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Phytoplankton Species Composition and Abundance in the Southwestern Caspian Sea

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Abstract
This study, accomplished is focused on the spatial and temporal distribution and species composition of phytoplankton in the southwestern Caspian Sea between January 2008 and December 2008. Samples were collected from 11 stations along three transects known as Lisar, Anzali and Sefidrood. This study identified 43 phytoplankton species comprised of diatoms (25 species), dinoflagellates (7 species), chlorophytes (6 species), cyanophytes (4 species), and euglenoids (1 species) were identified. The study showed, diatom *Dactyliosolen fragilissimus* and the dinofllagelate *Prorocentrum cordatum* numerically dominate the southwestern Caspian Sea. The annual average phytoplankton density was calculated as 2.35E+04 ± 1.63E+04 Cell L^{-1}, with the maximum value recorded in the winter (4.50E+04 ± 3.90E+04 Cell L^{-1}). Diatoms were dominant during the autumn and winter (77.0% and 96.0%, respectively), while dinoflagellates were prevalent during the spring and summer (89.0% and 86.0%, respectively). The annual average chlorophyll a was calculated as 9.26±3.54 μg L^{-1}, with the maximum values were recorded in the winter (16.9±5.60 μg L^{-1}). This is supported by the Spearman rank correlation result between phytoplankton abundance and chlorophyll *a* (r=0.551). The high phytoplankton cell density and chlorophyll *a* concentration coincided with the poor species composition.
Keywords: Abundance, Caspian Sea, chlorophyll *a*, Phytoplankton, Southwestern.

Güney Batı Hazar Denizi'nde Fitoplanktonun Tür Kompozisyonu ve Bolluğu

Özet
Ocak 2008 ve Aralık 2008 arasında yapılan bu çalışma Güney Batı Hazar Denizi'nde fitoplankton'un uzaysal ve zamansal dağılımları ve tür kompozisyoları üzerine odaklanmıştır. Örnekler Lisar, Anzali and Sefidrood olarak bilinen üç kesit boyunca uzanan 11 istasyon noktasından toplandı. Diatom (25 tür), dinoflagellat (7 tür), klorofit (6 tür), cyanofit (4 tür) ve euglenoidlerden (1 tür) oluşan toplam 43 fitoplankton türü tayin edildi. Çalışma, diatom *Dactyliosolen fragilissimus* ve dinofllagellat *Prorocentrum cordatum* türlerinin sayısal olarak Güney Batı Hazar Denizini kontrol ettiğini gösterdi. Yıllık ortalama fitoplankton yoğunluğu kış döneminde kaydedilen maksimum değeriyle (4,50E+04 ± 3,90E+04 Cell L^{-1}) 2,35E+04 ± 1,63E+04 Cell L^{-1} olarak hesaplandı. Dinoflagellatlar ilkbahar ve yaz döneminde (sırasıyla %89,0 ve 86,0), diatomeler sonbahar ve kış dönemi boyunca baskın grup olmuşlardır (sırasıyla 77,0% ve 96,0). Kışın kaydedilen maksimum değeriyle (16,9 ± 5,60 μg L^{-1}), yıllık ortalama klorofil *a* değeri 9,26 ± 3,54 μg L^{-1} olarak hesaplandı. Bu durum fitoplankton bolluğu ve klorofil *a* arasındaki Spearman rank korelasyon sonucu (r=0,551) tarafından da desteklenmiştir. Fitoplankton biyomas ve klorofil a yüksek olduğu halde, tür çeşitliliği bakımından fakir olmuştur.
Anahtar Kelimeler: Bolluk, Fitoplankton, Güney Batı Hazar Denizi, klorofil *a*.

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INTRODUCTION

The Caspian Sea is located in an inland depression on the border of Europe and Asia. It is the largest enclosed sea in the world, with a catchment area of 3.50 million square kilometers (km^2). Approximately, 130 rivers of various sizes drain into the Caspian Sea with an average annual input of about 300 km^3. The most important river is the Volga which provides about 80.0% of the total fresh water input. Other rivers such as the Ural, Terek, Sulak, Samur, Kura, and Caucasus provide the other 20.0% of the total fresh water input

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(Dumont 1998, Mamaev 2002). Fluctuations of water levels during the year in the Caspean Sea can not be connected only with river inputs, but can be connected with the fluctuations of the ground water levels as well (Bayramov and Memedov 2008).

The biological diversity in the Caspian Sea and its coastal zones make the region one of the most valuable ecosystems in the world. Many species are endemic and there are many representative forms of almost all of the major groups on the earth. Of all, the sturgeon is the most important one which constitute 85% of the standing stock of the world's sturgeon population (Mamaev 2002). On the other hand, marine living groups and their healthy life are very important for marine systems. In such systems phytoplankton must be taken into account first due to it's being the first link of the food chain.

Similar to other marine systems, phytoplankton groups are the major primary producers in the Caspian ecosystem and they are also an important food source for other organisms. However, since their species composition and density are dependent on complex physico-chemical interactions, they are quite sensitive to ecological changes incurred from anthropogenic pollution (Turkoglu and Koray 2002, Naz and Turkmen 2005). Recently, Khodaparast (2006) reported that there were two important blooms of phytoplankton in the southwestern Caspian Sea. High density and a shift in the phytoplankton species could propagate the effects of pollution in the Caspian Sea (Nasrollahzadeh et al. 2008).

The total number of phytoplankton species found from 1962 to 1974 was 449 (Kosarev and Yablonskaya 1994). These species consisted of 163 diatoms, 139 chlorophytes, 102 cyanophytes, 39 dinoflagellates, 5 euglenophytes and 1 chrysophyte. In addition, the number of species decreases from 411 species in the north to 225 species in the middle, and 71 species in the southern areas mainly due to the disappearance of fresh water forms towards the south. Primary production was studied except for the turbid northern area, where photosynthesis is inhibited in the subsurface, with the maximum rates at 4.0-8.0 m (Dumont 1998).

