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Primary Research Paper

Phytoplankton distribution in the Caspian Sea during March 2001

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Abstract

Phytoplankton abundance, biomass and species composition of the Caspian Sea were evaluated by using samples collected from the Iranian (southern Caspian Sea) and southern Kazakhstan (eastern Caspian Sea) surface waters in March 2001. A total of 45 taxa were found in the samples (20 diatoms, 17 dinoflagellates and 8 others). Abundance and biomass of diatoms were high at the eastern stations, while dinoflagellates were dominant in terms of both biomass and abundance in the southern region. Average abundance and biomass were 40 000 $\pm$ 35 000 cell l^{-1} and 580 $\pm$ 690 $\mu g\ l^{-1}$. The mean biomass value found here for the Middle and southern Caspian Sea in March are difficult to compare with the past due to limited information, but seems higher than previously registered values. Higher chlorophyll values were also apparent from the SeaWIFS images in 2001 compared to those in 1998. This is suggested to be due to decreased grazing of phytoplankton by zooplankton which is voraciously preyed by the recent invasive ctenophore *Mnemiopsis leidyi*.

Introduction

The Caspian Sea with a surface area of about 400 000 km^2 is the largest inland water body on earth. It is located at the far end of southeastern Europe, bordering Asia (Kosarev & Yablonskaya, 1994). The total depth of this large water body increases from north to south. While the maximum depth of the northern Caspian Sea is 20 m, it is 788 m in the central region and reaches 1025 m in the southern area. The salinity of the Caspian Sea ranges from 3 to 13‰ from north to south. The low salinity in the northern part is due to significant river inflows. The Volga River here supplies 82% of the annual riverine input to the Caspian Sea (Sur et al., 2000).

In the past, inorganic nutrient levels have been reported as low in the Caspian Sea even in the north, where the Volga River supplied considerable amounts of nutrients. The Volga Delta is largely covered by macrophytes and up to 70% of dissolved inorganic phosphorus and 50% of dissolved inorganic nitrogen is temporally stored here. This can explain low inorganic but high organic nutrient concentrations in the northern Caspian Sea. Nitrates range from 0.5 to 10 μM, phosphates from 0.12 to 0.8 μM and silicates from 20 to 60 μM in the northern Caspian Sea (Dumont, 1998).

There are more brackish and freshwater forms of phytoplankton than marine species in the Caspian Sea. The species richness of this enclosed sea is lower than in other open seas. In the north, fresh and brackish water species dominate while in the Middle and southern Caspian, euryhaline, marine and brackish forms are generally dominant in abundance (EXXON, 2001).

The total number of phytoplankton species found during 1962–1974 was 449 (Kosarev & Yablonskaya, 1994). These species consists of 163 diatoms, 139 chlorophytes, 102 cyanophytes, 39 dinoflagellates, 5 euglenophytes and 1 chrysophyte. In addition, the species number of phytoplankton 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.

The Caspian Sea is famous with its rich resources; such as oil, natural gas, fish and particularly caviar-producing sturgeons. 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, 1995). Recently, 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 (S. Bagheri & A. E. Kideys, unpublished data), pelagic fish stocks and other higher components of the ecosystem (Shiganova et al., 2001; Kideys, 2002; Kideys et al., 2004).

Since major changes in an ecosystem can affect all the trophic levels in the food chain, these ecological and environmental alterations can also be important at the phytoplankton level. There are very few studies available on phytoplankton of the Caspian Sea (Kosarev & Yablonskaya, 1994; CEP, 2000). There may be changes in the phytoplankton species number, abundance and biomass related with high levels in the biomass of the ctenophore *Mnemiopsis leidyi* (Kideys & Moghim, 2003) observed in last years. 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. This study is therefore important for presenting data on phytoplankton of the Caspian Sea from recent years.

