleve-Euler) Bethge, 1928	+	-
Stephanodiscus socialis Makarova & Proshkina-Lavrenko, 1958	-	+

Table 4. (Continued)

Phytoplankton	Sampling Period	
Taxonomic Groups and Species	2003	2004
Thalassionema nitzschioides (Grunow) Mereschkowsky, 1902	+	+
Thalassiosira variabilis Makarova, 1959	+	-
Ulnaria ulna (Nitzsch) P.Compere in Jahn *et al.*, 2001	-	+
Dinoflagellates	15.7%	10.9%
Diplopsalis lenticula Bergh, 1881	+	-
Glenodinium caspicum (Ostenfeld) J. Schiller, 2002	+	-
Gymnodinium sp.	-	+
Gymnodinium lacustre Schiller, 1933	+	-
Peridiniopsis penardii (Lemmermann) Bourrelly 1968	+	-
Peridinium sp.	+	+
Prorocentrum micans Ehrenberg, 1834	-	+
Prorocentrum cordatum (Ostenfeld) Dodge, 1975	+	+
Prorocentrum scutellum Schroder, 1900	+	+
Protoperidinium granii (Ostenfeld) Balech, 1974	+	-
Euglenoids	5.90%	4.30%
Euglena sp.	+	+
Phacus sp.	+	+
Trachelomonas sp.	+	-

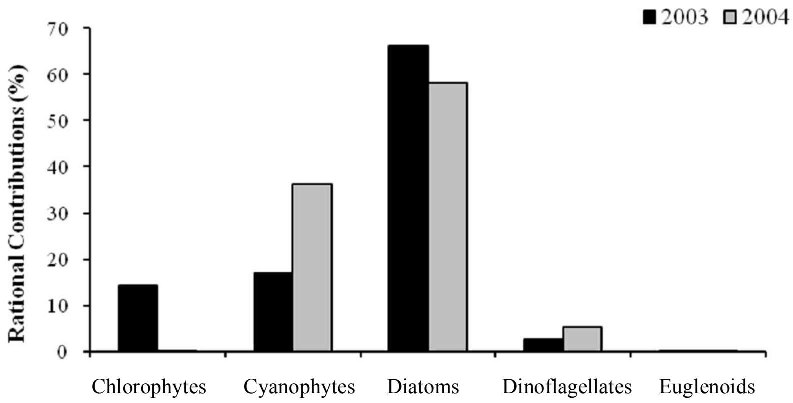

Figure 3. Rational contributions of different taxonomic groups to the total phytoplankton cell density in the south western Caspian Sea.

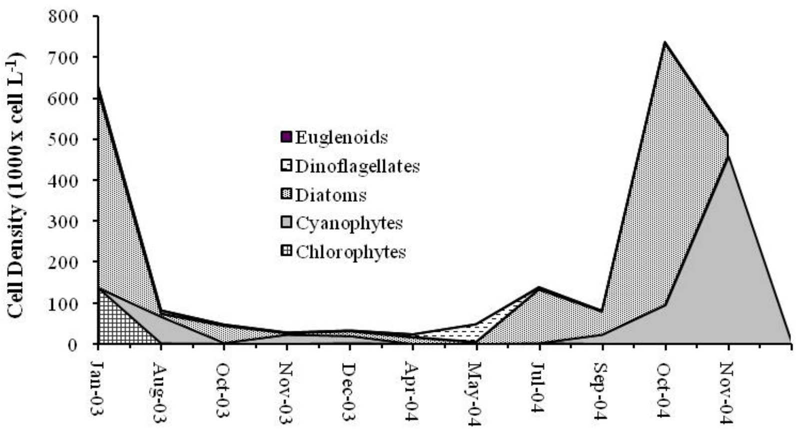

Figure 4. Contributions of different phytoplankton groups to the total phytoplankton cell density in different time periods in the south western Caspian Sea.

