Seasonal and regional distribution of phytoplankton in the southern part of the Caspian Sea

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Abstract

In the present study, seasonal distribution of species composition, cell abundance and biomass of phytoplankton in the southern part of the Caspian Sea were investigated. This survey were fulfilled in 6 transects and 26 stations. A total of 260 samples were collected during winter to autumn in 2005. Totally, 163 species of phytoplankton were identified, including phyla Bacillariophyta (71 species), Chlorophyta (31 species), Cyanophyta (27 species), Pyrrophyta (21 species), and Euglenophyta (13 species). The overall total average of cell abundance and biomass of phytoplankton were $56.30\pm 30.97 \times 10^6$ cells/m^3 and 221.70 ± 75.87 mg/m^3, respectively. Bacillariophyta accounted for 47% in cell abundance and Pyrrophyta consisted of 53% of the phytoplankton biomass. Maximum phytoplankton population was recorded in winter due to Bacillariophyta and the maximum biomass was recorded in spring due to Pyrrophyta. The maximum density of Bacillariophyta was in winter and autumn while maximum biomass was observed in spring due to larger size of Bacillariophyta such as *Rhizosolenia calcar avis* and *Nitzschia sigmoidea* followed by Pyrrophyta (*Exuviaella cordata*) with high cell abundance throughout the year.

Keywords: Phytoplankton, Seasonal distribution, Biomass, Cell abundance, Caspian Sea

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Introduction

Different groups of phytoplankton such as Bacillariophyta, Pyrrophyta, Chlorophyta, Cyanophyta and Euglenophyta determine the quality and quantity of the primary production in the aquatic systems. Caspian Sea has more brackish and freshwater phytoplankton species than marine (Exxon, 2001; Ganjian, 2007; Ganjian et al., 2008). For example, fresh and brackish water species dominate in north while euryhaline, marine and brackish in the middle and southern Caspian (Exxon, 2001). Dinoflagellates (Pyrrophyta) typically prosper in stratified conditions as their motility enables them to exploit both the overlying euphotic zone and the underlying nutrient-rich waters (Carter et al., 2005). Diatoms inhabit cool waters, whereas other phytoplankton (e.g., dinoflagellates) inhabits tropical waters. The total number of the Caspian Sea phytoplankton species was recorded 449 consisting of 163 diatoms, 139 Chlorophytes, 102 Cyanophytes, 39 Dinofagellates, 5 Euglenophytes and 1 Chrysophyta during 1962–1974. The species diversity decreases from the north (414 species) to the middle (225 species) and south (71 species) mainly due to the disappearance of fresh water forms towards the south (Proshkina- Lavrenko, et al., 1968; Kosarev, et al., 1994). Diatoms and pyrrophyta have the important role in primary production in the Sea (Ghasemov and Bagharrov, 1983; Salmanov, 1987; Ganjian, et al.; 1998, 2003, 2004b, 2009a; Ganjian, 2007). Comparing diatoms to other phyla has shown that this group has the highest growth in the whole seasons and also has the most density and biomass throughout the year. They spread out all of surface layer in the Caspian Sea as well as reach to maximum in autumn (Ghasemov and Bagharrov, 1983; Salmanof, 1987; Ganjian, et al., 1998, 2003, 2004a,b; Ganjian, 2007). According to Salmanof, 1987; Bagherof and Ghasemof , 1983 (for north and middel) and Ganjian et al., 2004b and 2009b (for south) the highest biomass of Phytoplankton in the Caspian Sea included in diatoms and pyrophyta and the maximum abundance of Phytoplankton included in blue–green algae (Cyanophyta) in the each late of summer. There are a few studies available on phytoplankton in the Caspian Sea (Kosarev and Yablonskaya, 1994). Recently, with the invasion of *Mnemiopsis leidyi*, phytoplankton species composition were flactuated widely (Roohi et al., 2008). Voracious feeding on zooplankton, (mainly copepods, cladocerans and meroplankton which are the major consumer of primary producers) by this ctenophore could lead to an abnormal increase in total phytoplankton quantity (Kideys and Moghim, 2003). However, at present, the Caspian Sea suffers from both natural, e.g., sea level changes and anthropogenic disturbances e.g. pollution, eutrophication and invasive species (Dumont, 1998). The impact of the accidentally introduced ctenophore *Mnemiopsis leidyi* (Ivanov et al., 2000) has been tremendous on the Caspian ecosystem causing sharp decreases in zooplankton levels, pelagic fish stocks and other higher components of the ecosystem (Shiganova et al., 2001; Kideys, 2002; Kideys et al., 2004). This study is therefore important for presenting data on phytoplankton of the Caspian Sea from recent years. Main objectives of this study were to identifiy phytoplankton taxa, and to determine the abundance, biomass and species composition of the main phytoplankton groups in the southern aprt of the Caspian Sea.

Materials and methods

Samples were collected at the west (Lisar-Anzaly), center (Sefidrod-Nooshar) and east (Babolsar-Amirabad) of the southern part of Caspian Sea (Fig. 1, Table 1). The sampling stations were established near shore. Sampling was performed seasonally, during winter 2005 to autumn 2006. This study was conducted along 6 transects with 4 stations at the depths of 5, 10, 20 and 50m (and 2 extra stations at 100 m in selected seasons). Two hundred and sixty Phytoplankton samples were collected from the depths of 5, 10, 20, 50 and 100m column waters (at 26 stations) from winter (January-February, N=60), spring (May, N=70), summer (July, N=70) and autumn (October-November, N=60) along the southern coast of the Caspian Sea with Van Dorn water bottle (Ruttner) (Vollenweider, 1974). Phytoplankton samples held in 0.5L bottles and preserved using buffered formaldehyde to obtain a final concentration of 4% (Sourina, 1978).Keeping the samples stagnant for at least 10 days then were concentrated to 30 ml by the sedimentation and centrifuge method (5 minute 3000 rpm), (Hettich-D7200, Tuttlingen: Germany). For micro and nanophytoplankton analyses, 0.1-ml subsamples were taken from the 30 ml sample and counted using a scanned slide (in two steps of quality and one step in quantity) under a phase contrast binocular microscope (covering slip 24×24 with magnification of 100×, 200× and 400×) (Kiselev, 1956; Vollenweider, 1974; Newell, 1977; Clesceri, et al.,1998). The volume of each cell was calculated by measuring morphometric characteristics (i.e., diameter, length and width) and geometric shape (Senichkina, 1986; Hillebrand et al., 1999; Robert 2000). Then, the volume values were converted to 1 m^3 biomass. Phytoplankton were identified according to previous studies (Zabelina, et al., 1951; Morosova-Vodanidskaya, 1954; Kiselev, 1956; Prescott, 1962; Piroshkina et al., 1968; Habit and Pankow, 1976; Eker et al., 1999; Kasimov, 2000). Depth water temperature was measured with a reversing thermometer and periodically checked with Multiparameter CTD (Idornaut Ocean Seven 320) probe device (Clesceri, et al., 1998). Salinity as a main effective parameter in the Caspian Sea waters were measured with a electrosolemer GM-65 M and also checked with Multiparameter CTD (Idornaut Ocean Seven 320) probe device at different depths.The existence of significant differences ($P < 0.05$) between sampling stations, transects and seasons was tested using a one-way analysis of variance (ANOVA).