Methods

Phytoplankton samples were taken from surface waters (at 15 stations) along the southern (i.e. Iranian) and eastern (i.e. Kazakhstan) coasts during 16–29 March 2001 (Fig. 1). The temperature and salinity of the water column at the stations were measured using a CTD probe. Phytoplankton samples were held in 0.5 l dark bottles and preserved using buffered formaldehyde to obtain a final concentration of 2.5%. Samples were concentrated to ~20 ml by the sedimentation method after keeping the samples stagnant for at least 2 weeks. The microphytoplankton present in a subsample of 1 ml taken from the ~20 ml sample were counted using a Sedgewick–Rafter cell under a phase contrast binocular microscope. For nanoplankton analysis, 0.01 ml subsamples were scanned using a slide. Minimum 200 cells were counted under microscope for each sample (Socal et al., 1999). The volume of each cell was calculated by measuring its appropriate morphometric characteristics (i.e. diameter, length and width) (Senichkina, 1986; Hillebrand et al., 1999). Volume values were converted to biomass assuming 1 μm^3 to be equal to 1 pg. Phytoplankton settling, counting and taxonomic classification methods were similar to previous studies (Morosova-Vodanidskaya, 1954; Kiselev, 1956; Eker et al., 1999; Kasimov, 2000).

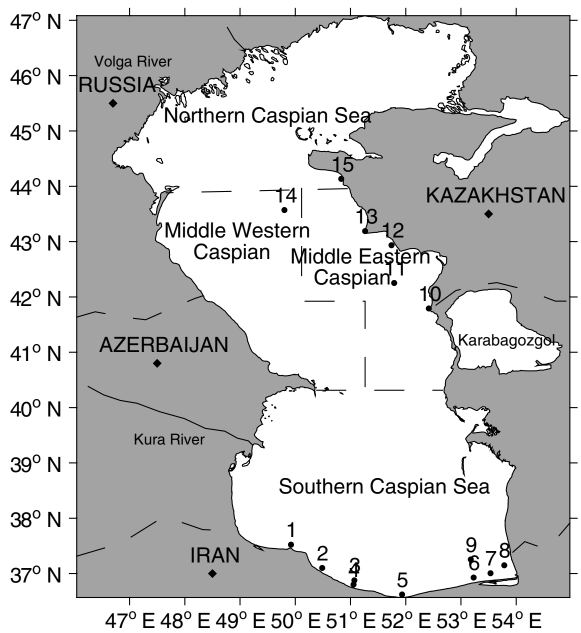

Figure 1. Sampling stations in the Caspian Sea during March 2001.

The satellite products used in this study were obtained after calibration and atmospheric correction of the SeaWiFS top-of-atmosphere measurements by the scheme described by Sturm & Zibordi (2002). Updates to the model and a validation study were presented by Mélin et al. (2003). The concentration of chlorophyll a was computed from the remote sensing reflectance spectra with the standard algorithm OC4v4 (O'Reilly et al., 2000). SeaWiFS scenes (full resolution Local Area Coverage images and sub-sampled Global Area Coverage images) covering the Caspian Sea have been processed for the study period (March of 1998 and 2001) mapped with a nearest neighbor technique on a 2-km resolution regular grid, as explained in Mélin et al. (2002). Comparison of chlorophyll-*a* values from SeaWIFS during March 1998 and 2001 (before and during *Mnemiopsis leidyi* impact, respectively) was done for different subregions based on average values of daily images (see Table 2). Subsequently, the mapped images were combined in time to yield monthly maps of geophysical products for the domain (so-called Level-3).

Results

In this study the surface temperature was found to be lower in the eastern Caspian than in the south. It gradually increased from 8 °C along the Kazakhistan waters in the eastern Caspian to 12 °C in the Iranian waters in the southern Caspian (Fig. 2a). However salinity was similar between these two regions being around at 12.5% (Fig. 2b).