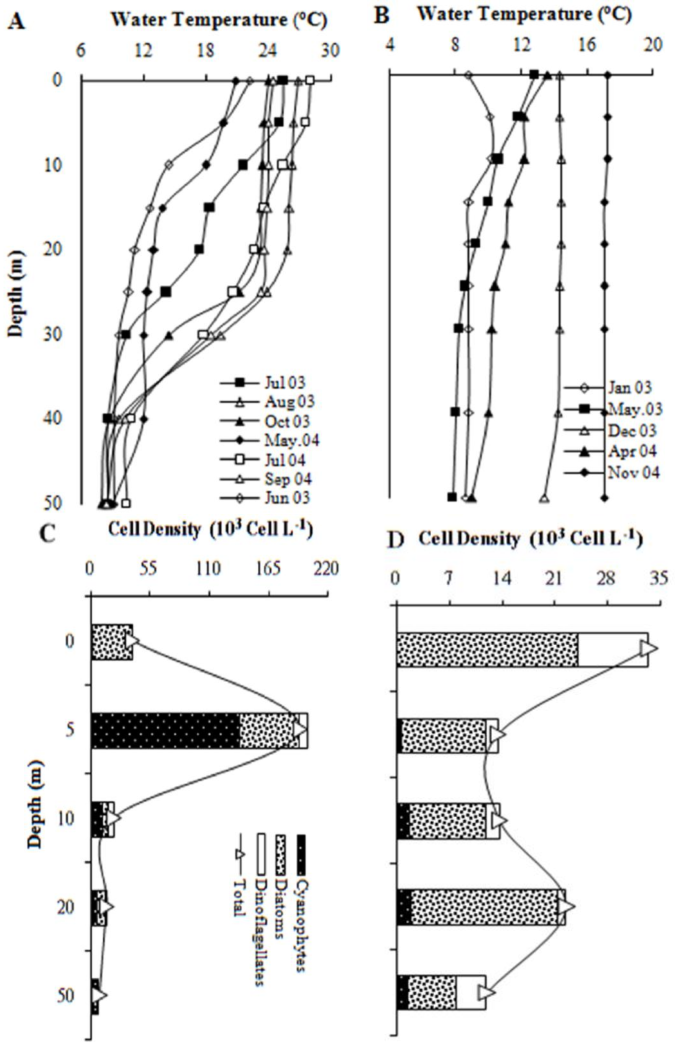

Figure 5. Vertical distribution of water temperature in thermocline (A) and water mixture periods (B), and average phytoplankton cell density in thermocline (C) and water mixture periods (D) at Station A4 on Anzali transect in the south western Caspian Sea.

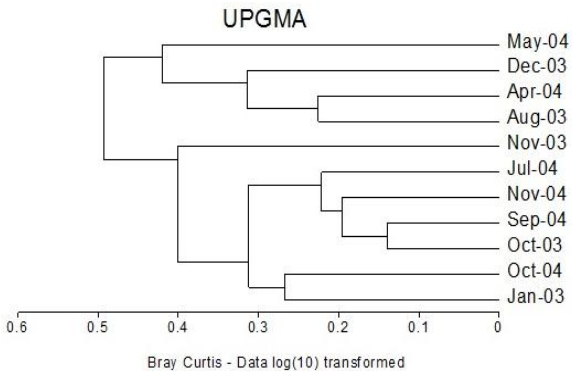

Figure 6. Bray–Curtis similarity index (UPGMA; log10 transformed) results of total phytoplankton density in different time periods during study.

periods (in summer period), the phytoplankton cell density changed between 7.86×10^3 and 1.95×10^5 cell L^{-1} in the water column. Although diatoms were found alone in superficial layer (0 m), cyanophytes shared with diatoms in sub-superficial layer (5 m) in the thermocline warm periods (Figure 5A and 5C). Phytoplankton cell density differences in the water column were important during the thermocline warm period ($P<0.05$). On the other hand, temperature variations were roughly stabile in the water mixture periods and the variations varied between 7.80 and 17.2°C (Figure 5B). In the water mixture periods, diatoms and dinoflagellates were dominant phytoplankton groups in surface (0 m) and deep waters (50 m). In other sampling depths, diatoms alone were responsible for phytoplankton cell densities (Figure 5D). In the water mixture periods, although there were no vertical variations in temperature, there were important variations in phytoplankton cell density and the density varied between 1.20×10^4 (50 m) and 3.35×10^4 cell L^{-1} (0 m) in water column. Otherwise, in addition to the peak value in the surface water (0 m), there was a secondary increase in phytoplankton density, particularly in diatoms in 20 m (Figure 5D). Statistical analysis revealed that there was no significant difference (P>0.05) in phytoplankton cell densities in water column in the mixture water periods.