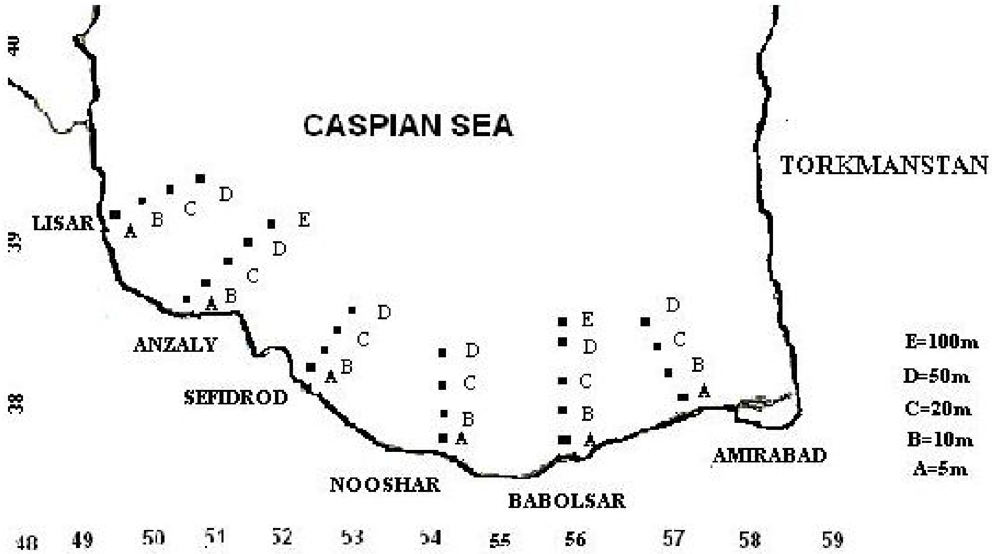

Figure 1: Map of the southern part of the Caspian Sea, showing the sampling sites

Table 1: Sampling transects and the location of stations in the southern part of the Caspian Sea

Transect	Stations	N	Depths (m)	Bottom Depths (m)	Longitude	Latitude
Lisar	Lis1	1	5	5	48.57.00	37.57.50
	lis2	2	5,10	10	48.58.00	37.57.5
	Lis3	3	5,10,20	20	49.05.00	37.57.5
	Lis4	4	5,10,20,50	50	49.12.30	37.57.20
Anzaly	Anz1	1	5	5	49.27.590	37.29.100
	Anz2	2	5,10	10	49.27.910	37.29.350
	Anz3	3	5,10,20	20	49.30.064	37.30.882
	Anz4	4	5,10,20,50	50	49.30.414	37.34.961
	Anz5	5	5,10,20,50.100	100	50.26.977	38.16.002
Sefidrod	Sef1	1	5	5	49.54.783	37.28..920
	Sef2	2	5,10	10	48.54.956	37.29.379
	Sef3	3	5,10,20	20	49.55.20	37.30.45
	Sef4	4	5,10,20,50	50	49.54.800	37.31.370
Nooshar	N1	1	5	5	51.30.704	36.40.042
	N2	2	5,10	10	51.31.177	36.40.261
	N3	3	5,10,20	20	51.32.075	36.40.976
	N4	4	5,10,20,50	50	51.33.429	36.42.968
Babolsar	B1	1	5	5	52.38.787	36.43.298
	B2	2	5,10	10	52.38.646	36.43.641
	B3	3	5,10,20	20	52.38.638	36.45.172
	B4	4	5,10,20,50	50	52.36.882	36.48.127
	B5	5	5,10,20,50.100	100	52.35.987	37.25.110
Amirabad	Am1	1	5	5	53.22.699	36.52.357
	Am2	2	5,10	10	53.23.306	36.53.661
	Am3	3	5,10,20	20	53.20.129	36.57.176
	Am4	4	5,10,20,50	50	53.16.350	37.00.750

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Prior to testing, normality and homoscedasticity of data were checked to comply with the assumptions of ANOVA (Zar, 1996). Subsequent significance between averages was delineated by Duncan's test. The relationship between cell abundance and biomass of phytoplankton at different transects in the southern part of the Caspian Sea was investigated by means of Canonical Discriminate Functions Analysis (CDFA), using the SPSS version 10 package (Garcia-Berthou and Moreno-Amich 1993; Dytham, 1999).

Results

The seasonal fluctuations of water temperature varied from 9.9℃ (20m) to 29.0℃ (5m). The highest and lowest temperatures were in summer and winter, respectively. The salinity values fluctuated between 9.1 and 12.6 (Table 2). A total of 163 phytoplankton species which comprised of 71 diatoms (Bacillariophyta; 43% of the total taxa), 31 Chlorophytes (19% of the total taxa), 27 Cyanophytes (17% of the total taxa), 21 Dinoflagellates (Pyrrophytes) (13% of the total taxa) and 13 Euglenophytes (8% of the total taxa) species were identified and quantified throughout the sampling period (Tables 3 to 5). A total of 77 phytoplankton's were recorded in winter (January-February), 91 in spring (May), 101 in summer (July) and 86 in autumn (October-November) (Table 3). In 2005, the predominant phytoplankton group was Bacillariophyta (diatoms) which observed in high number in summer (42 species) and autumn (41 species) while the lowest number of diatoms was observed in spring (32 species). The number of Pyrrophyta was observed more in spring (18 species) and summer (17 species). Also Cyanophyta were observed 17 species in summer, while Chlorophyta were more in spring (21 species). Euglenophyta were recorded more in spring and summer (9 species) (Table 3).