The Caspian Sea has, however, undergone significantly ecological alteration during the past 30 years. Apart from natural changes attributable largely to the variation in the sea level (Rodionov 1994), there are also major anthropogenic impacts on the system originating from domestic pollutants (e.g., phosphorous-containing detergents), industrial pollutants (e.g., heavy metals and other industrial byproducts), and agricultural pollutants (e.g., nitrogen-containing fertilizers and pesticides). Furthermore, development of oil and gas fields creates stress on the ecosystem and its biological producers especially the fish species (Salmanov 1999, Ivanov 2000, Aladin and Plotnikov 2003). Pollution is thus a significant threat to the biodiversity of the Caspian Sea. The value of the biodiversity, mainly fish resources, has a high commercial significance calculated to be as much as 5-6 billion USD per year. The high economical value of the fish resources creates an additional threat due to the overfishing pressure on the biodiversity of the most important commercial species. Therefore, the annual fish catch in the Caspian (without sprat) was reduced from 283 thousand tones in 1951-55 to 81 thousand tones in 1990 continuing until 1995 (Aladin and Plotnikov 2003).

Although various phytoplankton studies have been performed in the southern Caspian Sea in recent years (Hosseini et al. 1998, Laloei 2001, Bagheri et al. 2002, 2010a, 2011a, 2012, Ganjian and Makhlough 2003, Khodaparast 2006, Nasrollahzadeh et al. 2008), there are a few phytoplankton studies in detail reported from the southwestern Caspian Sea. This study describes the temporal and spatial distributions of phytoplankton abundance and species composition in detail in the southwestern Caspian Sea in 2008 and the results were compared to studies from previous years.

MATERIAL AND METHODS

Phytoplankton abundance and species composition were evaluated through samples collected from 11 stations along three transects (Lisar, Anzali and Sefidrood) on the western Iranian coast of the Caspian Sea. The study was seasonally planned and samples were collected in the winter (16-18 February 2008), spring (26-28 May 2008), summer (26-28 July 2008) and autumn (3-5 November 2008). Each sampling station consisted of four vertical water sampling points, located at fixed depths of 5.0 m (L1, A1 and S1), 10.0 m (L2, A2 and S2), 20.0 m (L3, A3 and S3) and 50.0 m (A4 and S4) (Fig. 1). The sampling of all the station grids was performed in three days between 09.00 and 17.30 hours. And each transect was sampled in one

day using a speedboat.

Water samples were collected using a 1.71 L Nansen Water Sampler (Hydro-Bios, TPN; Transparent Plastic Nansen water sampler, No: 436201). Temperature and salinity were recorded in situ by using a reverse thermometer (Hydro-Bios, TPN), and digital salinometer. Water transparency was measured with a Secchi disk.

Samples of chlorophyll *a* were taken from the surface waters. Three liters of the water samples were filtered with a pump through glass fiber filters (Whatman GF/C). After filtrations, 0.10 mL $MgCO_3$ was added to the filter paper and the volume of filtered water was recorded. Filters used for the filtration process were wrapped in aluminum foil and kept frozen for analysis. Chlorophyll *a* concentration was analyzed spectrophotometrically after an extraction with 90% acetone (Anonymous 1992).

Phytoplankton samples were collected from the same depths (5.0, 10.0, 20.0 and 50.0 m) with a 1.71 liter Nansen Water Sampler (Hydro-Bios, Germany, TPN Series). The samples were preserved using buffered formaldehyde to obtain a final concentration of 4.00%. The samples were later concentrated to 20.0 mL using Uterhmöhl Sedimentation Chambers for sedimentation for at least 10 days. For the enumeration of the phytoplankton species, 1.00 mL subsamples taken from the 20.0 mL samples of sediment were calculated using the Neubauer and Sedgewick-Rafter counting slide combinations according to dimensions of the organisms under a phase contrast microscope (Newell and Newell 1977, Vollenweider 1974, Sournia 1978). The phytoplankton settling, counting, and taxonomic classification methods were similar to previous studies (Prescott 1962, Kasimov 2000).

Statistical comparisons between seasons were made by using statistical (Statsoft) software SPSS version 13 for Windows. The analysis of variance comparisons (One-way ANOVA) were used to identify the importance of variables among different seasons. The Spearman rank correlation coefficients (r) were calculated in order to evaluate the relationships between phytoplankton abundance (diatoms and dinoflagellates), chlorophyll *a*, Secchi disk depth, water temperature and salinity. Descriptive statistics (minimum, maximum, mean, and standard deviation) were conducted using Biodiversity Professional Version 2 (McAleece et al. 1999). Mean and standard deviation results in the text have been presented as "mean ±SD".

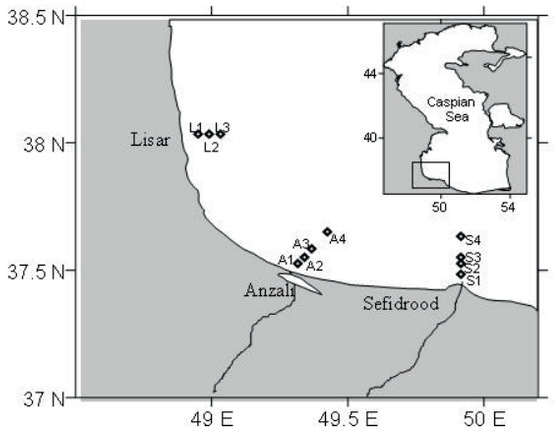


Fig 1. Sampling transects and stations in the southwestern Caspian Sea in 2008.