However, Bray–Curtis similarity index results revealed that in view of cell densities three phytoplankton groups were estimated by cluster analysis between October 2003 and November 2004 (Figure 6). The six high phytoplankton groups were observed with the most similarity in January and October 2003; July, September, October, and November 2004 as compared to other months. These six months clustered separate from the other months in the analysis cluster. The remaining five months which were included the low densities revealed two groups; the larger group covered to August, December 2003 and April, May 2004, and the small group included November 2003 in the analysis cluster (Figure 6).

Discussion

The annual temperature variations in the surface waters of the study area (south western Caspian Sea) generally vary between 7.00°C and 29.0°C during the year (Dumont, 1998; Kideys and Moghim 2003; Roohi *et al.*, 2010; Hosseini, 2011; Bagheri *et al.*, 2012a, 2012b). However, during the study the temperature values were relatively similar to the previous years. For instance, the average temperatures varied between 10.8°C (January) and 27.4°C (August) during the study (Table 1) which were similar to findings in 1996-1997 recorded by Nasrollahzadeh *et al.* (2008a). On the other hand, our average temperature findings for 2003 and 2004 were different from each other. For instance, the annual average temperature finding in 2003 (18.1±7.07°C) was higher than the finding in 2004 (20.3±5.42°C). But, although some researchers reported that there was an increase trend in annual average temperature values of the Caspian Sea during 2001 and 2002 (Bagheri *et al.*, 2010, 2014), it is difficult to say that there was an increase trend in annual average temperature values according to previous years, because there was no regular data during the period of study.

The average annual surface salinity values for 2003 and 2004 (Table 1) were lower (11.3±0.63 in 2003; 11.1±0.63 in 2004) than the values (>12) reported for 1996–1997 (Nasrollahzadeh *et al.*, 2008a) and 2001–2002 (Bagheri *et al.*, 2010). On the other hand, due to the excessive river discharges to the coastal zones, there was an increasing trend in surface salinity from inshore (St. A1) to offshore (St. A4) on Anzali transect in the south western Caspian Sea during the study (Figure 2). According to Bagheri *et al.* (2010), there was a strongly negative correlation between salinity and freshwater discharge in the south western Caspian Sea during 2001–2002. Zaker *et al.* (2007) reported that the decrease in horizontal water salinity values could be connected with fresh water discharges of the Babol River. On the other hand, Sharifi (2006) noted that the monthly average precipitation amounts exceeded monthly average evaporation levels in the south western Caspian Sea. Reverse to the annual findings in temperature, the salinity values during the study were more similar to the previous findings (Dumont, 1998; Kideys and Moghim, 2003; Roohi *et al.*, 2010; Hosseini, 2011; Bagheri *et al.*, 2012b, 2012c).

Rise in anthropogenic inputs from the Lisar and Sefidrood rivers, and the Anzali wetlands caused an increase in suspended inorganic and organic materials decreasing Secchi disk depth. On the other hand, when compared to the findings of Nasrollahzadeh *et al.* (2008a) and Roohi *et al.* (2010), lower Secchi disk readings in 2003 and 2004 (Table 1) could also be related to the increase of phytoplankton during 2003 (average: 1.46×10^5 cell L^{-1}) and 2004 (average: 1.97×10^5 cell L^{-1}).

Due to excessive river discharges, the study area generally contains higher nutrient levels compared to previous years. However, although there were important variations in nutrient concentrations, annual average nutrient concentrations in 2003 and 2004 were nearly similar (Table 2). On the other hand, although average annual river discharge levels in 2003 (76.6 million m^3) and 2004 (98.1 million m^3) were different from each other, average DIN concentrations in both years were similar to each other (mean: 3.86±1.65 µM in 2003; 3.37±1.13 µM in 2004). Moreover, in spite of the different sampling periods in 2003 and 2004 (Table 2), the average DIP and DIS concentrations in 2003 (DIP: 1.45±1.37; DIS: 8.14±6.35) and 2004 (DIP: 1.99±0.67; DIS: 7.83±5.00) were not different (Table 2). These results showed that DIP and DIS concentrations were more affected by river discharges than DIN concentrations. The coastal systems of the south western Caspian Sea received higher riverine phosphate and silicate concentrations than nitrogen. On the other hand, variations in DIS concentrations during the study were higher than those of other nutrient concentrations compared to river discharges (Table 2). However, lower positive correlation between DIS concentrations and river discharges (r=0.357) revealed that DIS was either quickly utilized by diatoms such as *D. fragilissimus* and *T. nitzchioides* which were dominant phytoplankton species in the system or lower it's river content. It is known that DIS contents of rivers discharged to coastal areas of the Caspian Sea are higher (Kideys *et al.*, 2005b, Bagheri *et al.*, 2012a, b). Therefore, the first option was more practical than the second option. On the other hand, except DIN, one of the causes of high DIP and DIS concentrations in January 2003 and October 2004 were probably high river discharges in these periods (Table 2). The average DIN, DIP, and DIS concentrations (3.86±1.65, 1.45±1.37 and 8.14±6.35 µM, respectively) were substantially high. With this in mind, nutrient concentrations in the winter and autumn were higher than those in the summer and spring (Table 2).

