American-Eurasian J. Agric. & Environ. Sci., 8 (2): 146-155, 2010
ISSN 1818-6769

Seasonal Succession of Phytoplankton Community Structure in the Southern Part of Caspian Sea

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Abstract: The composition and seasonal variations of Phytoplankton in the southern part of Caspian Sea were investigated from summer 1994 to winter 2007. Number of Phytoplankton species identified in spring, summer, autumn and winter were 199, 216, 241 and 211, respectively. Between eight main divisions, maximum contributions (46%) belong to *Bacilariophyta* division. In 2001-2002, most of the cell abundance of Phytoplankton (*Exuviella cordata* and *Rhizosolenia fragilissima* species) and high density related to *Bacillariophyta* and *Pyrophyta* were observed in winter season. The most biomass of Phytoplankton and abundant biomass source of diatoms were observed that reached with *Cyanophyta* in summer season. The long term taxonomic structure of Phytoplankton biomass and cell abundance shows a likely shift from a diatom dominant system (constituting 59% biomass and 27% cell abundance of total of Phytoplankton) to an apparent dominance of opportunistic *Pyrrophyta* (45% biomass and 52% cell abundance) in spring. The temperature and nutrient levels are affected by composition and seasonal variations of Phytoplankton. In 1994-1997, the most seasonal variation of Phytoplankton in cell abundance and biomass were observed in spring and summer, respectively. In 1999-2007, after the invasion, the cell abundance was shifted from spring to winter and autumn and biomass from summer to winter and spring.

Key words: Phytoplankton · Seasonal variation · Cell abundance · Biomass · Caspian Sea

INTRODUCTION

Caspian Sea is the largest enclosed basin on the planet, located inside the Eurasian continent, is distinguished by special, very rich natural resources both biological and mineral. Phytoplankton in aquatic environments plays a critical role in biogeochemical cycles and serves as the base of the aquatic food web. This role is especially important in coastal areas where Phytoplanktons are central to material transformations and primary production rates are very high. Phytoplanktons are often categorized into groups based on their primary role in biogeochemical material fluxes and/or primary production. For example, diatoms are considered the principal Phytoplankton group contributing to primary production and carbon export in coastal areas; dinoflagellates are often important contributors to biomass in stratified or silica limited areas and are well examined in harmful algal bloom literature; and *Cyanobacteria* are the dominant algal group in offshore continental shelf and oceanic waters [1].

As planktonic algae have very short generation times, they also react rapidly to shifts in the environment. The variations of physical and or chemical status of the water body are traced after some weeks through alterations of the species and their abundances. Long-lasting water quality changes may be reflected among the planktonic algae from one growth season to another [2]. Knowledge about the compositional changes in the Phytoplankton community during the course of a growth season is very important, e.g. when interpreting deviations in species composition and biomass [2]. Therefore, Phytoplankton species and density fluctuate according to the seasons. It has been shown that many

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of these fluctuations, called seasonal successions, could result from the life activities of the previously existing Phytoplanktons and zooplanktons, fishes and other organisms. The seasonal succession of the Phytoplankton is a problem that has attracted the attention of algologists for a long time, but many of the studies on periodicity have been restricted to limited areas [3]. Phytoplankton abundance and biomass has increased in relation to a net increase in nutrient concentrations, the species composition has changed with a relative increase in species number, abundance and biomass of dinofagellates compared to diatoms and there has been a trend towards small sized Phytoplankton groups. Physical, chemical and biological conditions of the water have large spatial, seasonal and inter annual variations and these variations have a direct effect on Phytoplankton composition, abundance and biomass over different spatial and temporal scales [4, 5].

A total of 450 species, varieties or forms of Phytoplankton are found in Caspian Sea. Between them, the dominant forms are *Cyanophyta, Bacillariophyta* and *Chlorophyta*. In middle and south part of Caspian Sea Phytoplankton are mixed with marine, brackish and freshwater forms. By contrast, in north of Caspian Sea Phytoplankton are all freshwater forms [6]. Composition of Phytoplankton species is represented by 441 species of algae including: blue-green–116, yellow-green–2, diatom–165, periphytos–32, euglenas-4, yellow–122. The Phytoplankton of northern part of Caspian Sea are different from those of in middle and southern part of Caspian Sea in typical features of estuarine plankton depleted by sea elements. In respect to salinity, algae can be divided into five ecological groups mostly freshwater, brackish and brackish-freshwater with a small share of marine and halophobes [7].