In the present study, a total of 45 phytoplankton species (20 diatoms, 17 dinoflagellates and 8 others; Table 1) were present in the samples from which 37 were identified to species level. Species composition was also quite dissimilar between the eastern and southern Caspian Sea; among 45 species, only 21 taxa were found co-occurring in these regions (Table 1).

In this study, the overall average abundance and biomass of phytoplankton were 40 000 ± 35 000 cell l^{-1} and 580 ± 690 $\mu g\ l^{-1}$, respectively (Fig. 3a, b). When overall means were regarded, dinoflagellates formed almost half the total abundance (47%). The dinoflagellates *Prorocentrum compressum, Prorocentrum cordatum* and *Prorocentrum scutellum* were the species having the highest overall abundance among all phytoplankton. Their overall mean abundances were 8000, 5000 and 3000 cells l^{-1}, respectively. Despite their relatively lower abundance (30% of total), diatoms accounted for the bulk of total biomass (70%) in our study (Fig. 3a, b). Their high contribution to the total biomass of 580 $\mu g\ l^{-1}$ was due to the dominance of the diatom *Pseudosolenia calcar-avis* that made up 65.5% of total. *Cerataulina pelagica* was the species displaying the highest overall mean abundance (about 4000 cells l^{-1}) among diatoms.

Diatoms were dominant in the colder waters of the east while dinoflagellates were prevalent in the

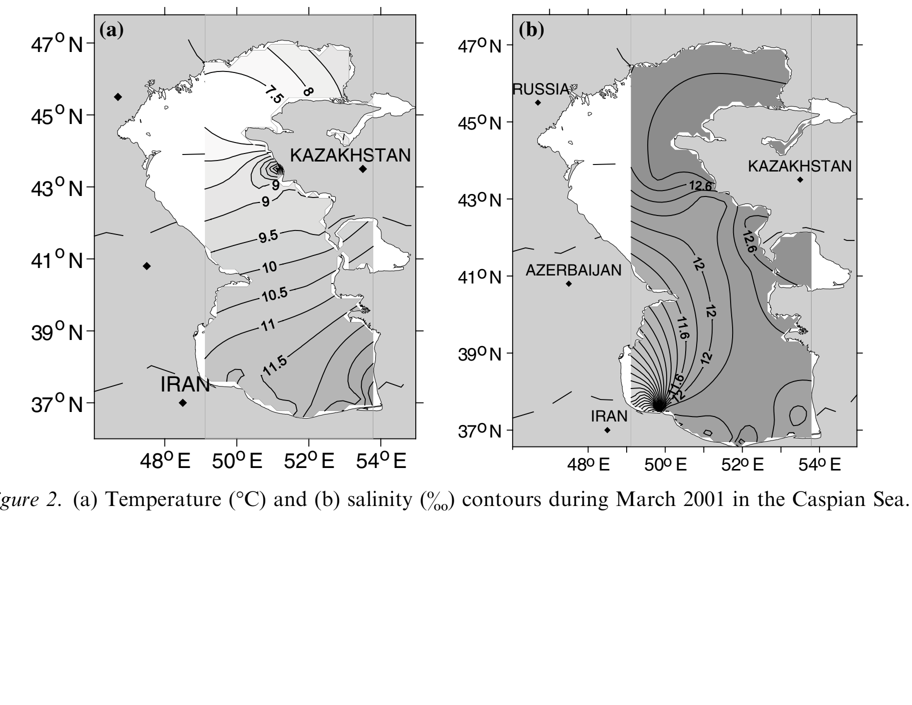

Figure 2. (a) Temperature (°C) and (b) salinity (‰) contours during March 2001 in the Caspian Sea.