The overall average cell abundance and biomass total of phytoplankton were (56.30± 30.97) $\times 10^6$cells/m^3 and 221.70±75.87 mg/m^3, respectively. The overall mean of cell abundance was belonging to 47% Bacillariophyta and overall mean biomass pertaining to 53% Pyrrophyta. The maximum cell abundance and biomass of the other groups were between 2 to 16% and 2 to 4%, respectively (Figs. 2a, b, 3). The maximum average abundance of phytoplankton in winter was due to Bacillariophyta, while the maximum average biomass in the spring was due to Pyrrophyta. The maximum average of biomass and cell abundance belonged to Bacillariophyta (26×10^6cells/ m^3, 84.60 mg/m^3) and Pyrrophyta (12×10^6cells/m^{3,} 116.89mg/m^3) in 2005. The same situation (average of biomass and cell abundance) exhibited for other phyla of phytoplankton in four seasons (Tables 4 and 5).

The minimum biomass of Bacillariophyta was observed in autumn (51.84 mg/m^3), but the maximum biomass was observed in spring (129.05 mg/m^3). The biomass of Bacillariophyta showed no significant difference in different seasons. The minimum cell abundance of Bacillariophyta (9×10^6 cell/m^3) was in summer. The maximum cell abundance was observed (53×10^6cells/m^3) in winter. The cell abundance of Bacillariophyta in different seasons showed significant

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difference ($p<0.007$); N=108; (Tables 4 , 5). The maximum and minimum average of biomass and cell abundance Bacillariophyta was observed in middle and eastern parts, respectively (Figs. 4a, b).

The maximum biomass and cell abundance of Pyrrophyta were observed in spring (238.30 mg/m^3 and 31 $\times 10^6$ cells/m^3), while the minimum biomass and cell abundance observe in summer (62.07mg/m^3) and autumn (4×10^6cells/m^3). The biomass and cell abundance of Pyrrophyta showed significant difference in spring ($P<0.003$, $P<0.042$, N=108, respectively (Tables 4 , 5). The minimum and maximum average biomass of this phylum was observed in the eastern and middle area, while the minimum and maximum average of cell abundance were observed in the east and west, respectively (Figs. 4a, b).

Table 2: Seasonal fluctuation of temperature (^{o}C) and salinity (‰) in the southern part of the Caspian Sea

Transect	Stations	Depth (m)	Water temperature ^{o}C				Salinity$^0/_{00}$			
			WI	SP	SU	AU	WI	SP	SU	AU
Lisar	Lis1	5	10.0	23.4	28.0	13.8	12.5	9.7	12.0	12.0
	lis2	10	10.0	20.3	26.0	13.7	10.7	11.6	12.1	12.1
	Lis3	20	9.9	18.7	25.1	13.7	12.3	10.1	12.4	12.4
	Lis4	50	10.9	15.8	21.3	14.2	12.6	11.4	12.4	12.4
Anzaly	Anz1	5	11.0	22.4	27.6	17.5	11.0	11.3	11.9	11.9
	Anz2	10	10.8	20.0	27.4	15.6	11.5	10.3	11.5	11,5
	Anz3	20	10.7	18.2	25.5	16.3	9.1	11.6	12.2	12.2
	Anz4	50	10.6	16.0	21.2	15.7	12.2	11.0	12.3	12.3
	Anz5	100	-	15.8	20.1	-	-	12.5	12.5	-
Sefidrod	Sef1	5	12.9	22.0	27.5	20.5	10.7	12.3	12.0	12.0
	Sef2	10	12.8	20.5	24.6	17.9	11.7	11.8	12.4	12.4
	Sef3	20	11.9	18.2	23.4	18.4	12.1	11.2	12.5	12.5
	Sef4	50	11.2	16.4	20.0	16.0	12.5	11.7	12.6	12.6
Nooshar	N1	5	11.8	23.0	27.8	24.2	11.9	11.1	10.8	10.8
	N2	10	11.8	20.4	27.6	23.9	12.5	11.6	11.6	11.6
	N3	20	11.6	17.5	27.6	19.8	11.5	12.4	12.1	12.1
	N4	50	11.7	15.8	24.1	20.6	12.4	12.1	11.8	11.8
Babolsar	B1	5	11.4	23.2	28.0	24.0	12.1	10.9	10.8	10.8
	B2	10	12.3	22.1	28.3	23.0	11.6	11.8	11.6	11.6
	B3	20	12.4	19.5	27.9	19.8	11.9	11.5	12.1	12.1
	B4	50	12.0	17.5	23.7	20.1	12.4	11.6	11.8	11.8
	B5	100	-	17.0	22.3	-	-	11.0	11.0	
Amirabad	Am1	5	13.0	25.7	29.0	20.8	11.6	10.5	10.8	10.8
	Am2	10	12.5	23.8	28.2	20.8	12.0	10.8	11.4	11.4
	Am3	20	11.7	18.8	27.8	20.9	12.4	11.2	12.6	12.6
	Am4	50	13.1	17.2	24.0	20.2	11.6	10.4	12.4	12.4

Note: Wi: Winter, Sp: Spring, Su: Summer, Au: Autumn

Table 3: List of seasonal distribution of phytoplankton species identified in the present study