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Caspian Sea being the largest inland sea and thus considered to be a lake, has its surface level below the level of the world's oceans. Caspian Sea is located at the centre of the watersheds of major rivers such as Volga, Ural, Kura and Terek and has no connection with oceans. Due to a combination of these factors and having the largest evaporation area of any lake, Caspian Sea has apparently reacted to global climate change earlier than other seas. Investigation of Caspian Sea is therefore of great importance to studies of the effects of climate changes and prediction.

Analysis of the structure of the Phytoplankton community in any area is very important for commercial fisheries. Phytoplanktons are the primary producers of the pelagic marine ecosystems and some of the Phytoplankton species may also reflect the ecological changes in the environment, acting as an indicator organism. Unfortunately, limited studies carried out on the Phytoplankton succession and composition in the southern Caspian Sea (SCS). Therefore, this study was carried out to investigate the seasonal change of Phytoplankton composition, diversity and cell abundance and biomass and to study the nutrients and physico-chemical factors and their impacts on the abundance of the Phytoplankton by seasonal samplings in the SCS. This study was to determine the biomass and examine the seasonal succession of Phytoplanktonic organisms in Lake.

MATERIALS AND METHODS

Site Study, Date and Sampling Strategy: All samples were collected during 33 cruises carried out on board the R/V Guilan from summer 1994 to winter 2007 in the SCS at 18 transects (1994-2000) and at 6 transects (2001-2007). Along each transect four stations were located at depths of 10, 20, 50 and 100 m (38° 38′ N 49° 54′ E), (Figure 1).

Phytoplankton Sampling: Phytoplankton samples were collected along the southern part of Caspian Sea using a Van Dorn water bottle sampler [8], from the surface, 2, 5, 10, 20, 50 and 100m depth of column waters. A total of 4556 of Phytoplankton samples were collected from 1994 to 2007 and were held in 0.5 L bottles and preserved using buffered formaldehyde to obtain a final concentration of 4% [9]. The samples were kept stagnant for at least 10 days then concentrated to 30 ml by the sedimentation and centrifugation (5 minutes with 3000 rpm), in a clinical centrifuge (Hettich- D7200, Tuttlingen: Germany). For micro and nano Phytoplankton analysis, 0.1 ml sub-sample taken from the 30 ml sample was 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×) [8, 10, 11]. The volume of each cell was calculated by measuring morphometric characteristics (i.e., diameter, length and width) and geometric shape [12]. Finally, the volume values were converted to biomass. Phytoplankton were identified to the possible taxon using the previous studies [13, 14].