Table 1. Species identified in the eastern and southern Caspian Sea in March 2001. Occurence of each species in the Black Sea is also shown

Dinoflagellates	Black Sea	Southern Caspian	Eastern Caspian	Diatoms	Black Sea	Southern Caspian	Eastern Caspian
Amphidinium cf. rhynchocephalum Anissimowa	–?	+	–	*Chaetoceros affinis* Lauder	+	+	+
Prorocentrum compressum (Bail.) Abé ex Dodge	+	+	–	*Amphora hyalina* Kützing	+	+	–
Prorocentrum cordatum (Ostenfeld) Dodge ex Dodge	+	+	+	*Cerataulina pelagica* (Cleve) Hendey	+	+	+
Glenodinium obliquum (Pouchet)	+	+	–	*Fragilaria* sp.		–	+
Glenodinium paululum Lindemann	+	+	+	*Licmophora ehrenbergii* (Kützing) Grunow	+	–	+
Oblea rotunda (Lebour) Balech ex. Sournia	+	+	–	*Paralia sulcata* (Ehrenberg) Cleve	+	+	+
Gonyaulax polygramma Stein	+	+	+	*Navicula gracilis* Ehrenberg	+	–	+
Gymnodinium fuscum (Ehrenberg) Stein	+	+	–	*Nitzschia palea* (Kützing) Smith	+	–	+
Gyrodinium pingue (Schütt) Kofoid & Swezy	+	+	+	*Pseudonitzschia seriata* Grun	+	+	+
Gyrodinium fusiforme Kofoid & Swezy	+	+	+	*Nitzschia tenuirostris* Mer.	+	–	+
Gymnodinium sanguineum Hirasaka	+	+	+	*Pleurosigma rigidum* Smith	+	–	+
Gymnodinium najadeum Schiller	+	–	–	*Pseudosolenia calcar-avis* (Schultze) Sundström	+	+	+
Gymnodinium wulffii Schiller	+	+	–	*Skeletonema costatum* (Greville) Cleve	+	+	+
Peridinium minusculum Pavillard	+	+	–	*Striatella delicatula* Kützing	+	–	+
Scripsiella trochoidea (Stein) Loeblich	+	+	–	*Synedra* sp.	+	–	+
Prorocentrum micans Ehrenberg	+	+	–	*Synedra tabulata* (Ag.) Kützing	+	–	+
Prorocentrum scutellum Schiller	+	+	+	*Thalassionema nitzschioides* (Grunow) Mereschkowsky	+	+	+
Small flagellates	+	+	+	*Thalassiosira eccentrica* (Ehrenberg) Cleve	+	+	+
Coccolithophores				*Thalassiosira parva* Pr-Lavr.	+	+	–
Coccolithus sp.	+	+	+	*Thalassiosira* sp.	+	+	–
*Emiliania huxleyi*Lochmann	+	+	+	Cyanophytes			
Chlorophytes				*Anabaena* sp.	+	+	+
Halosphera viridis Schmitz	+	+	+	*Oscillatoria* sp.	+	+	–
Spirogyra sp.	+	+	+	Silicoflagellates			
Ulothrix sp.	–?	–	+	*Ebria tripartita*			
	+	+	+	(Schumann) Lemmmermann	+	–	+

warmer southern Caspian Sea in term of both abundance and biomass (Figs. 4a–d and 5a, b). Related with the difference of phytoplankton groups, big-sized diatom species dominated in the eastern Caspian Sea (*Pseudosolenia calar-avis*, *Cerataulina pelagica*, *Thalassionema nitzschioides*) and small-sized dinoflagellate species (*Prorocentrum cordatum*) were abundant in the southern

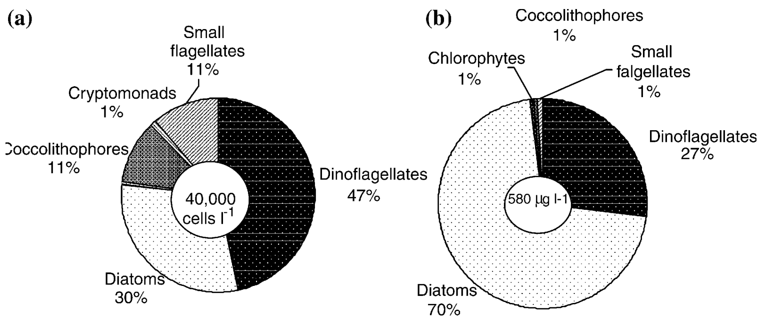

Figure 3. Contribution of different phytoplankton groups to the mean (a) abundance and (b) biomass in the Caspian Sea in March 2001.