Bacillariophyta	Wi	Sp	Su	Au	Bacillariophyta	Wi	Sp	Su	Au
Rhizosolenia calcaravis Schultze	+	+	+	+	*Fragilaria capucina* Desmazière	-	-	+	-
Rhizosolenia fragilissima Bergon	+	+	+	+	*Nitzschia acicularis*	+	+	+	+
Thalassionema nitzschiodes Mereschkowsky	+	+	+	+	*Nitzschia tenirustris* .	+	+	+	-
Thalassiosira parva Ehrenberg	-	+	+	+	*Nitzschia tryblionella* Rakhmatulina.	-	-	+	-
Thalassiosira hustdti Anissimova	+	+	+	+	*Nitzschia closterium*	-	-	+	-
Thalassiosira variabilis Makapoba	-	+	+	+	*Nitzchia thermalis*	-	-	-	+
Thalassiosira aculeate Proshkina-Lavrenko	-	+	-	-	*Nitzschia seriata H. Peragallo*	+	+	-	+
Thalassiosira caspica Makapoba	+	-	-	-	*Nitzschia reversa*	+	-	+	-
Thalassiosira sp	-	+	+	+	*Nitzschia sigma*	-	+	-	+
Tribonema vulgar	+	+	+	+	*Nitzschia sigmoidea W. Smith*	-	+	+	-
Cyclotella menenghiniana Kützing	+	+	+	+	*Nitzschia* sp	+	+	+	+
Chaetoceros wighamii Brightwell	-	-	-	+	*Nitzschia* sp1	-	-	+	-
Chaetoceros muelleri Lemmermann.	+	+	+	+	*Nitzschia* sp2	+	+	+	-
Chaetoceros rigidus Ostenfeld	-	-	-	+	*Nitzschia* sp3	+	-	+	-
Chaetoceros subtilis Cleve	-	+	+	+	*Navicula cryptocephala Kützing.*	-	-	-	+
Chaetoceros simplex Ostenfeld	-	-	-	+	*Navicula bombus Greg*	+	-	-	+
Chaetoceros delicatulus Van Goor	-	-	-	+	*Navicula* sp	+	+	+	+
Chaetoceros sp	+	-	+	+	*Navicula* sp1	+	+	+	+
Cymbella tumidae Cleve	+	-	+	+	*Melosira moniliformis O.F. Müller.*	-	-	+	-
Cymbella sp	+	+	+	+	*Melosira varians C.A. Agardh*	-	-	-	+
Cocconeis placentula Ehrenberg	+	-	+	-	*Melosira granulate Ralf.*	-	-	+	-
Coconeis husteli Krasske.	-	-	+	-	*Melosira juergensii C.A. Agardh.*	-	-	+	-
Cocconeis scutellum Ehrenberg	-	-	+	-	*Melosira* sp	-	-	+	-
Coconeis sp	+	-	+	-	*Gyrosigma strigile Rakhmatulina.*	+	-	-	-
Coscinodiscus perforatus Ehrenberg	-	+	+	+	*Gyrosigma attenuatum akhmatulina*	+	+	-	+
Coscinodiscus proximus Makar	-	-	-	+	*Gomphonema* sp	+	-	-	-
Coscinodiscus granii Gough	-	-	-	+	*stephonodiscus* sp	-	-	-	+
Coscinodiscus gigas Ehrenberg	+	+	+	+	*Surirella aracta*	+	-	-	-

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Table 3: Continued

Bacillariophyta	**Wi**	**Sp**	**Su**	**Au**	**Bacillariophyta**	**Wi**	**Sp**	**Su**	**Au**
Actinocyclus parduxus Makapoba.	-	-	-	+	*Synedra ulna*	+	+	-	+
Amphora sp	+	+	-	-	*Skletonema subsalsum Bethge*	-	+	+	+
Diatoma ochki sp	+	-	-	-	*Skeletonema costatum Greville*	+	+	+	+
Diatoma bombus Cleve	+	-	-	-	*Skeletonema costata Greville*	-	-	-	+
Diatoma sp	+		-	-	*Pleurosigma elongatum W. Smith*	-	+	+	+
Diploneis interupta Kutz	+	+	+	+	*Pleurosigma delicatulum W. Smith*	-	-	+	-
Dinobryon sp	-	+	-	-	Total	**36**	**32**	**42**	**41**
Pyrrophyta	**Wi**	**Sp**	**Su**	**Au**	**Pyrrophyta**	**Wi**	**Sp**	**Su**	**Au**
Exuviaella cordata Ostenfeld.	+	+	+	+	*Glenodinium lenticula Schiller*	+	+	+	-
Prorocentrum scutellum Schröder	+	+	+	+	*Glenodinium danticulum Paulsen*	-	+	-	-
Prorocentrum praximum Makapoba.	+	+	+	+	*Gymnodinium variabile Herdman*	+	+	+	+
Prorocentrum obtusum Ostenfeld	+	+	+	+	*Goniaulax polyedra Stein*	+	+	+	+
Prorocentrum micans Ehrenberg	+	+	+	+	*Goniaulax digitale Kofoid.*	+	+	+	+
Peridinium achromaticum Levander	+	+	+	+	*Goniaulax minima Matzenauer*	-	+	+	+
Peridinium trochoideum Lemmermann	-	+	-	*	*Goniaulax spinifera Diesing.*	+	+	+	+
Peridinium subsalum Ostenfeld	-	+	-	-	*Gonyastomum depressum Herdman*	+	+	+	-
Peridinium latum Paulsen.	+	+	+	+	*Total*	**16**	**18**	**17**	**15**
Peridinium sp	+	-	-	+					
Peridinium sp1	-	-	+	-					
Glenodinium behningii Kissel.	+	+	+	+					
Glenodinium penardii Lemmermann	+		+	-					
Chlorophyta	**Wi**	**Sp**	**Su**	**Au**	**Chlorophyta**	**Wi**	**Sp**	**Su**	**Au**
Ankistrodesmus convolutes Corda	+	+	-	+	*Crucigenia quadrata Morren*	-	+	+	-
Ankistrodesmus falcatus Ralfs	-	+	-	-	*Codotella* sp	-	-	-	+
Ankistrodesmus arcuatus Korschikov	-	+	+	-	*Scheroderia setigea Schröder*	-	-	-	+
Ankistrodesmus sp	+	+	-	-	*Selenstrum bibrajanum Reinsch*	-	-	+	+
Binuclearia lauterbornii Schmidle	+	+	+	+	*Scenedesmus quadricauda Brebisson*	-	+	+	+