RESULTS

Temperature and Salinity

Temporal variations of surface water temperature and salinity in the southwestern Caspian Sea in the period from January and December, 2008 are shown in Figs. 2 and 3. The surface water temperature ranged from 6.80°C to 29.8°C due to seasonal variations in air temperature throughout the year. Seasonal surface water temperature variations were significant (ANOVA, $p = 0.000$). However, water temperature was not significantly different between the three transects during the study (ANOVA, $p = 0.961$).

The minimum and maximum salinity was recorded as 8.63 ppt and 12.83 ppt (Fig. 3). There were some fluctuations in salinity values in surface water (10.14-12.34 ppt) due to variations in fresh water input from rivers at different periods (Fig. 3). According to the ANOVA findings, these seasonal salinity differences were meaningful (ANOVA, $p = 0.000$). However, the salinity was insignificant in the three transects during the sampling period (ANOVA, $p = 0.177$).

Secchi Depth

Temporal variations of the Secchi disk depth, an indicator of water turbidity affected by suspended solid and decomposed materials in the southwestern Caspian Sea in the sampling period are shown in Fig. 4. The Secchi depth changed from 1.70 m to 8.00 m (4.60 ± 1.30 m) during the study period (Fig. 4). Statistical variance analysis (ANOVA)

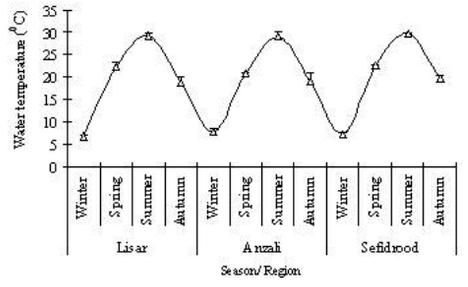


Fig 2. Seasonal variations of surface water temperature in the southwestern Caspian Sea in 2008.

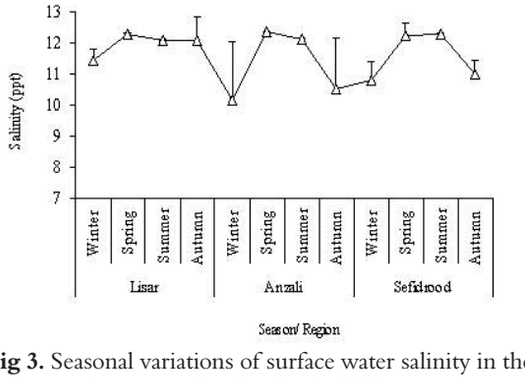


Fig 3. Seasonal variations of surface water salinity in the southwestern Caspian Sea in 2008.

showed that seasonal Secchi depth variations were more significant than regional Secchi depth variations ($p<0.05$). Furthermore, the Spearman rank correlation results revealed that there was a significant negative correlation at the 0.01 level between Secchi depth and phytoplankton number ($r= -0.499$).

Phytoplankton

Qualitative Phytoplankton Composition

Surface phytoplankton list together with seasonal presence (+) or absence (-) indexes in the southwestern Caspian Sea are presented in Table 1. Taxonomic composition of phytoplankton and contributions of different taxonomic groups to the total phytoplankton are also presented in Table 2.

According to the findings of the study on the community structure and diversity, a total of 43 phytoplankton taxa were distinguished. Of these taxa, 25 taxa (58.2%) Bacillariophyceae (19 genera, 25 species), 7 taxa (16.3%) Dinophyceae (7 genera, 7 species), 6 taxa (13.9%) Chlorophyceae (6 genera, 6 species), 4 taxa (9.30%) Cyanophyceae (4 genera, 4 species) and 1 species (2.30%) Euglenophyceae were identified during the study period (Tables 1 and 2). The seasonal phytoplankton community structures

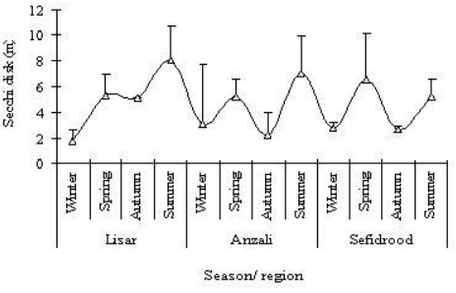


Fig 4. Seasonal variations of Secchi disk depth (water transparency) in the southwestern Caspian Sea in 2008.

Table 1. Phytoplankton list and seasonal variations in availability and frequency in the southwestern Caspian Sea in 2008 (1-20 %: rare, 21-40 %: common, 41-60 %: abundant, 61-80 %: very abundant, 81-100: continuous species, +: present, -: absent).