Without ammonia, DIN:DIP (min-max: 0.15 - 6.16, mean: 2.66±1.66 in 2003; min-max: 0.27 - 4.10, mean: 1.69±1.17 in 2004) and DIS:DIP ratios (min-max: 0.73-30.9, mean: 5.61±3.44 in 2003; min-max: 1.15 - 11.4, mean: 3.93±2.49 in 2004) in the surface water of the south western Caspian Sea were significantly lower (Table 3) than the assimilatory optimal of the Redfield ratios (Redfield, 1934; Redfield *et al.*, 1963). However, due to the extra silicate input into the system by river discharges, average DIS:DIN ratio (min-max: 0.98-9.90, mean: 2.11±0.55 in 2003, min-max: 1.00-12.1, mean: 2.32±1.20 in 2004) was two fold higher (Table 3) than Redfield-Brzezinski nutrient ratio (Brzezinski, 1985). It is known that Redfield ratio is the atomic ratio of carbon, nitrogen and phosphorus found in plankton and throughout the sea water. This empirically developed ratio was found to be C:N:P = 106:16:1 (Redfield, 1934; Redfield *et al.*, 1963). It is also known that diatoms also need silicate to create biogenic silica for their cell walls. As a result, the Redfield-Brzezinski nutrient ratio was proposed for diatoms to be C:Si:N:P = 106:15:16:1 (Brzezinski, 1985).

Except for 2001, although there was no significant differences in total phytoplankton species number in different years, there were some important differences in species number of different taxonomic groups between 1996 and 2004. These differences may have been due to the different sampling periods (Table 5). On the other hand, although temporal dominance was detected by different phytoplankton groups in study area, the most dominant phytoplankton group in qualitative were diatoms with 25 taxon in 2003 (49.0% of total) and 21 taxon (45.7% of total) in 2004, except 2001 and 2002 sampling periods (Table 5). Low species numbers of diatoms in 2001 and 2002 (5 species in both periods) were related to the decline of freshwater discharged and drought in 2001 and 2002 (Bagheri *et al.*, 2010). However, there were major changes in phytoplankton community as compared to earlier surveys between 1990s and 2000s (Roohi *et al.*, 2010). Although there were some important fluctuations in species numbers of different taxonomic groups, one of the major shifts was a decreasing tendency in species number even in short time period between 1996 and 2004 (Table 5). On the other hand, with regard to species number, there were decrease not only in diatoms, but also in all other taxonomic groups (Table 5), compared to species number in the period of 1982-1994 (Roohi *et al.*, 2010). Furthermore, even in short time period between 1996 and 2004 the species numbers of cyanophytes, chlorophytes, dinoflagellates, and euglenoids (Table 5) were extremely lower than numbers in the period of 1982-1994 (Roohi *et al.*, 2010).