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Table 3: Continued

Chlorophyta	**Wi**	**Sp**	**Su**	**Au**	**Chlorophyta**	**Wi**	**Sp**	**Su**	**Au**
Binuculeria sp	+	-	-	+	*Scenedesmus denticulatus Lagerheim*	-	-	-	-
Chlorella sp	+	+	+	+	*Scendesmus abundans Kirchner*	-	+	-	-
Clamydomonas monasovalis Shen	-	-	+	-	*Scenedesmus acuminatus R. Chodat*	-	+	+	+
Clamydomonas ovalis Shen	+	+	+	-	*Selenstrum bibrajanum Reinsch*	-	+	-	-
Clamydomonas olifanii Korsch	-	+	+	-	*Oocystis nodulosa West*	-	+	-	-
Clamydomonas globosa Snow	-	+	+	-	*Oocystis solitaria Wittrock*	+	-	+	+
Clamydomonas floscularia Korsch	-	-	+	-	*Oocystis borgi Snow*	+	+	-	-
Clamydomonas sp	+	+	+	+	*Oocystis pulvevea G.S.West*	-	+	-	-
Closterium spharicum Nägeli	-	-	+	-	*Mougeotia* sp	+	-	-	-
Closterium moniliferum Ehrenberg	+	+	-	-	*Pediasreum tetras Ralfs*	-	-	+	-
Crucigenia sp	-	+	-	-	Total	**11**	**21**	**16**	**11**

Cyanophyta	**Wi**	**Sp**	**Su**	**Au**	**Cyanophyta**	**Wi**	**Sp**	**Su**	**Au**
Anabaena spirodes Pankow	+	-	-	+	*Spirulina laxissma West*	+	+	+	+
Anabaena aphanizomenoides Ostenfeld	-	-	-	+	*Spirulina subtilisima Kutzing*	-	-	+	+
Anabaena bergii Ostenfeld	-	+	-	-	*Spirulina* sp	-	+	-	-
Anabaena reniformis Lemmermann	-	-	+	-	*Merismopedia punctata Meyen*	+	-	-	-
Anabaena kisselerii Proshki	-	-	+	-	*Merismopedia mimima G.Beck*	-	-	-	+

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Table 3: Continued

Cyanophyta	**Wi**	**Sp**	**Su**	**Au**	**Cyanophyta**	**Wi**	**Sp**	**Su**	**Au**
Anabaenopsis arnoldii Miller	-	-	+	+	*Microcystis pulverea Wood*	-	+	+	-
Anabeanopsis rasiborskii Woloszinska	-	-	+	-	*Microcystis aeruginosa Kuetzing*	+	+	+	-
Anabeanopsis nodsonii Woronichim	-	-	+	-	*Microcystis* sp	-	-	+	-
Aphenizominon ussaczevii Proshkina-Lavrenko	-	-	-	+	*Nodularia harveyana Thuret*		+	-	-
Aphanotece sp	-	-	-	+	*Lyngbya limneticula Lemmermann*	+	+	+	+
Aphanothece elabens Berb	-	-	+	+	*Lyngbya birgei Agardh*	-	+	-	-
Oscillatoria limosa Agardh	+	+	+	+	*Lyngbya* sp	+	+	+	+
Oscillatoria tennuis Agardh	-	-	+	-	*Gloeocapsa minor Kutzin*	-	-	+	-
Oscillatoria sp	+	+	+	+	*Total*	**8**	**11**	**17**	**13**
Euglenophyta	**Wi**	**Sp**	**Su**	**Au**	**Euglenophyta**	**Wi**	**Sp**	**Su**	**Au**
Euglena acus Ehrenberg	-	+	+	+	*Tracholemonas similes Stokes*	-	+	+	+
Euglena viridis Ehrenberg	+	+	+	-	*Trachelomonas planctoniea Swirenko*	-	+	-	-
Euglena tuba Philipose	-	-	+	-	*Trachelomonas tambavica Stokes*	-	+	+	+
Euglena wangi Chu	-	+	+	-	*Trachelomonas* sp	+	+	+	+
Euglena sp	+	-	+	+	*Trachelomonas* sp1	+	-	-	-
Euglena sp1	+	-	-	-	*Phacus* sp	-	+	+	+
Trachelomonas spiculifera Schkorbatov	+	+	-	-	Total	**6**	**9**	**9**	**6**

Note: Wi: Winter, Sp: Spring, Su: Summer, Au: Autumn

Table 4: The cell abundance (cells×10^6/m^3) of phytoplankton groups in different seasons in the present study (means± SD)

Division	**Winter**	**Spring**	**Summer**	**Autumn**	**Average**
Bacillariophyta	53.84 ± 36.27 ^{b}	12.53 ± 8.83 ^{a}	9 .35± 5.86 ^{a}	29.99 ± 20 .55^{ab}	26.43 ± 10.78
Pyrrophyta	9.56 ± 7.72 ^{a}	31.57 ± 33.31 ^{b}	5.39 ± 1.35 ^{a}	4.50 ± 3.91 ^{a}	12.75 ± 7.59
Cyanophyta	4 .82 ± 4.08 ^{a}	3 .88 ± 1.41^{a}	19.60 ± 18.18 ^{a}	8.70 ± 11.30^{a}	9.25 ± 7.47
Cholorophyta	10 .59 ± 5.47 ^{b}	2.35 ± 1.22^{a}	11.17 ± 7.83 ^{b}	2.56 ± 2.41 ^{a}	6.67 ± 2.81
Euglenophyta	1.21 ± 1.47	0.24 ± 0.16 ^{a}	3.03 ± 6 .80^{a}	0.38 ± 0.69 ^{a}	1.17 ± 2.05

Note= Values with different superscript letters within each row are significantly different ($P < 0.05$)

Table 5: The biomass (mg/m^3) of phytoplankton groups in different seasons in the present (means± SD)

Division	**Winter**	**Spring**	**Summer**	**Autumn**	**Average**
Bacillariophyta	83.32 ± 54.06 ^{a}	129.05 ± 81.47^{a}	74.20 ± 60.55 ^{a}	51.84 ± 33.61^{a}	84.60 ± 25.34
Pyrrophyta	84.62 ± 34.79 ^{a}	238.30 ± 117.34^{b}	62.07 ± 28.37 ^{a}	83.58 ± 90.99 ^{a}	116.89 ± 33.34
Cyanophyta	8.21 ± 11.32 ^{a}	4.58 ± 6.25^{a}	5.53 ± 2.98 ^{a}	10.33 ± 11.99^{a}	7.16 ± 3.96
Cholorophyta	16.57 ± 32.17^{a}	1.72 ± 0.96^{a}	11.88 ± 6.25^{a}	1.04 ± 1.83 ^{a}	7.80 ± 8.44
Euglenophyta	9.33 ± 8.17 ^{a}	1.81 ± 2.17 ^{a}	6.44 ± 10.52 ^{a}	1.76 ± 0.50 ^{a}	5.25 ± 4.79