Phytoplankton	Sampling Period				
Taxonomic Groups and Species	Winter 2008	Spring 2008	Summer 2008	Autumn 2008	f (%)
Cyanophyceae (Cyanophytes)					
Chroococcus Nageli, 1849	-	-	-	+	25.0
Lyngbya C.A. Aaardh ex Gomont, 1892 nom. Cons	-	-	-	+	25.0
Oscillatoria fenestrata Corda ex Gomant 1892	+	-	+	+	75.0
Planktolyngbya limnetica (Lemmermann) J. Komárková-Legnerová & G. Cronberg, 1992	+	-	-	-	25.0
Dinophyceae (Dinofelagellates)					
Diplopsalis lenticula Bergh, 1881	-	-	+	-	25.0
Gymnodinium Stein, 1878	-	+	+	+	75.0
Lingulodinium polyedrum (F. Stein) J.D.Dodge, 1989	-	-	+	-	25.0
Protoperidinium achromaticum (Levander) Balech 1974	-	+	+	+	75.0
Peridiniopsis pernardii (Lemmermann) Lebour	-	-	+	-	25.0
Prorocentrum cordatum (Ostenfeld) Dodge, 1975	+	+	+	+	100
Prorocentrum scutellum Schröder, 1900	+	+	+	+	100
Bacillariophyceae (Diatoms)					
Caloneis amphisbaena (Bory de Saint Vincent) Cleve, 1894	-	+	-	-	25.0
Chaetoceros Ehrenberg, 1844	-	-	-	+	25.0
Coscinodiscus granii Gough, 1905	+	-	-	+	50.0
Coscinodiscus perforatus Ehrenberg, 1844	+	+	-	-	50.0
Cyclotella meneghiniana Kützing, 1844	+	+	+	+	100
Cymbella C.A. Agardh, 1830 nom. Cons.	-	-	-	+	25.0
Cymbella tumida (Brébisson in Kützing) van Heurck, 1880	+	-	-	-	25.0
Dactyliosolen fragilissimus (Bergon) Hasle in Hasle & Syvertsen 1996	+	-	+	-	50.0
Gyrosigma acuminatum (Kützing) Rabenhorst, 1853	-	-	-	+	25.0
Gyrosigma attenuatum (Kützing) Cleve 1894	+	-	-	-	25.0
Navicula Bory, 1822	-	+	-	+	50.0
Navicula radiosa Kützing, 1844	+	-	-	-	25.0
Neidium affine (Ehrenberg) Pfitzer, 1871	-	+	-	-	25.0
Nitzschia Hassall, 1845 nom. Cons.	+	+	-	+	75.0
*Nitzschia acicular*i (Kützing) W. Smith, 1853	+	+	-	+	75.0
Nitzschia palea (Kützing) W. Smith, 1856	+	-	-	-	25.0
Pinnularia nobilis (Ehrenberg) Ehrenberg 1843	+	-	-	-	25.0
Pseudosolenia calcar-avis (Schultze) B.G.Sundström, 1986	+	-	-	-	25.0
Pseudo-nitzschia seriata (Cleve) H. Peragallo,1908	+	-	-	-	25.0
Skeletonema costatum (Greville) Cleve, 1873	+	-	-	+	50.0
Stephanodiscus minutulus (Kützing) Cleve & Möller 1982	+	-	-	-	25.0
Synedra Ehrenberg, 1830	+	-	-	-	25.0
Thalassionema nitzschioides (Grunow) Grunow ex Hustedt, 1896	+	-	-	+	50.0
Nitzschia *tryblionella Hantzsch in Rabenhorst, 1860*	+	-	-	-	25.0
Ulnaria ulna (Nitzsch) P. Compère in Jahn et al. 2001	+	-	-	-	25.0
Chlorophyceae (Chlorophytes)					
Actinastrum hantzschii Lagerheim, 1882	+	-	-	-	25.0
Ankistrodesmus Corda, 1838	+	-	-	-	25.0
Binuclearia lauterbornii (Schmidle) Proschkina-Lavrenko, 1966	-	+	-	-	25.0
Closterium parvulum Nägeli, 1849	+	-	-	-	25.0
Lagerheimia genevensis (Chodat) Chodat, 1895	+	-	-	-	25.0
Monoraphidium arcuatum (Korshikov) Hindák, 1970	+	-	-	-	25.0
Euglenophyceae (Euglenoids)					
Euglena Ehrenberg, 1838	-	-	+	-	25.0

Table 2. Seasonal variations of taxonomic composition in phytoplankton and contributions of different taxonomic groups to the total phytoplankton in the southwestern Caspian Sea in 2008.

Taxonomic Groups	Genus	Sp.	Taxa	f (%)	Cell L^{-1}	f (%)
Diatoms	19	20	25	58.2	1.62E+04	69.0
Dinoflagellates	7	6	7	16.3	6.20E+03	26.4
Cyanophytes	4	2	4	9.30	8.70E+02	3.70
Chlorophytes	6	5	6	13.9	2.00E+02	0.86
Euglenoides	1	0	1	2.30	1.00E+01	0.04
Total	36	33	43	100	2.35E+04	100

were quite different at stations.

According to the results of the frequency of coefficients in the community structure of the phytoplankton species, 29 taxa (67.4% of total 43 taxa) were "common" (frequency: 21-40%), 6 taxa (14.0% of total 43) were "abundant" (frequency: 41-60%), 5 taxa (11.6% of total 43 taxa) were "very abundant" (frequency: 61-80%), and 3 taxa (7.00% of total 43 taxa) taxa were "continuous" (frequency: 81-100%) species during the year in the southwestern Caspian Sea (Table 1).

Quantitative Phytoplankton Composition

The contributions of different phytoplankton groups to the total phytoplankton abundance during the year and in different seasons are shown in Figs. 5 and 6, respectively.

In this study, the average density of phytoplankton was 2.35E+04 ± 1.63E+04 Cell L^{-1} (Fig. 5). Among the phytoplankton groups, diatoms formed more than half of the total abundance (69.0%). Dinoflagellates were the second important group in terms of contribution to the total phytoplankton (26.0%). The chlorophytes (1.00%) and cyanophytes (4.00%) were the other contributors of total phytoplankton (Fig. 5).