The findings on both nutrients and their ratios, and qualitative and quantitative phytoplankton distributions indicated that the system was underneath eutrophication processes, as were indicated in previous studies (Bagheri *et al.*, 2010, 2011, 2012b). However, according to previous trophic index (TRIX) values in the study area showed that the system was mesotrophic (Nasrollahzadeh *et al.*, 2008b). Considering contributions of different taxonomic groups to the total phytoplankton cell density, diatoms were still an important group both qualitatively and quantitatively in the south western Caspian Sea in the study period (Figure 3). Similar to previous studies in the Caspian Sea (Nasrollahzade *et al.*, 2008a, 2008b; Bagheri *et al.*, 2011, 2012b, 2012c), this study showed that diatom communities were represented by a few dominant species such as *D. fragilissimus* and *T. nitzschioides* in the system. However, it is known that as aquatic systems are polluted by excessive anthropogenic nutrient inputs by rivers or other discharges such as domestic waste waters, qualitative and quantitative exchanges between different taxonomic groups of phytoplankton will generally be broken down against to the diatoms (Turkoglu and Koray, 2000, 2002, 2004; Turkoglu, 2005;

Table 5. Phytoplankton species number according to taxonomic groups in the south western Caspian Sea between 1996 and 2004

Phytoplankton Groups	Previous Data			Current Data	
	1996-1997 Nasrollahzadeh *et al.* (2008a)	2001 Bagheri *et al.* (2010)	2002 Bagheri *et al.* (2010)	2003	2004
Chlorophytes	5	34	22	7	11
Cyanophytes	5	13	9	8	7
Diatoms	25	5	5	25	21
Dinoflagellates	11	13	5	8	5
Euglenoids	4	4	2	3	2
Total	50	69	43	51	46

Nasrollahzadeh *et al.*, 2008a; Turkoglu, 2010a, 2010b). Shifts in taxonomic groups in time tunnel could not be only explained by excessive anthropogenic nutrient inputs. On the other hand, there are other factors such as climatological and hydrological regimes of the systems effecting contribution levels of different taxonomic groups to total phytoplankton. For instance, Bagheri *et al.* (2010, 2014) reported that the arresting shifts in community structure of phytoplankton in the south western Caspian Sea could be connected to changes in the atmospheric and hydrological regimes of the basin since the early 1990s in addition to anthropogenic impacts. On the other hand, there were additional silicate and phosphate inputs to the system by river discharges. Due to the this phenomenon, while the ratio of DIS to DIN (DIS:DIN) was risen two fold compared to Redfield nutrient ratios (Redfield *et al.*, 1963), the ratio of DIS to DIP (DIS:DIP) was largely decreased (Table 3) compared to Redfield-Brzezinski nutrient ratios (Brzezinski 1985). Although the system was eutrophic due to the fresh water inputs rich in nutrients, the extra input of DIS and DIP to the system according to the DIN and thereby the increase in DIS:DIP according to DIN:DIP provided an extra advantage to the diatoms. This provided the prepotency of diatoms in the system, although the system was generally eutrophic (Kideys *et al.*, 2008; Nasrollahzadeh *et al.*, 2008a; Bagheri *et al.*, 2012a).

In addition to other nutrients such as DIN and DIP, diatoms also need inorganic silicate (DIS) for their cell wall structures (Sommer, 1994; Eker and Kideys, 2003; Humborg *et al.*, 2004; Piehler *et al.*, 2004; Yunev *et al.*, 2005; Turkoglu, 2008; Bagheri *et al.*, 2011, 2012b). On the other hand, larger phytoplankton species such as *Rhizosolenia setigera* Bright, 1858 and *D. fragilissimus* are the best competitors for dissolved inorganic nitrogen (DIN) owing to their higher specific nitrogen storage capacity (Eker *et al.*, 1999; Kormas *et al.*, 2002; Turkoglu and Erdogan, 2010). For instance, Nasrollahzadeh *et al.* (2008a) and Bagheri *et al.* (2010) noted that *D. fragilissimus* and *T. nitzschioides* comprised 6.00-32.0% and 20.0-39.0% of the total phytoplankton abundance in the Caspian Sea during 1996-1997 and 2001-2002, respectively. In the current study, the contributions of both species to the total phytoplankton density were in level of 52.2% and 62.8%, respectively.