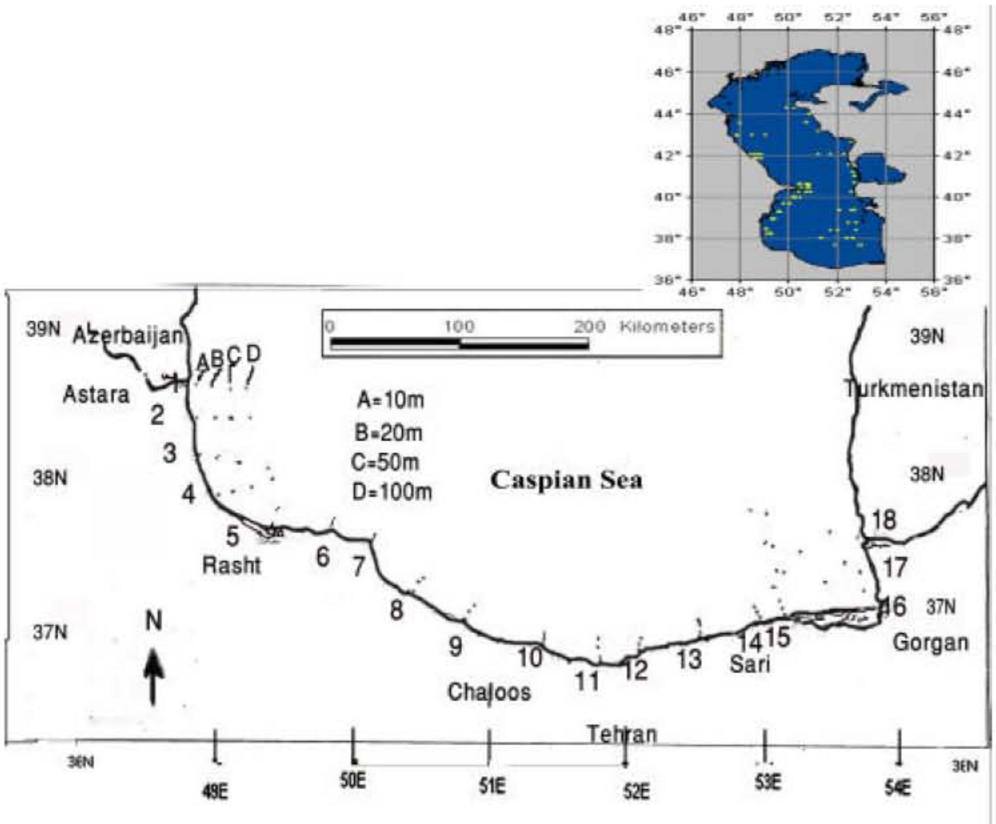

Fig. 1: Sampling transects and stations position in the southern part of Caspian Sea

RESULTS

Environmental Parameters: The seasonal average physico-chemical parameters of water body in southern part of Caspian Sea from 1994 to 2007 are showed in Table 1. Water temperature varied from 11.1°C to 25°C in winter and summer, respectively. The salinity values varied with maximum difference (0.1) during four seasons (12.1 to 12.2 ppt (part per thousand)). The pH level variation is a very narrow range difference (0.1 units) in all four seasons (Table 1). The Transparency (Secchi disk) values fluctuated between 3.2 to 5.1m in autumn and summer, respectively. The maximum and minimum concentration of dissolved oxygen is fluctuated from 8.0 to 6.3 mg/l in winter and summer, respectively. The nitrite concentration varied from 1.0 to 1.5 µg/l in summer and winter, respectively. The nitrate concentration fluctuated from 15.0 to 25.5 µg/l in summer and autumn, respectively. The total nitrogen concentration varied from 618.2 to 710.2 µg/l in spring and autumn, respectively. The organic nitrogen concentration fluctuated from 188.2 to 460.3 µg/l in summer and spring, respectively. The maximum and minimum concentration of ammonium ion is fluctuated from 22.3 to 14.6 µg/l in spring and autumn, respectively. The silicate concentration fluctuated from 197.3 to 275.1 µg/l in summer and winter, respectively. The maximum and minimum concentration of orto-phosphate is fluctuated from 16.5 to 11.7 µg/l in autumn and summer, respectively. The total phosphor concentration fluctuated from 31.9 to 36.8 µg/l in winter and autumn, respectively. The maximum and minimum concentration of organic phosphate is fluctuated from 17.2 to 14.8 µg/l in summer and winter, respectively (Table 1).

Biological Parameters: In the present study, a total of 334 Phytoplankton species which comprised of 155 (46%) Bacillariophyta, 61 (18%) Chlorophyta, 55 (16%) Cyanophyta, 30 (9%) Dinoflagellata (Pyrophyta) and 25 (7%) Euglenophyta, 4 (1%) Chrysophyta, 3 Xanthophyta and 1 Cryptophyta were identified (Table 2). The numbers of Phytoplankton species recorded in spring, summer, autumn and winter were 216, 241, 211 and 199, respectively. The most species diversity was observed in summer season with 241 species are shown in Table 2.

Table 1: The average physicochemical parameters seasonally data from 1994 to 2007 in the southern part of Caspian Sea

Seasons	Transparency (m)	Dissolved Oxygen (mg/l)	Salinity (ppt)	Water temp. (°C)	pH	NO_2^- (µg/l)	NO_3^- (µg/l)
Winter	3.9 ±3.3	8.0±1.6	12.1±0.9	11.1±2.0	8.3±0.2	1.5±1.2	21.1±20.6
Spring	4.6±6.3	7.6±1.4	12.1±0.7	16.6±5.4	8.3±0.1	1.4±1.2	19.6±20.6
Summer	5.1±4.33	6.3±1.6	12.2±0.8	25.0±6.8	8.3±0.2	1.0±0.9	15.0±19.1
Autumn	3.2±3.4	7.5±1.6	12.2±0.6	17.2±4.6	8.3±0.2	1.2±1.0	25.5±42.6