The diatoms *Dactyliosolen fragilissimus* (Bergon) Hasle in Hasle & Syvertsen, 1996, *Thalassionema nitzschioides* (Grunow) Grunow ex Hustedt, 1896 and *Skeletonema costatum* (Greville) Cleve, 1873 were the species recorded with the highest abundance among the phytoplankton species during the study. Their average abundance was calculated as 6.80E+03, 3.30E+03 and 1.55E+03 Cell L^{-1}, respectively. Among the dinoflagellates, *Prorocentrum cordatum* (Ostenfeld) Dodge, 1975, *Prorocentrum scutellum* Schröder, 1900, and *Peridinium* sp. were the most important species in view of abundance (4.70E+03, 1.40E+03 and 5.70E+02 Cell L^{-1}, respectively) in the Caspian Sea. The diatoms were

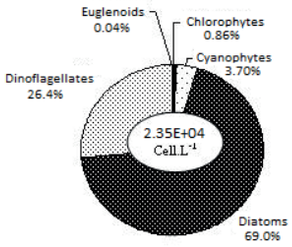


Fig. 5. Contributions of different taxonomic groups to the average total phytoplankton abundance in the southwestern Caspian Sea in 2008.

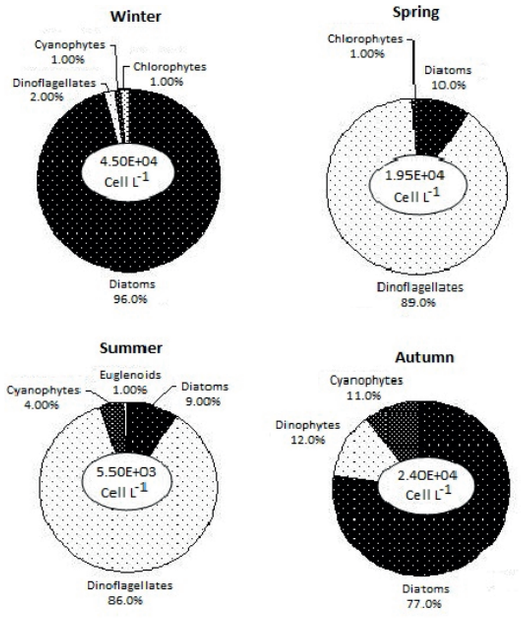


Fig. 6. Seasonal contributions of different phytoplankton groups to the total phytoplankton abundance (Cell L^{-1}) in the southern Caspian Sea in 2008.

dominant during the autumn and winter seasons (77.0% and 96.0%, respectively) characterized with lower water temperatures, while dinoflagellates were prevalent during the spring and summer (89.0% and 86.0%, respectively) when water temperatures were high (Figs. 2 and 6).

The maximum average phytoplankton abundance was measured as 4.50E+04 ± 3.90E+04 Cell L^{-1} (ranged from 7.60E+03 to 1.24E+05 Cell L^{-1}) (Table 3) and *D. fragilissimus* was the most dominant diatom species (2.18E+04 Cell L^{-1}) in the winter (Fig. 6). According to the correlation findings, diatoms showed a strong negative correlation with temperature and salinity ($r = -0.647$, $p < 0.01$ and $r = -0.544$, $p < 0.01$, respectively). The lowest average phytoplankton abundance was recorded as 5.50E+03 ± 4.80E+03 Cell L^{-1} (ranged from

4.00E+02 to 2.20E+04 Cell L^{-1}) (Table 3) with *P. cordatum* as the most dominant species (2.60E+03 Cell L^{-1}) of dinoflagellates in the summer (Fig. 6). Besides, dinoflagellates revealed a positive significant corelation with temperature and salinity ($r = 0.362$, $p<0.05$ and $r = 0.574$, $p<0.01$, respectively).

Chlorophyll *a*

Temporal variations of surface chlorophyll a concentration in the southwestern Caspian Sea are shown in Table 4.

The annual average chlorophyll a was calculated as 9.26 ± 3.54 $\mu g\ L^{-1}$ with the maximum values recorded in the winter (16.9 ± 5.60 $\mu g\ L^{-1}$). According to the Spearman rank correlation analysis, there was a positive correlation between phytoplankton abundance and chlorophyll a ($r = 0.551$), and this relationship was important at the 0.01 level. Furthermore, an analysis of variance comparison (One-way ANOVA) showed that this relation was significant ($p < 0.05$).

Table 3. Seasonal fluctuations of phytoplankton abundance in the southwestern Caspian Sea in 2008.

	Phytoplankton (Cell L^{-1})			
Season	Min	Max	Mean	SD
Winter	7.60E+03	1.24E+05	4.50E+04	3.90E+04
Spring	2.40E+03	4.48E+04	1.95E+04	1.20E+04
Summer	8.00E+02	2.10E+04	5.50E+03	4.80E+03
Autumn	3.40E+03	5.80E+04	2.40E+04	1.60E+04

Table 4. Descriptive statistical analysis of chlorophyll a in the southwestern Caspian Sea in 2008.

		Chlorophyll *a* ($\mu g\ L^{-1}$)			
Sampling Period	N	Min	Max	Mean	SD
Winter	11	8.27	22.6	16.9	5.60
Spring	11	1.90	14.3	7.57	3.49
Summer	11	2.68	4.70	3.61	0.54
Autumn	11	1.79	15.9	8.95	4.51
Annual	44	1.79	22.6	9.26	3.54