Caspian Sea. The average biomasses of cells in the southern and eastern Caspian Sea were 10.6 (SD 6.2) and 37.9 (SD 47.3) ng, respectively.

According to SeaWIFS images in March of 1998 and 2001, the chlorophyll-*a* (Chl-*a*) concentration ranged from ~0.01 to ~20 μg l^{-1}, the major primary production region being primarily the northern Caspian which receive the major riverine inflow due to the Volga and Ural rivers (Fig. 6). Chl-*a* concentrations were also high along the entire coastal strip (except the eastern Caspian), but lower in the offshore regions (around 1 μg l^{-1}). The chl-*a* values from all regions increased significantly ($p < 0.05$, Single Factor ANOVA) in March 2001 compared to 1998 (Table 2). Whilst the average value for the entire

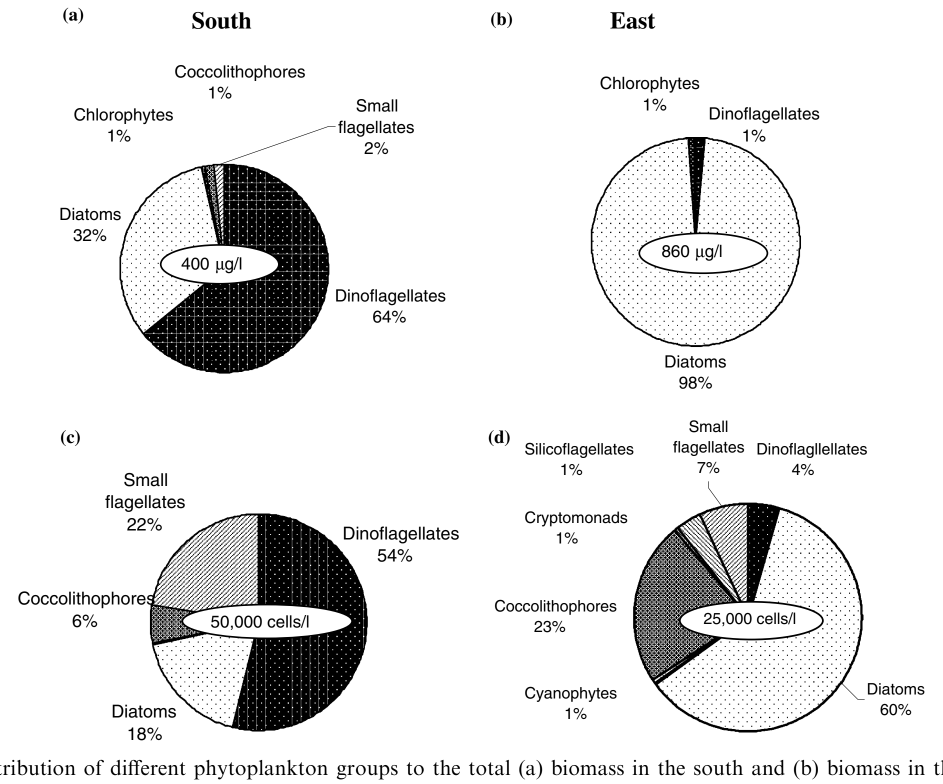

Figure 4. Contribution of different phytoplankton groups to the total (a) biomass in the south and (b) biomass in the east and (c) abundance in the south (d) abundance in the east of the Caspian Sea (the groups having very low contribution to the total were not shown).