Seasons	T- Nitrogen (µg/l)	Org.- Nitrogen (µg/l)	NH_4^+ (µg/l)	SiO_2 (µg/l)	PO_4^{3-} (µg/l)	T- Phosphate (µg/l)	Org. phosphate (µg/l)
Winter	651.4±335.1	253.6±298.2	15.9±18.2	275.1±165.7	13.8±9.7	31.9±15.5	14.8±14.7
Spring	618.2±335.1	460.3±342.6	22.3±32.4	228.3±177.8	12.5±9.4	32.4±20.8	16.2±21.3
Summer	657.2±377.6	188.2±294.8	19.6±29.6	197.3±144.9	11.7±6.2	34.1±16.8	17.2±15.4
Autumn	710.2±357.9	388.7±326.9	14.6±16.5	270.9±184.5	16.5±12.9	36.8±20.3	16.6±21.9

Table 2: Seasonal of Phytoplankton species richness in the southern Caspian Sea in 1994-2007

Division	Spring	Summer	Autumn	Winter	Total
Bacillariophyta	97	105	100	111	155
Chlorophyta	46	44	39	28	61
Cyanophyta	31	40	32	23	55
Pyrrophyta	25	25	24	24	30
Euglenophyta	13	23	14	9	25
Chrysophyta	2	1	2	1	4
Xanthophyta	1	2	1	2	3
Cryptophyta	1	1	-	1	1
Total	216	241	211	199	334

Winter: The seasonal mean of total Phytoplankton cell abundance and biomass were $54.08 \times 10^6 \pm 4.60 \times 10^6$ cells/m^3 and 220.08 ± 19.60 mg/m^3 in winter, respectively (Figure 2). Annual fluctuation in winter showed that total Phytoplankton cell abundance and biomass varied in various years (Figure 3). For example, *Sceletonema costatum* and *Exuviella cordata* were most dominant species based on their cell abundance in 1999-2000 while *Exuviella cordata* and *Rhizosolenia fragilissima* dominated in 2001-2002 and *Binuclearia lauterbornii* and *Nitzschia seriata* in 2005-2006. *Rhizosolenia fragilissima* in 2001-2002 *Exuviella cordata* and *Rhizosolenia fragilissima* in 2005-2006 as dominant species consisted the highest biomass (Table 3). In winter, the dominant groups were *Bacillariophyta, Pyrrophyta* and total of Phytoplankton cell abundance represented the greatest one between other seasons (Figure 4a). While biomass efficiency in summer is lower one between other seasons (Figure 4b). The maximum, minimum and mean amounts of Transparency (Secchi disk) values during seven periods of winter were 6.1 (1996-7), 1.9 (1999-2000) and 3.9m, respectively.

Spring: The total cell abundance and biomass of the mean Phytoplankton were $33 \times 10^6 \pm 2.13 \times 10^6$ cells/m^3 and 217.82 ± 18.36 mg/m^3, respectively (Figure 2). The most cell abundance was observed due to the species of *Scytonema hofmanni* in 1994-1996, whereas the most biomass was *Anabaena spirodes* in 2004-2005 (Figure 3, Table 3). As regards of quantity *Bacillariophyta* and *Pyrophyta* biomass prevail in springtime (Figure 4b), while replacement of *Pyrophyta* cell abundance occurs in the spring and other groups were met in small quantities (Figure 4a).

Summer: The cell total abundance and biomass of Phytoplankton mean were $15 \times 10^6 \pm 1.09 \times 10^6$ cells/m^3 and 305.67 ± 17.82 mg/m^3 in summer, respectively (Figure 2) During the summer season the dominant groups were *Bacillariophyta* and *Cyanophyta* The most biomass was due to the major species *Rhizosolenia calcaravis* and *Nostoc linckia* in 1994-1996, while it was *Rhizosolenia calcaravis* and *Gyrosigma attenuatum* in 1996-1997 and *Rhizosolenia calcaravis* in 1999-2000 (Figure 3, Table 3). The highest biomass of Phytoplankton occurs in summer time due to *Bacillariophyta* (Figure 4b), while the maximum development of *Cyanophyta* cell abundance was noted in the summer season (Figure 4a).