Note: Values with different superscript letters within each row are significantly different ($P < 0.05$)

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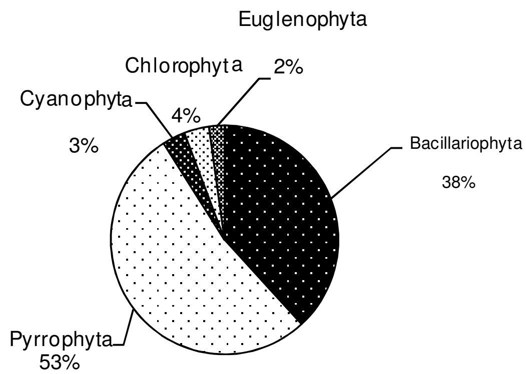

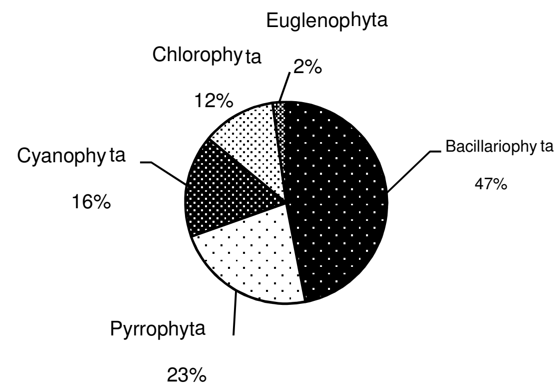

(a) (b)

Figure 2: The mean percent of biomass (a) and cell abundance (b) of different phytoplankton groups in the present study

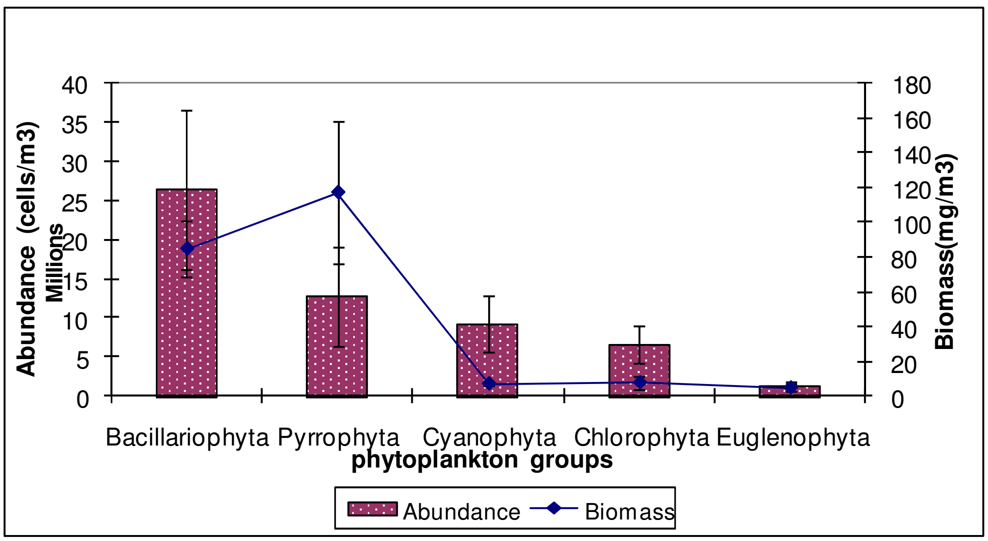

Figure 3: The annual distribution changes in the mean biomass (mg/m^3) and cell abundance (cells/m^3) of phytoplankton groups in the present study

As a comparison, the biomass of Cyanophyta phylum was less than two previous phyla. The minimum amount was in spring (4.58 mg/m^3) but the maximum amount was in autumn (10.33 mg/m^3). The minimum and maximum of cell abundance were observed in spring and summer (3×10^6cells/m^3 and 19 $\times10^6$ cells/m^3, respectively). The biomass and cell abundance of Cyanophyta in different seasons did not show significant difference (Tables 4, 5). The minimum and maximum average biomass of this phylum was observed in the west and middle area, while the minimum and maximum averages of cell abundance were observed in the west and east, respectively (Figs. 4a, b).

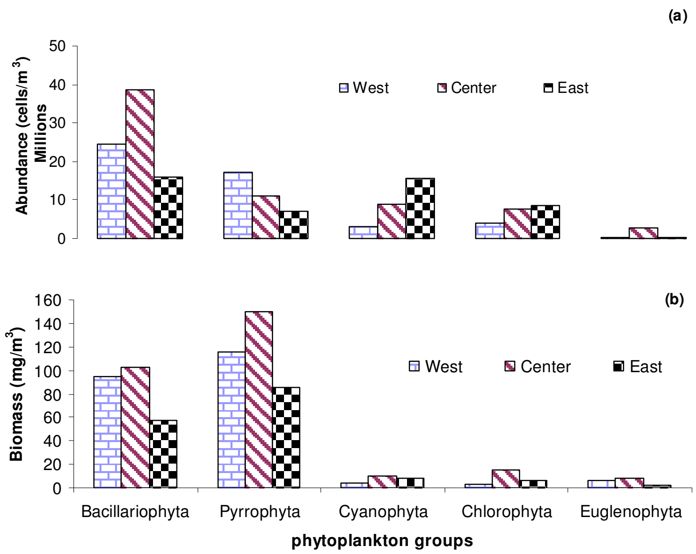

Figure 4: The regional distribution of different phytoplankton groups to the mean cell abundance (a) and biomass (b) in the southern part of Caspian Sea (in the present study)

The minimum and maximum biomass estimated in autumn and in winter were 1.04 mg/m^3 and 16.57 mg/m^3, respectively. The cell abundance and biomass of this phylum were as low as those for the phylum Chlorophyta. The minimum and maximum of cell abundance were in autumn and summer that were 2×10^6cells/m^3 and 11 $\times10^6$ cells/m^3 respectively. The biomass in different seasons has no significant difference, while the cell abundance in different seasons showed a significant different ($p<0.005$) N=108 (Tables 4, 5). The minimum and maximum average biomass of Chlorophyta was observed in the west and middle area, while the minimum and maximum average of cell abundance observed in the west and east, respectively (Fig. 4a, b). As a comparison, this phylum of biomass was less than other phyla, the minimum and maximum biomass were observed in autumn (1.76 mg/m^3) and in Winter (9.33mg/m^3), respectively. The minimum and maximum cell abundance was in autumn and in summer, being 0.3×10^6 cells/m^3, and 3×10^6 cells/m^3, respectively. The biomass and cell abundance in Euglenophyta had no signification difference (Tables 4, 5). The minimum and maximum average biomass of Euglenophyta were observed in the east and middle area, while the minimum and maximum average of cell abundance were observed in the west and middle, respectively (Figs. 4a, b). Canonical discriminate function analysis based on the biomass of phytoplankton groups at different transects shown similarity of the scatter plots overlapping 2, 5, 6 transects were thick cluster due to Pyrrophyta include more than 50 %, while in 1 (Lisar) transect which was separated on the impacts of diatoms species.