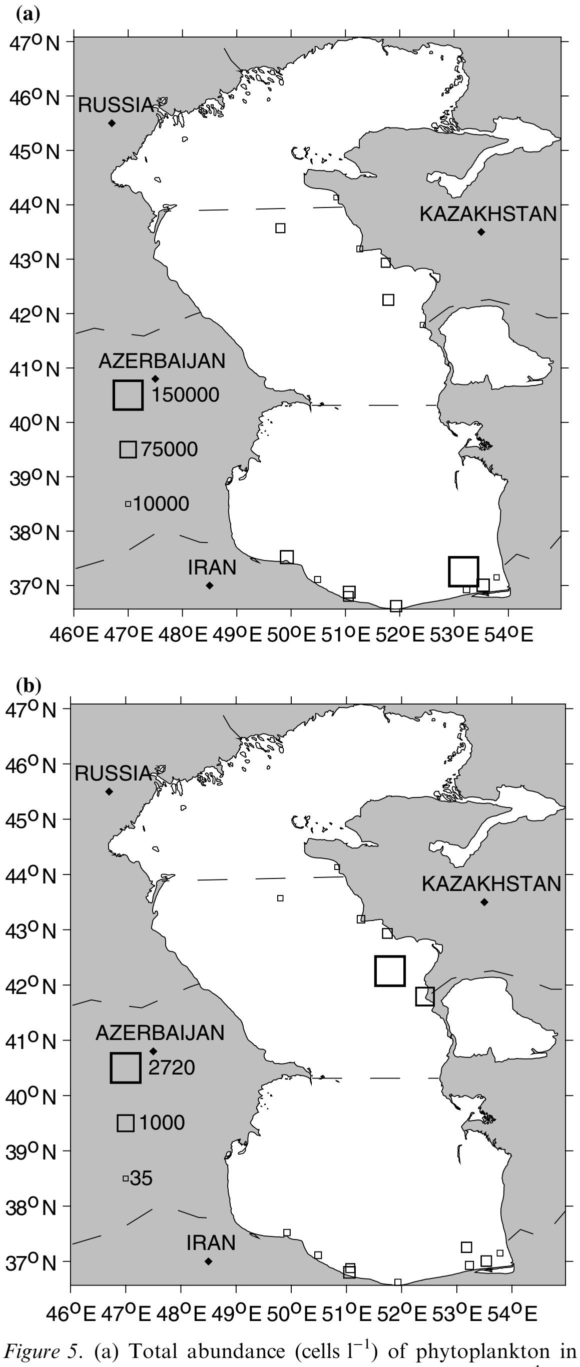

Figure 5. (a) Total abundance (cells l^{-1}) of phytoplankton in the Caspian Sea in March 2001 (b) Total biomass (μg^{-1}) of phytoplankton in the Caspian sea in March 2001.

Caspian was 1.63 ± 1.35 μg l^{-1} in 1998, it was measured as 2.62 ± 1.55 μg l^{-1} in 2001. The differences between years were even higher for Middle and southern Caspian (Table 2). It was striking that high chl-*a* concentrations extended to offshore regions in March 2001 (Fig. 6).

Discussion

The salinity does not usually vary much between the surface waters of the eastern and southern Caspian Sea ranging around 12.5–13.4‰ during the course of the year (Kosarev & Yablonskaya, 1994). Vertical changes in salinity are also minimal (0.1–0.2‰). However, the average annual temperature difference between these two regions for the surface waters would be higher throughout the year. In April, the surface temperature ranges from 9 to 10 °C in the eastern Caspian while it changes between 11 and 14 °C in the South Caspian Sea (Kosarev & Yablonskaya, 1994). In the present study the surface temperatures gradually increased from 8 °C along the Kazakhistan waters in the eastern Caspian to 12 °C in the Iranian waters in the southern Caspian. Therefore the eastern Caspian coasts sampled in our study were a few degrees cooler than the southern coasts, as was expected.