Autumn: The seasonal mean of total Phytoplankton cell abundance and biomass were $42.81 \times 10^6 \pm 3.81 \times 10^6$ cells/m^3 and 244.97 ± 11.16 mg/m^3, respectively

Table 3: Seasonal succession of Phytoplankton in different years in the southern part of Caspian Sea (1994 – 2007)

	Years							
Species	1994-1996	1996-1997	1999-2000	2001-2002	2003-2004	2004-2005	2005-2006	2006-2007
Rhizosolenia calcaravis	w, sp, su, au	w, su, au	w, su, au	au	sp	-	-	-
Thalassionema nitzschiodes	w, sp, su, au	w, au	au	-	au	au	-	au
Skeletonema costatum	w	-	w	-	-	-	-	-
Skeletonema subsalsum	-	w, su	-	-	au	-	-	w
Rhizosolenia fragilissima	-	-	-	w	w, su	-	w	sp
Chaetoceros sp	-	-	-	-	W	-	-	-
Pleurosigma angulatum	-	-	-	-	W	-	-	-
Nitzschia sp3	-	-	-	-	-	w	-	-
Chaetoceros mulerii	-	-	-	-	-	w	w	w
Nitzschia seriata	-	-	-	-	-	-	-	sp
Coscinodiscus jonesianus	-	-	sp	-	-	-	-	-
Cyclotella menenghiniana	-	sp	-	-	-	sp	-	-
Coscinodiscus jonesianus	-	-	-	-	sp	-	-	su
Navicula sp1	-	-	-	-	sp	-	-	-
Melosira varians	-	-	-	-	-	sp	-	-
Nitzschia sublinearis	-	-	-	-	-	sp	-	-
Gyrosigma attenuatum	-	-	-	-	-	sp	-	-
Nitzschia distans	-	su	-	-	-	-	-	-
Nitzschia sigmoidea	-	-	-	-	-	-	su	-
Coscinodiscus gigas	-	au	-	-	-	-	-	-
Pleurosigma elongatum	-	-	-	-	-	-	-	au
Pleurosigma angulatum	au	-	-	-	-	-	-	-
Exuviella cordata	w, sp	sp	w, sp, su	w, sp, au	sp	sp	-	-
Prorocentrum praximum	-	-	-	Sp	-	sp	-	-
Prorocentrum micans	-	-	-	-	-	su	-	-
Prorocentrum obtusum	-	-	-	-	-	-	au	-
Exuviella marina	-	-	-	-	-	-	au	-
Oscilatoria geminata	w	-	-	au	-	-	-	-
Aphanothece elabens	w, sp, su	-	-	-	-		au	-
Microcystis aeruginosa		-	-	-	-	w	-	-
Anabaena spirodes	Sp	-	-	-	-	-	-	-
Scytonema hofmanni	Sp	-	-	-	-	-	-	-
Nostoc linckia	Su	-	-	-		-	-	su
Oscillatoria sp	-	-	-	su	-	su	-	su
Oscillatoria limosa	-	-	-	-	-	-	su	su
Spirulina laxissma	-	-	-	-	-	au	-	
Chlorella sp	-	-	-	-	-	w	-	
Binuclearia lauterbornii		su	-	-	su	-	`w	-
Scenedesmus armatus	-	-	-	su	-	-	-	-
Cryptonema marconi	-	-	-	-	-	su	-	-

Note: w = Winter, sp = Spring, su = Summer, au =Autumn

(Figure 2). During the autumn, the dominant groups were *Bacillariophyta* and *Cyanophyta*. The most cell abundance was observed because of the major species *Thalassionema nitzschiodes* in 2003-2004 and *Spirulina laxissma* in 2004-2005 (Figure 3, Table 3). In the autumn there was an increase in the cell abundance of *Bacillariophyta* and *Cyanophyta* (Figure 4a) and maximum biomass was observed of *Bacillariophyta* (Figure 4b).

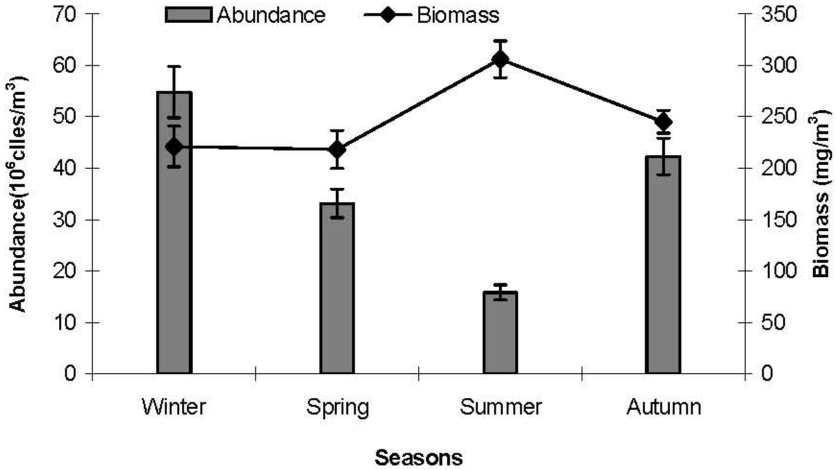

Fig. 2: Seasonal variation in total of Phytoplankton cell abundance (10^6 cells/m^3) and biomass (mg/m^3) in the southern part of Caspian Sea (1994-2007)