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Euglenophyta caused separation at transect 3 (Sefidrod) in addition of diatoms and Pyrrophyta species. Chlorophyta had also the main phytoplankton role in transect 4 (Nooshar) in addition to the other groups (Fig. 6).

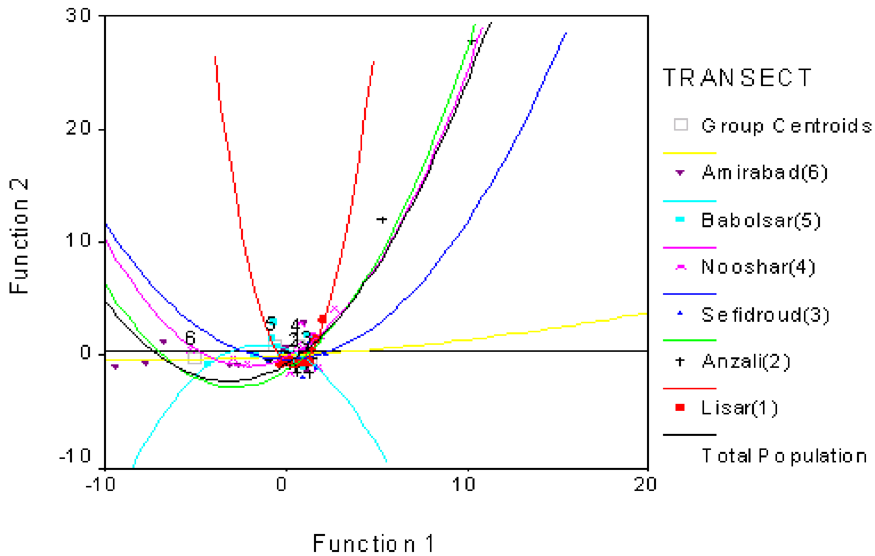

Figure 5: Canonical discriminate function analysis based on cell abundance of Phytoplankton groups at different transects in the southern part of the Caspian Sea

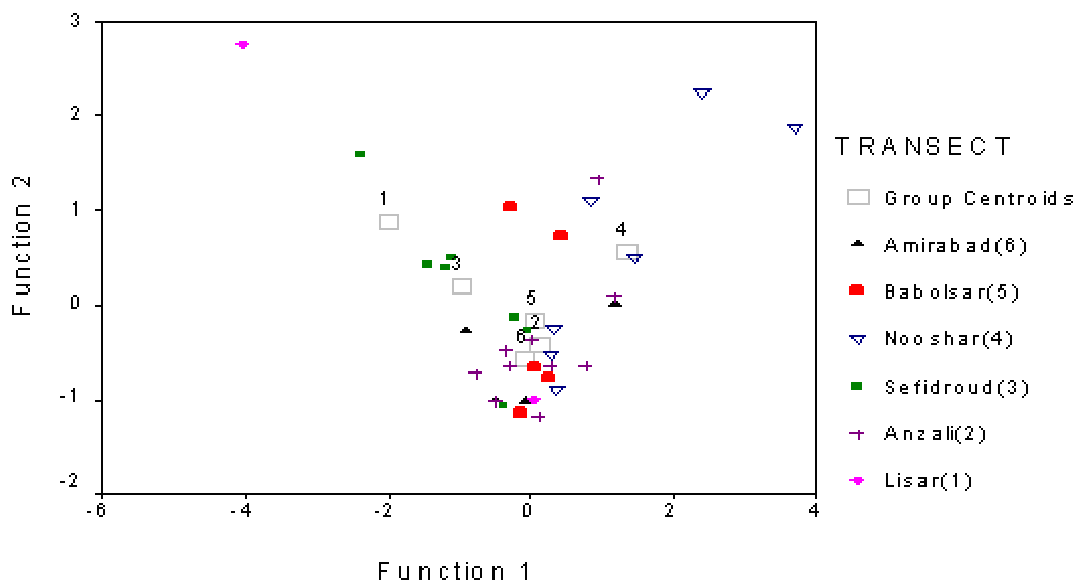

Figure 6: Canonical discriminate function analysis based on biomass of phytoplankton groups at different transects in the southern part of Caspian Sea, in the present study