Twenty diatom, 17 dinoflagellate and 8 other phytoplankton species (Table 1) were present in the samples. Despite the fact that the main phytoplankton groups are known as diatoms, chlorophytes and cyanophytes in the Caspian Sea (Kosarev & Yablonskaya, 1994), the species number (as well as abundance) of dinoflagellates was found to be relatively high in March 2001.

The species composition of phytoplankton was quite similar to those identified in the Black Sea (Table 1); almost all species encountered in the present study have already been reported for the Black Sea. This is not surprising since these two water bodies share, geologically, the same origin and are collectively termed as Ponto-Caspian (Dumont, 2000). However, the total species number is much lower than that obtained in the Black Sea (i.e. 121 species) for the similar period (i.e. March–April of 1995, Eker et al., 1999). This is in agreement with the total species numbers reported from both seas (about 750 sp from the Black Sea – Zaitsev & Mamaev, 1997 and about 450 from the Caspian Sea, Kosarev & Yablonskaya, 1994). Yet, there was also a noticeable difference with respect to species diversity even between the eastern and southern Caspian Sea; among the total 45, only 21

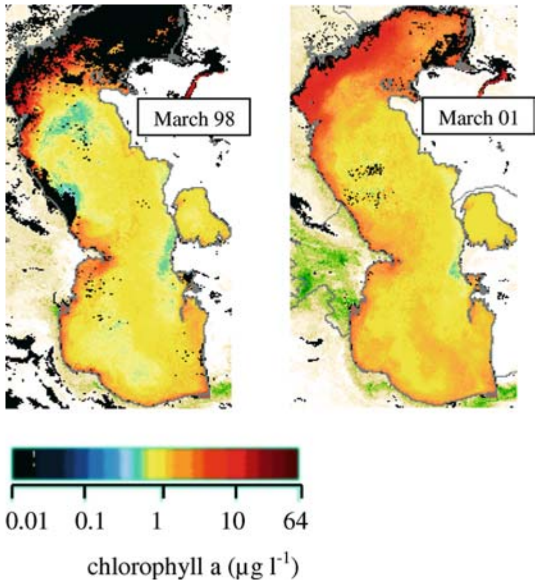

Figure 6. Average chlorophyll-*a* concentration in March of 1998 (left) and 2001 (right) from remote sensing using SeaWIFS.

species were found co-occuring in these regions (Table 1). Unfortunately, there is a lack of recent available data on the species composition of phytoplankton from the Caspian Sea to allow futher comparisons.

In general, diatom species are reported to form the most abundant and widespread group throughout the Caspian Sea (Kosarev & Yablonskaya, 1994). After diatoms, chlorophytes and cyanophytes are the abundant groups in the north (since they are chiefly fresh and brackish water forms), while, dinoflagellates (mainly *Prorocentrum cordatum*) are dominant in the Middle (including eastern) and southern Caspian Sea all year round in terms of abundance (Kosarev & Yablonskaya, 1994).

In the present study, diatoms were dominant in the east while dinoflagellates prevailed in the southern Caspian Sea both in terms of abundance and biomass (Fig. 2). The colder temperatures in the eastern Caspian (Fig. 2, as well as in August 2001 as given in Kideys & Moghim, 2003) could be one of the reasons for the diatom prevalence as this group is often reported to be dominant in colder waters. When overall means were regarded, dinoflagellates formed the majority of total abundance (47%) in the present study. In spring 1975, diatoms were the most abundant group accounting for 58–94% of the total number of algal cells in the North Caspian Sea (being closer to the Kazakhstan waters samples in our study, Kosarev and Yablonskaya, 1994). Despite their relatively lower abundance (30% of total), diatoms constituted the bulk of total biomass (70%) in our study (Fig. 3a, b).