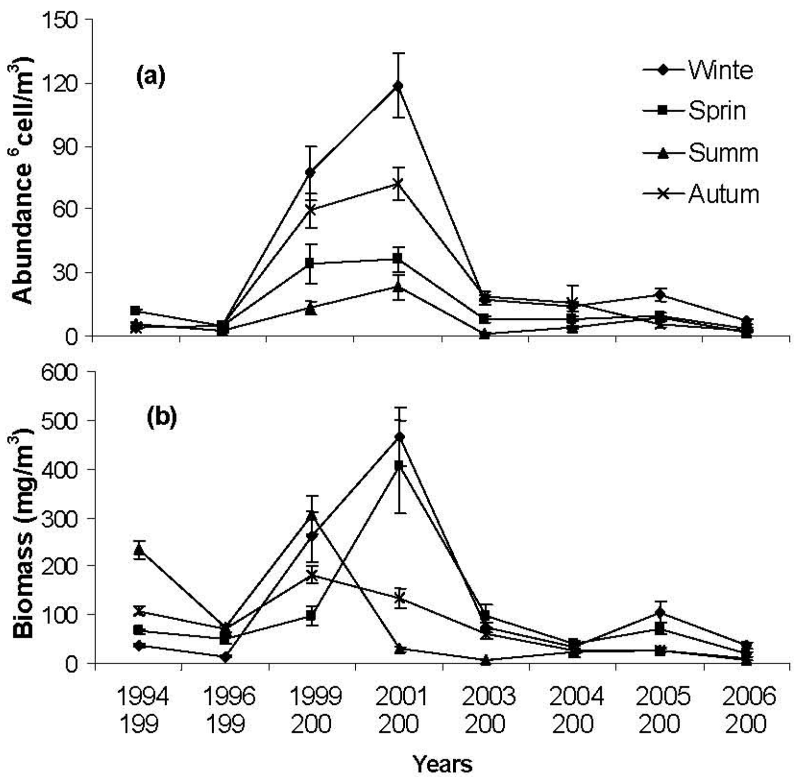

Fig. 3: Seasonal variation in total of phytoplankton (a) cell abundance (10^6cells/m^3) and (b) biomass (mg/m^3) in the southern part of Caspian Sea during 1994-2007

In general, the overall average cell abundance and biomass of Phytoplankton were $13.87\times10^6 \pm 5.96\times10^5$ cells/m^3 and 256.7 ± 42.7 mg/m^3, respectively. The most cell abundance of Phytoplankton was observed in 2001-2002 while the high density was noticed due to *Bacillariophyta* and *Pyrophyta* in winter (Figures 2, 3a). The most biomass of Phytoplankton was observed in summer while diatoms represented the most abundant biomass and *Cyanophyta* reached highest in summer (Figures 2, 3b). Diatoms and *Pyrophyta* dominated in the growing Phytoplankton community in this period (Figure 4).