DISCUSSION

Many researchers (Hosseini et al. 1998, Dumont 1998, Kideys and Moghim 2003, Nasrollahzadeh et al. 2008, Roohi et al. 2008) reported that temperature variations in surface waters in the southern Caspian Sea varied between 7.00°C (in winter) and 29.0°C (in summer) from 1996 to 2006. Similarly, during the present study, temperature variation in the surface waters varied between 6.80°C (in winter) and 29.8°C (in summer). Kideys et al. (2005) reported that temperature was an important factor in the fluctuations of phytoplankton composition in the Caspian Sea. They showed that diatoms were dominant in the colder waters of the eastern Caspian Sea, while dinoflagellates were prevalent in the warm waters of the southern Caspian Sea. Resende et al. (2007) also revealed that temporal variations of the phytoplankton species was mainly effected by the temporal gradient of temperature using a canonical correspondence analysis (CCA) to identify the environmental variables governing the composition and structure of the phytoplankton assemblages. Statistical findings in the present study revealed that seasonal surface water temperature variations were significant (ANOVA, $p = 0.000$). In contrast to the seasonal variations, there were no significantly regional variations in the study area throughout the study (ANOVA, $p = 0.961$). On the other hand, it is known that more and more rise in temperature in the study area caused rational decrease of diatoms into the phytoplankton composition. This reality was confirmed by the negative correlation between diatoms and temperature ($r = -0.552$). It is also known that the decline in diatoms was supported by the process of eutrophication due to high nutrient concentrations and their change of ratios in such systems (Boalch 1987, Smayda 1997, Hallegraeff 1993, Schollhorn and Graneli 1996, Anderson et al. 2002, Turkoglu 2010a, Turkoglu and Erdogan 2010).

Surface salinity variations ranged between 8.63 ppt and 12.83 ppt. Salinity values in spring and summer seasons were higher than the values in the winter and autumn. The low water temperature and salinity in the winter of 2008 might be related to snow water input carried by rivers during the winter. Similarly, the low salinity values during the autumn of 2008 (Fig. 3) could also be related to fresh water inputs of the rivers.

In this study, the average Secchi depth was recorded as 4.60 ± 1.30 m (Fig. 4). Higher turbidity in some areas may have resulted from anthropogenic inputs flowing from the Lisar and Sefidrood rivers, as well as an inflow of suspended organic and inorganic materials from the Anzali wetlands (Bagheri 2012). With regard to the relationship between the Secchi depth and phytoplankton, there was a significant negative correlation ($r = -0.449$). This correlation was significant at the 0.01 level. Nasrollahzade et al.

(2008) reported that the mean values of the Secchi depth were 6.65 m in 1996 and 5.83 m in 2005. Bagheri et al. (2010a, 2011a) reported that the overall average Secchi depth was 3.01±1.01 m from 2001 to 2006 in the south Caspian Sea. Although the average Secchi depth value recorded in this study was higher than the average value in Bagheri et al. (2010a, 2011a), according to both our data and previous data we suggest that the increase of phytoplankton was influenced by the discharge of the rivers which decreased the transparency in the soutwestern Caspian Sea.

Chlorophyll a values continuously increased from the middle of the 1990s to the end of the 2000s. Khodaparast (2006) reported that chlorophyll a levels changed between 0.56 μg L^{-1} and 1.34 μg L^{-1} in 1994, they however changed between 2.71 μg L^{-1} and 35.3 μg L^{-1} in the present study. Kideys et al. (2008) also revealed that after 1999 chlorophyll a levels gradually increased and reached extremely high levels of 9.00 μg L^{-1} in August 2001 using satellite imagery. In addition, the average chlorophyll a value for the Caspian Sea was calculated as 1.63 μg L^{-1} in March 1998 (Kideys et al. 2005) and as 2.62 μg L^{-1} in 2001 by Kideys et al. (2005). In our study, the annual average chlorophyll a value during the sampling period was calculated by far higher (9.26 ± 3.54 μg L^{-1}) than those reported in previous studies.

As compared to earlier surveys carried out in the southern Caspian Sea, major changes in the phytoplankton community were obvious after 2000 (Nasrollahzadeh et al. 2008). In fact, the number of phytoplankton species drastically decreased in 2008 compared to the findings of Nasrollahzadeh et al. (2008), whereas in 2005 he identified 45 diatoms species in the southern Caspian Sea. We found only 25 species the present study. However, 16 dinoflagellates species were idendified by Nasrollahzadeh et al. (2008) in 2005, but in this study only 7 dinoflagellates species were identified. In paralled, there was a decrease in the number of cyanophytes (4 taxa), chlorophytes (6 taxa), and euglenoids (one taxa) in the present study, whereas 11 cyanophytes, 17 chlorophytes and, 7 euglenoids were identified by Nasrollahzadeh et al. (2008) in 2005 (Tables 1 and 5). In conclusion, a total of 43 phytoplankton species were identified in our study that is lower than the total phytoplankton numbers found by Kosarev and Yablonskaya (1994) (71 taxa) and Nasrollahzadeh et al. (2008) (96 taxa) in the Caspian Sea.

The total annual average density of phytoplankton in 2008 was higher due to some excessive algal blooms cultivated by *P. cordatum* and *D. fragilissimus* (Table 2 and Fig. 5) than the average data between 1962 (7.00E+03 Cell L^{-1}) and 1976 (1.70E+04 Cell L^{-1}) (Kosarev and Yablonskaya 1994) and the data in the period of 1996-1997 (1.30E+04 Cell L^{-1}) (Nasrollahzadeh et al. 2008). More and more increase in the average phytoplankton density revealed that the system have some algal bloom anomalies due to the high nutrient inflow to the system. According to Khodaparast (2006), the cyanophyte *Nodularia Spumigena* Mertens in Jürqens 1822 and dinoflagellate *Heterocapsa* sp. produced two anomalous algal blooms for the first time in the southwestern Caspian Sea in the period of September 2005 and October 2006, respectively. This phenomenon occurred due to the entrance of waste waters rich in nutrient which came from the domestic and agricultural fields, shippina and also waste waters rich in heavy metal from the industrial areas (Jamshidi et al. 2009, Bagheri 2012).