Compared to earlier findings, there was an increasing trend in phytoplankton cell density in study area, especially during January 2003 and October 2004 which confirmed by the cluster analysis (Figure 6). For instance, the annual average cell densities of phytoplankton reported by Kosarev and Yablonskaya (1994) (1.4×10^4 cell L^{-1}), Kideys *et al.* (2005b) (4.0×10^4 cell L^{-1}), Khenari *et al.* (2010) (5.6×10^4 cell L^{-1}), Bagheri *et al.* (2010) (2.10×10^5 – 3.90×10^5 cell L^{-1}) and the present study (1.47×10^5 –1.97×10^5 cell L^{-1}) for the period of 1962-2004 showed that there were striking variations of the phytoplankton abundance in the southern Caspian Sea. Compared to previous years, phytoplankton community changes in the south western Caspian Sea during 2003–2004 might be related to man-made shocks and climate changes (Richardson, 2008). Mirzajani *et al.* (2010) stated that the nutrient inputs by rivers have arisen and eutrophication tendency increased after 2000. More than 80 rivers carrying municipal, industrial agriculture and medical wastewaters discharge into this area (Jafari, 2009). This eutrophication trend has continued in 2003–2004 and the nutrient concentrations have increased more than 3.5-fold (Table 2) compared to levels in 1996–1997 (Nasrollahzadeh *et al.*, 2008a).

The findings showed that cyanophytes *A. raciborskii* and *Oscillatoria* sp. were dominant from July to October during 2003–2004 (Figure 4). Loizzo *et al.* (1988) and Bagheri *et al.* (2012b) reported that cyanophytes usually crop up between middle summer and early autumn, when water temperatures and nutrients concentrations, especially inorganic phosphate and nitrate concentrations increase. Although increase in nutrient levels was an important factor favoring cyanophyte blooms, increase in water temperature was the main stimulus in the shift of other phytoplankton blooms observed during the current survey. Change of phytoplankton community from cyanophytes to diatoms was observed when temperature started to drop after October (Figure 4). Various researchers reported that temperature was an important factor in the fluctuations of phytoplankton composition and diatoms were dominant species of the cold season in the Caspian Sea (Kideys *et al.*, 2005; Makaremi *et al.*, 2006; Resende *et al.*, 2007; Bagheri *et al.*, 2012b, 2012c).

Kideys and Moghim (2003) noted that thermocline was located between 20 and 40 m in the summer and autumn in the southern Caspian Sea. However, Bagheri *et al.* (2012) reported that vertical temperature variation in summer caused no seasonal thermocline in the south western Caspian Sea. The thermocline interval (20-40 m) in the current study (Figure 5A) was similar to the thermocline intervals reported by Kideys and Moghim (2003), Zaker *et al.* (2007), Roohi *et al.* (2010) and Bagheri *et al.* (2011). The striking finding in this thermocline structure was that thermocline interval (20-40 m) was thicker than ones in other similar marine systems such as the Black Sea ecosystem (Turkoglu and Koray, 2002; Turkoglu, 2005) and the Sea of Marmara (Turkoglu *et al.*, 2006; Turkoglu, 2008, 2013). This could be related to river discharges and meteorological conditions during 2003-2004 for this area known as Guilan region.

Vertical phytoplankton distribution in thermocline warm period in summer (Figure 5C) was different than that in water mixture periods (Figure 5D). For instance, while cyanophytes and diatoms were dominant especially in the surface layer in thermocline warm period (Figure 5C), diatoms and dinoflagellates were dominant in water mixture periods (Figure 5D). On the other hand, phytoplankton abundance in the surface layer (0-5 m) was higher than at deeper layers during thermocline warm periods and peaked at 5 m (Figure 5C), whereas there was an additional increase in phytoplankton in sub surface layer (20 m) along with a peak value of phytoplankton in surface layer (0 m) in water mixture period (Figure 5D). These variations might be related to water stratifications in different time periods (Figure 5A, B) during the study. These findings on vertical phytoplankton distribution were consisted with findings reported by Kangro *et al.* (2005) and Nasrollahzadeh *et al.* (2008a).

The study revealed that diatoms such as *D. fragilissimus*, *T. nitzschioides* and cyanophyte *Oscillatoria* sp. numerically dominated in the phytoplankton community in the study area. The impacts of meteorological and hydrological conditions as well as climate anomalies on the ecosystem were important for phytoplankton growth in the south western Caspian Sea. Rodionov (1994), Bilio and Niermann (2004), and Polonskii *et al.* (2004) theorized that hydro-biological changes in the Caspian Sea, Black Sea, and Baltic Sea during the 1990s and 2000s could be definitely correlated with climatical and hydrological characters. We believe that hydrological variations, increased fresh water inflow via rivers and rises in nutrient levels have contributed a significantly in the excessive production of diatoms and cyanophytes in the system.

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