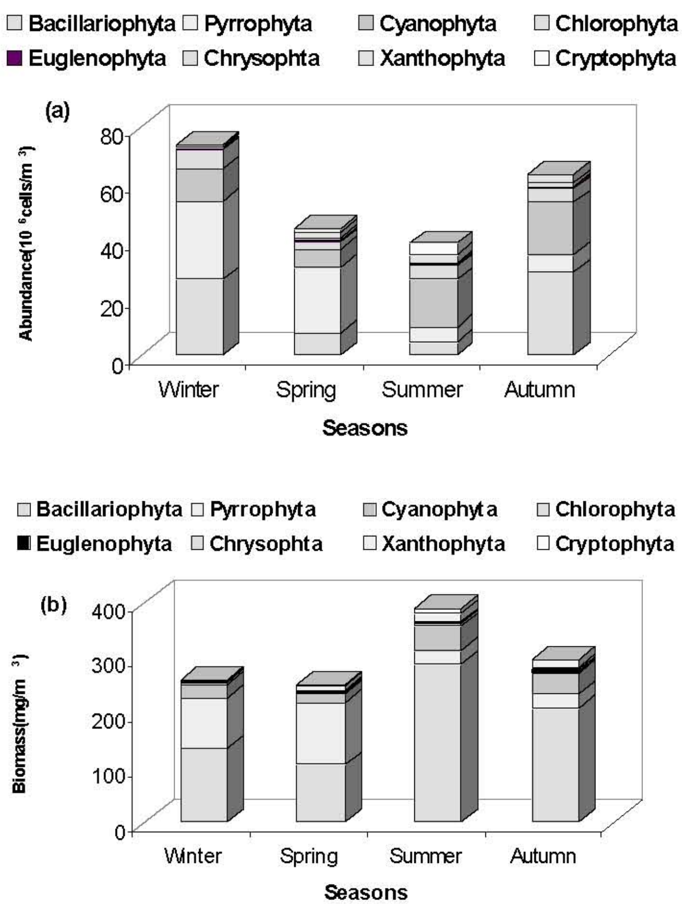

Fig. 4: The mean seasonal variation of Phytoplankton taxonomic structure (a) cell abundance (10^6cells/m^3) and (b) biomass (mg/m^3) during 1994-2007 in the southern part of Caspian Sea

The most cell abundance of *Bacillariophyta* was observed in autumn and winter but lowest in the spring and summer with the maximum biomass in summer and autumn, respectively and lowest in winter and spring. *Pyrophyta* reached a maximum density and biomass in winter and spring and decline in autumn and summer. In the late summer and early autumn the most cell abundance and biomass of *Cyanophyta* was high and from winter to spring was reduced. Other groups density and biomass in different seasons and years, the lowest and have less importance (Figure 4). Seasonal successions of Phytoplankton in different years in the southern part of Caspian Sea indicated in Table 3.

DISCUSSION

The main Phytoplankton groups in the Caspian Sea consist of diatoms, *Pyrrophyta* and *Cyanophyta* [15-17]. There are very few studies available on Phytoplankton biodiversity of the Caspian Sea [18].

Since ecological and biological parameters are responsible for the blooming of diatoms species and their most abundant and widespread group throughout the southern part of Caspian Sea [15, 16, 19].

A study showed [20] that, the maximum diatoms and *Pyrophyta* biomass in Beatrix Bay appeared between 1994 and 2002. Diatoms dominated the Phytoplankton biomass, with the exceptions being occasional *Pyrophyta* blooms during summer months. And, in 2001 – 2003 the Phytoplankton community in the Western Australia Ocean was characterized by a relatively low diversity of taxonomical structures and a predomination of heterotrophic *Dinophyceae* species during most part of the year [21].

Numbers of studies [15, 16] are reported that in Iranian coast of Caspian Sea between 1994 and 1996 and found that the maximum cell abundance of diatoms was observed in autumn. A survey [15] noted that the maximum cell abundance of diatoms was observed in winter and autumn dominated by small-sized diatoms

Thalassionema nitzschoides and *Cyclotella meneghiniana*) while, the maximum biomass was observed in summer with large- sized diatoms *Rhizosolenia calcar-avis* and *Rhizosolenia fragilissima* predominant.

In addition to the marked changes in abundance observed in the Phytoplankton over the course of a year, there is also a marked change in species composition. This change in the dominant species from season to season is called *seasonal succession*. Under seasonal succession, one or more species of diatom, dinoflagellate, dominate the plankton for a shorter or longer period of time and then are replaced by another set of species. This pattern is replaced by yearly [22]. Caspian Phytoplankton consists of representatives of thermophilic, warm-requiring, moderate-thermophilic and moderate cold-requiring, species. In the summer the temperature on all water surface of the SCS changes 23 up to 30°C and goes down to 6-9°C in an open seapart an to 2-4°C in a coastal shallow zone in the winter. Thus water temperature in the SCS is unequal in the various parts and it plays an important role in seasonal changes oh Phytoplankton [23].

The results of this study indicate the main Phytoplankton biodiversity was found to be *Bacillariophyta* with more than 155 species and contribution 46% of the Phytoplankton community structure. This group was more diversified in winter and summer with 111 and 105 species, respectively. The highest number of Phytoplankton species was recorded in summer with 241 species (Table 2). *Bacillariophyta, Chlorophyta* and *Cyanophyta* were more abundant in this season. It seems that the thermophilic Phytoplankton species in summer survive in a high water temperature as reported in the literature [24, 25]. Phytoplankton species reported in the southern Caspian Sea during this study was also reported in the Black Sea due to nearly similar topography and some environmental factors such as climate and water temperature [19].