The seasonal dominant abundance of phytoplankton groups presented by Nasrollahzadeh et al. (2008) and by us displayed drastic changes of the phytoplankton stock in the southern Caspian Sea. Nasrollahzadeh et al. (2008) reported that diatoms were prevalent in all seasons in 1996-1997 (90.0%, 81.0%, 92.5% and 79.0% of the phytoplankton abundance in spring, summer, autumn, and winter, respectively). This study revealed that diatoms were dominant during the autumn (77.0% of the total phytoplankton) and winter periods (96.0% of the total phytoplankton) which exhibit low water temperature values, while dinoflagellates were prevalent during the spring (89.0% of the total phytoplankton) and summer periods (86.0% of the total phytoplankton) which exhibit high water temperature levels in the Caspian Sea (Fig. 6). This situation was verified by a negative correlation between diatoms and temperature ($r = -0.552$).

An increase of dinoflagellates was observed in weak upwelling conditions in the summer of 2003. The period of August and October are generally characterized by a relaxation of the upwelling events (Moita et al. 2003) as seen in the growth of

Table 5. Comparison on previous and current data of phytoplankton species diversity in the south-western Caspian Sea.

	2005 (Nasrollahzadeh *et al.* 2008)	2008 (Current Study)
Phytoplankton Groups	Species Number	
Diatoms	45	25
Dinoflagellates	16	7
Cyanophytes	11	4
Chlorophytes	17	6
Euglenoids	7	1
Total	96	43

dinoflagellates after the upwelling pulses in the Atlantic coasts of Portugal (Figueiras and Rios 1993). Khodaparast (2006) revealed that a dinoflagellate bloom by *Heterocapsa* sp. was registered in October 2006 in the southwestern Caspian Sea. The construction of upwelling in the spring and summer periods during the study was one of the possible reasons in the dinoflagellate increase in the south of the Caspian Sea. Field studies have revealed that there are important temporal and spatial variations in the phytoplankton species composition, abundance, and phytoplankton chlorophyll a in a variety of nutrient-enriched environments, including the Dutch Wadden Sea (Riegman et al. 1992), the Baltic Sea (Olli 1996) the Black Sea (Turkoglu 1999, Turkoglu and Koray 2000, 2002, 2004, Turkoglu 2005), Turkish Straits Systems (Turkoglu and Oner 2010, Turkoglu and Erdogan 2010), the mediterranean sea (Tugrul et al. 2011) and the New York Bay (Mahoney and McLaughlin 1977). Another general change in the phytoplankton community is the increase in the abundance of smaller species in cell size during the eutrophication in the southern Black Sea (Turkoglu 2005, Turkoglu and Koray 2000, 2002, 2004). In this study, *D. fragilissimus*, a comparatively smaller species in cell size among the diatoms was the species that have the highest abundance among all the phytoplankton species in the Caspian Sea. With Regard to the dinoflagellates, *P. cordatum*, *P. scutellum* and *Peridinium* sp. were important dinoflagellate species displaying the highest phytoplankton abundance among the other taxonomic groups other than diatoms (Table 1). Like in various ecosystems rich in nutrient, it is normal that smaller forms in size and also opportunist ones due to their short life cycles were found in this study area, too. It is known that the study area was a meso-eutrophic ecosystem (Nasrollahzadeh et al. 2008). Ganjian and Makhlough (2003) reported that *P. cordatum* was one of the widespread opportunist species among dinoflagellates in the south Caspian Sea which is one of the meso-eutrophic systems in the world.

Compared to previous years, the change in the phytoplankton community in the southwestern Caspian Sea could be related to a serious anthropogenic impact from the early 1980s where the south western area of the Caspian Sea became more and more eutrophic (Salmanov 1999, Sharifi 2006, Stolberg et al. 2006, Bagheri et al. 2011b). Nasrollahzadeh et al. (2008) reported that the process of eutrophication is accompanied by a shift in the existing qualitative and quantitative relationship between the major phytoplankton taxa. They showed that while there was relative decrease in qualitative and quantitative levels of diatoms, there was relative increase in qualitative and quantitative levels of dinoflagellates in the Caspian Sea. Therefore, they reported that southern Caspian Sea ecosystem shifted from an oligotrophic to meso-eutrophic ecosystem. It is known that there are generally some biological indicators in such systems. Excessive phytoplankton densities in these systems are generally controlled by smaller forms in size and having generally a short life cycle, such as coccolithophorid *Emiliania huxleyi* (Lohmann) Hay and Mohler, 1967, dinoflagellate *Prorocentrum* spp., and diatoms *D. fragilissimus* and *Leptocylindrus* spp. (Turkoglu and Koray 2002, 2004, Turkoglu and Oner 2010, Turkoglu and Erdogan 2010). A lot of phytoplankton fixed in the present study has been such smaller and opportunist species. Dinoflagellate *P. cordatum* and diatom *D. fragilissimus* were two important small species in size and number. Both were numerically predominant in the system during the year.

An important piece of evidence of the shift towards a meso-eutrophic ecosystem from the oligotrophic system is that nutrient levels increased nearly 3-fold in the period of 1996-1997 and 1.50-fold in 2005 in the Caspian Sea (Nasrollahzadeh et al. 2008). According to the studies of Nasrollah-zadeh et al. (2008), inorganic nitrogen and phosphore concentrations in the coastal waters of the southern Caspian Sea were raised from 5.60 μM to 7.13 μM and from 0.71 μM to 1.55 μM between 1996 and 2005 and in contrast to the ratio of organic nitrogen to inorganic nitrogen in 1996 (from 10.4 to

17.4), the ratio increased about two-fold in 2005 (from 21.5 to 34.4). The southern Caspian Sea is highly affected by fresh water inflow which has high nutrient contents (Salmanov 1999, Sharifi 2006, Stolberg et al. 2006). Bagheri et al. (2010a, 2011b) reported that the high nutrient values in 2008 in the Caspian Sea could be related to the harsh winter of 2008 and river discharges. The nutrients were washed out of the fields by snow water and transported to the sea (Bagheri et al. 2010a, 2011b). This increase in nutrient concentrations might have caused the raise in the chlorophyll a level (Table 4) and phytoplankton abundance in 2008 in the Caspian Sea (Figs. 5 and 6) according to the results of 1996-1997 and 2005 (Nasrollahzadeh et al. 2008).