Discussion

Seasonal distribution, cell abundance, biomass and species composition of Phytoplankton in northern part of the Caspian Sea are well known (Ghasemof and Bagherof, 1983; Salmanof, 1987). The main phytoplankton groups in the Caspian Sea are diatoms, Pyrrophyta and Cyanophyta (Ghasemof and Bagherov, 1983; Salmanof, 1987; Ganjian, et al., 1998; 2003; 2004a,b; 2009a, b; Ganjian, 2007). During this study, the main phytoplankton group was Bacillariophyta (diatoms) with more than 71 species and 43% of the total taxa. This group was more diversified in summer and autumn with 42 and 41 species, respectively. It seems that temperature has more effect on the growth of this phylum. The occurrence of phytoplankton in summer was more varied and diatoms, Pyrrophyta and Cyanophyta were more abundant in this season (Ghasemof and Bagherof, 1983; Salmanof, 1987; Ganjian, et al., 1998, 2003, 2004a,b, 2009a, b; Ganjian, 2007). Previously diatoms species were reported to be the most abundant and widespread group throughout the Caspian Sea (Kosarev and Yablonskaya, 1994). After diatoms, Chlorophytes and Cyanophytes are the most abundant groups in the north (since they are chiefly fresh and brackish water forms), while dinoflagellates are dominant in the middle (included eastern) and southern part of the Caspian Sea all year round terms of cell abundance (Kosarev and Yablonskaya, 1994; Ganjian et al., 2004b; 2009b Ganjian, 2007). In this study, the highest number of phytoplankton species was recorded in summer with 101 species in the southern part of the Caspian Sea. Bacillariophyta (diatoms), Pyrrophytes (dinoflagellates) and Cyanophytes were more abundant in summer. Chlorophytes and Pyrrophytes were more abundant in spring and may be the environmental conditions, during spring, are conducive for their growth. Only a small number of Euglenophytes recorded in this study and contributed less to the phytoplankton community structure in the Southern part of Caspian Sea. Ghasemof and Bagherof (1983) and Salmanof (1987) carried out some investigations in the middle and the southern part of the Caspian Sea. Based on these studies, diatoms and Pyrrophyta constitute two main phyla in the Caspian Sea, and also the survey of southern part of the Caspian Sea (Iranian coasts) were performed in 1994-1996 (Ganjian et al., 1998; 2003; 2004 a, b; 2009b; Ganjian, 2007), which revealed two phyla constitute the dominant groups of phytoplankton. These surveys revealed that the highest cell abundance and biomass in the first rank belong to diatoms and the second rank is regarded to Pyrrophyta. Salmanof (1987) mentioned that the summer phytoplankton include in diatoms, Pyrrophyta and Cyanophyta. The main group of phytoplankton in the Caspian Sea contains diatoms and dinoflagellates. The Blue-green algae (Cyanophyta) were increased in the late of summer. Carter et al. (2005) reported that maximum diatoms and Pyrrophyta biomass in Beatrix Bay appeared between 1994 and 2002. Diatoms dominated the phytoplankton biomass, with the exceptions being occasional Pyrrophyta blooms during summer months. In 2001 – 2003, the phytoplankton community in the Western Australian Ocean was characterized by a relatively low diversity of taxonomical structures and a predomination of heterotrophic Dinophyceae species during most part of the year (Floreat et al., 2005). Of the total 146 phytoplankton species, varieties and forms and the species composition were dominated by diatoms and dinophlagellates (Floreat et al., 2005). The high increase in cyanobacteria cell abundance, from 35% of the population in June to values close to 100% as the summer progressed, suggests existence of a strong relationship between cyanobacteria abundance and water temperature, as observed in the Blanes Bay (Agawin et al. 1998; Agawin et al., 2000; Hense and Beckmann, 2006). In the present study, canonical discriminate function analysis (CDFA) on cell abundance of members of the phylum Cyanophyta showed that cell abundance was higher in summer and in the Amirabad transect than to other phyla. It seems that the temperature has the most important role in this transect. The surface layer community structure at the fixed station changed from Cyanophyta typical summer bloom community to one dominated by Euglenophyta, Bacillariophyta and Pyrrophyta were also abundant (Richadson et al., 2000; Izaguirre et al, 2001; Vahtera et al., 2005). The five years survey from 1960 to 1965, conducted by Salmanof (1987) and Kosarev and Yablonskaya (1994) showed that cell abundance of phytoplankton was higher in the middle and the southern parts of the Caspian Sea with the diatoms being the most predominant in the autumn. In comparison to the spring blooms, the autumn phytoplankton was rich of biomass and cell abundance. Ghasemove and Bagherov, (1983) showed that the diatoms reach to maximum in autumn season and can be observed throughout the year. In the survey carried out in the Iranian coast (1994-1996), Ganjian et al. (1998, 2004b), the maximum cell abundance of Bacillariophyta was observed in autumn. In another survey (Ganjian, et al., 2003) in the southern part of the Caspian, the maximum cell abundance of Bacillariophyta was observed in winter and autumn while, maximum biomass observed in summer. As a result of this study, the maximum cell abundance of Bacillariophyta was in winter and autumn and maximum biomass observed in the spring due to bigger size of diatoms *Rhizosolenia* spp and *Nitzschia sigmoides* followed by Pyrrophyta with cell abundance throughout year due to *Exuviaella cordata* and maximum biomass in spring due to *Prorocentrum* spp. The cell abundance of Bacillariophyta (Table 4) in different seasons showed significant difference ($p<0.007$). After Bacillariophyta, Pyrrophyta has maximum cell abundance throughout year and biomass was higher than Bacillariophyta, it reaches to maximum in spring season. The growth and blooms of this phylum observed in spring season. The biomass and cell abundance of Pyrrophyta (Tables 4 , 5) showed significant difference in spring ($P<0.05$).

In a survey in 1994-1996 (Iranian coast), Ganjian et al. (1998, 2003, 2004a, b) indicated that the maximum density of Pyrrophyta were in spring, and Bacillariophyta, Pyrrophyta has highest

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density throughout year. The cell abundance and biomass of Chlorophyta and Euglenophyta were decrease. The maximum cell abundance and biomass of Chlorophyta and Euglenophyta were in summer and winter, respectively. The cell abundance of Chlorophyta is higher than that for Euglenophyta but the biomass of Euglenophyta is higher than that in Chlorophyta due to their large-sized and high weight (Adame et al., 2008). In the regional survey of Bacillariophyta indicated that the maximum density and biomass were in central regions. Phyrrophyta phylum has the maximum biomass and density in west and center region, respectively. The maximum cell abundance and biomass of Cyanophyta and Chlorophyta were in east and center regions, respectively and Euglenophyta was in central region. It seems that the distribution of the phyla in different regions and also the increase of primary production in each phylum are related to vital factors and vital elements in any phylum in each region. The salinity usually does not vary much between the surface waters of the east and west of the southern part of the Caspian Sea ranging around 12.5–13.4 ppt during the course of the year (Kosarev and Yablonskaya, 1994). Kideys et al., (2005) also reported that salinity was similar between several regions being around at 12.5 %. Shiganova et al., (2003) studied the hydrochemical and biological characteristic of the north and central parts of the Southern Caspian Sea. They also reported that there was a small change of salinity between surface and lower column of the water (almost 2.6%). Vertical changes in salinity are also minimal (0.1–0.2 ppt). In the present study, the salinity between the surface waters of the four seasons was from 9.1 to 12.6 ppt.

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