A few studies were reported that, the *Bacillariophyta* and *Pyrrophyta* constituted the main phyla in southern part of Caspian Sea duration of 1994-1996 and 2005 [15-17]. The surveys discovered that diatoms had the highest cell abundance and biomass, followed by *Pyrrophyta*. In this study the highest cell abundance was observed in winter dominant groups *Bacillariophyta* and *Pyrrophyta* and major species small size such as *Thalassionema nitzschiodes, Skeletonema costatum, Chaetoceros* spp and *Exuviella cordata* while the highest biomass was observed in summer due to *Bacillariophyta* (*Rhizosolenia calcaravis, Nitzschia spp*) and Cyanophyta (*Oscillatoria spp* and *Nostoc linckia*). This was due to the combined effects of physico-chemical parameters for example in winter heavy rainfall increased NO_2, SiO_2, DO and P-inorganic. In summer season increased transparency, water temperature and salinity.

Many studies in the field [26, 27] and laboratory [28] have shown that diatoms dominate Phytoplankton assemblage when the concentrations of nutrients N, P and SiO_2 remain high. When the concentration of any of these nutrients, for example, N, P or SiO_2 remains low diatoms cannot dominate Phytoplankton assemblages [29]. A study showed that, in a laboratory experiment that diatoms did not dominate the Phytoplankton assemblage when concentrations of N, P and SiO_2 were high [30].

Size is an important characteristic in determining both nutrient uptake efficiency in Phytoplankton and their susceptibility to grazing. While smaller size offers increased nutrient uptake efficiency through a greater surface area to volume ratio, smaller size may also increase susceptibility to grazing. Many diatoms form chains that can be hundred of cells in length. This may help prevent grazing without sacrificing nutrient uptake ability [20]. The typical dominance of small-size Phytoplankton in the Levantine Basin has been reported even during the annual Phytoplankton bloom [30, 31].

A quite typical pattern of seasonal variation of Phytoplankton in 1991-1993 was reported [33] that, a maximum abundance of Phytoplankton was always observed at the end of winter, when the ice and snow cover attained its maximum thickness. Another survey shown [34] noted that one of the reasons for the diatoms prevalence was due to cold waters. Hereby, this study also emphasis that the overall Phytoplankton means were consisted of diatoms which formed (47%) of total cell abundance. The long term taxonomic structure of Phytoplankton biomass and cell abundance shows a likely shift from a diatom dominant system (constituting 59% biomass and 27% cell abundance of total of Phytoplankton) to an apparent dominance of opportunistic Pyrrophyta (45% biomass and 52% cell abundance) in spring.

Numerous changes in the biodiversity of organisms have been observed in the Caspian Sea following the invasion of the ctenophore *Mnemiopsis leidyi* [35, 36]. A decrease in total zooplankton abundance and an increase in total Phytoplankton abundance were among the most obvious changes recorded after the introduction of *M. leidyi* [37]. Certainly other factors such as overfishing, climate change and anthropogenic pollution might also have played a role in the variations of the Caspian Sea ecosystem, in addition to the impact of *M. leidyi* [36].

There were also changes in the highest seasonal means of Phytoplankton cell abundance and biomass. While the maximum Phytoplankton cell abundance and biomass were recorded in spring and summer during 1994-1997 respectively, after the invasion of *M. leidyi* shifted to a winter – autumn period and biomass shifted to winter-spring during 1999-2007 (Figures 3 and 4). Dominant Phytoplankton groups changed from diatoms to dinoflagellates and cyanophytes when *M. leidyi* abundance was at a maximum level during summer-autumn of 2001-2002 in the southern Caspian Sea [37]. In the present study the highest cell abundance and biomass were observed in 1999- 2000 and 2001-2002 due to *Pyrrophyta, Cyanophyta* and *Bacillariophyta*, respectively.

ACKNOWLEDGEMENT

Authors acknowledge Iranian Fisheries Research Organization (IFRO) and Caspian Sea Research Institute of Ecology for their technical and financial support and ecology department colleagues. Special thanks go to the crews of research Vessel (Guilan) trough Phytoplankton physico-chemical sampling. Additional thanks are devoted to Dr. Yousefiyan, Dr. Farabi and Mahdavi for their kind contributions.

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