In addition to inorganic nitrogen and phosphorus, diatoms require inorganic silicate for their siliceous shell composed of two valves known as frustules. It is known that 90% of the silicate discharged to global marine systems is estimated to have come from rivers (Moncheva et al. 2001, Eker and Kideys 2003, Humborg et al. 2004). An increase in number of diatoms of the Caspian Sea can be related to more freshwater input due to the high silicate levels coming from the rivers during the autumn and winter. It is known that in the northern Caspian Sea, inorganic phosphate levels are on average 0.12-0.80 μM. Nitrogen is largely present in organic form (10.0-250.0 μg L^{-1}). Nitrate reaches up to 0.50 μM in spring and summer and 10.0 μM in winter. Silica shows a strong seasonal cycle and decreases from 60.0 μM in winter to <20.0 μM in summer, when diatoms bloom (Dumont 1998).

However, some studies claim that the drastic changes in the phytoplankton community in the Caspian Sea since the early 2000s mainly depended on a serious impact of the invasion of ctenophora *Mnemiopsis leidyi* (A. Agassiz, 1865). Roohi et al. (2010) and Nasrollahzadeh et al. (2008) reported that vicissitudes in phytoplankton (diatoms and cyanophytes) and in nutrients in 2003 and 2004 were related to variations of the *M. leidyi*. Besides, dominant phytoplankton groups changed from diatoms to dinoflagellates and cyanophytes when *M. leidyi* abundance was at a maximum level in the summer and autumn of 2001-2002 in the southern Caspian Sea (Roohi et al. 2010). It preys voraciously on mesozooplankton which is the major consumer of phytoplankton and so phytoplankton continues to increase due to extensive predation on zooplankton of this ctenophore. Also Kideys et al. (2008) showed that the increase in phytoplankton population density was supported by satellite image data on the chlorophyll *a* values in the Caspian Sea which is a hyper-eutrophicated ecosystem symbolized with invasive ctenophore. They also reported that there is a significant positive ($r = 0.600$, $p < 0.01$) correlation between *M. leidyi* and chlorophyll *a*.

In our study, it is hard to estimate the impact of *M. leidyi* on the annual and seasonal fluctuation of the phytoplankton. However, phytoplankton abundance and chlorophyll *a* levels were strongly negative ($r = -0.365$, $p < 0.05$, and $r = -0.402$, $p < 0.01$, respectively) when correlated with the number of *M. leidyi* (Fig. 7) (Spearman rang correlation data for *M. leidyi* was been provided by Bagheri et al. 2010b).

CONCLUSIONS

Our survey documented the spatial and temporal distribution of the phytoplankton in the southwestern Caspian Sea in 2008. The study showed that diatoms such as *D. fragilissimus* and dinofllagelates *P. cordatum* numerically dominated the southwestern Caspian Sea. Excessive phytoplankton densities in the Caspian Sea are generally controlled by such smaller forms in size and having generally a short life cycle. It is known that eutrophic systems are controlled by such species, as was shown in the Black Sea ecosystem (Turkoglu and Koray 2002, 2004) and sea of Marmara (Turkoglu 2010a, 2010b). The study (Table 2) revealed that the contribution of diatoms was higher than those of other taxonomic groups to the total phytoplankton population during the sampling year. On the other hand, succession of diatoms was more dominant than successions of other taxonomic groups during the sampling year in view of qualitative and quantitative (Tables 1 and 2). In addition, phytoplankton cell density (Table 3) and especially chlorophyll a concentrations (Table 4) showed that the coastal system is a more eutrophicated area than similar any other coastal system such as the Black Sea (Turkoglu 1999, Turkoglu and Koray 2002, 2004, Turkoglu 2005).

Further monitoring of the system in terms of anomalies in the temperature, salinity and nutrient changes as well as the phytoplankton species composition is needed to uncover the ecological analysis of the system in detail. Our suggestion is that a working group should be formed to constitute a main database on phytoplankton composition, cell

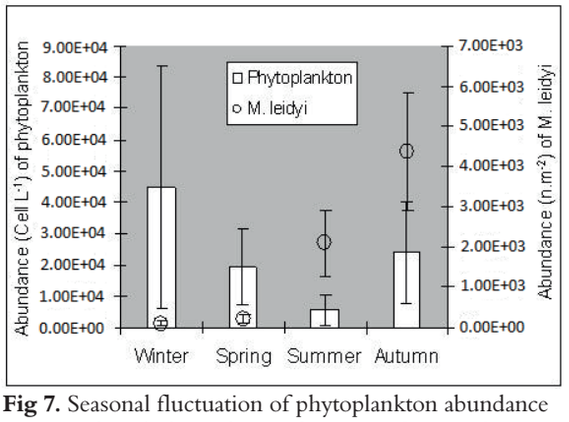


Fig 7. Seasonal fluctuation of phytoplankton abundance and *M. leidyi* in the southwestern Caspian Sea in 2008 (Spearman rang correlation data for *M. leidyi* has been provided by Bagheri et al. 2010b).

densities and other similar interrelated studied topics in the Caspian Sea. Similar studies on the results of the effects of eutrophication on biological and hydrological processes should be taken into account in near future.

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