This high contribution to the total biomass was due to dominance of large-sized exotic diatom *Pseudosolenia calcar-avis*. *Pseudosolenia calcar-avis* was first recorded in the Black Sea waters in 1926 and probably transported from there to the Caspian Sea in the 1930s (Zaitsev & Ozturk, 2001). After its introduction, it became an important species in the Caspian Sea as in the Black Sea, forming the majority of the total phytoplankton biomass in certain months similar to this study. *Prorocentrum compressum, Prorocentrum cordatum* and *Prorocentrum scutellum* were the dinoflagellate species displaying the highest overall abundance among the other groups. The dinoflagellate *Prorocentrum cordatum* is reported to be widespread in the Middle and especially southern

Table 2. Comparison of chlorophyll-*a* values from SeaWIFS between March 1998 and 2001 (before and after *Mnemiopsis leidyi*, respectively)

Area	Chl-*a* concentrations (μg l^{-1}) from Sea WIFS	
	March-1998 $\bar{X}$ ± SD	March-2001 $\bar{X}$ ± SD
All Caspian	1.63 ± 1.35	2.62 ± 1.55
North Caspian	4.01 ± 2.90	4.32 ± 2.55
Middle Caspian	1.31 ± 0.67	2.54 ± 1.12
Middle east	1.19 ± 0.45	2.26 ± 0.88
Middle west	1.41 ± 0.63	2.93 ± 1.15
South Caspian	1.41 ± 0.71	2.09 ± 0.79

Caspian Sea throughout the year, with a little seasonal change in its abundance (Kosarev & Yablonskaya, 1994).

It should be noted that lower biomass, but higher abundance values in the southern Caspian Sea, indicate the dominance of the smaller sized phytoplankton in this region which is reverse for the eastern Caspian Sea (Fig. 5a, b).

In this study, the overall average abundance and biomass of phytoplankton were 40 000 ± 35 000 cell l^{-1} and 580 ± 690 $\mu g\ l^{-1}$, respectively (Fig. 3a, b). It is very difficult to compare our values with those available from the literature, as there is insufficient and contradictory data particularly from the southern Caspian Sea. It should be noted that most phytoplankton studies in the Caspian Sea were concentrated in the fertile waters of the north which were not sampled in our study. In the northern Caspian Sea, phytoplankton biomass is reported to be generally higher (e.g. ranging from 850 to 2110 $\mu g\ l^{-1}$ in spring during 1936–1978). One other unknown for the Middle and southern Caspian is the seasonality in phytoplankton parameters (i.e. chl or biomass). All these make any long-term evaluation extremely difficult. Based on chlorophyll or phytoplankton biomass, perhaps we could speak, only by proxy, about any possible long-term changes in the Middle or southern Caspian. For example, phytoplankton biomass in the Middle (including the eastern) Caspian Sea was lowest (13 $\mu g\ l^{-1}$) in winter compared to summer (422 $\mu g\ l^{-1}$) and autumn (741 $\mu g\ l^{-1}$) between 1975 and 1976 (CEP, 2000). Similarly, in the southern Caspian Sea the biomass increased from 155 $\mu g\ l^{-1}$ in winter to 929 $\mu g\ l^{-1}$ in summer (CEP, 2000). Contrary, chl-*a* concentrations in winter (2.29 $\mu g\ l^{-1}$) was higher than in spring (0.87 $\mu g\ l^{-1}$) and summer (1.08 $\mu g\ l^{-1}$), only being lower than autumn values (3.17 $\mu g\ l^{-1}$) in 1976 for the Middle eastern Caspian (Kosarev & Yablonskaya 1994). Similarly, spring chl-*a* values were reported to be either higher or lower than summer values in the Middle Caspian.

Summer phytoplankton biomass in the Middle Caspian Sea changed between 164 and 849 $\mu g\ l^{-1}$ while it ranged from 133 to 175 $\mu g\ l^{-1}$ in the southern Caspian Sea during 1934–1976 (Kosarev & Yablonskaya, 1994). The value of 400 $\mu g\ l^{-1}$ found here (in March) for the southern Caspian Sea therefore is notably higher than the summer 1934–1976 value. Our mean value from the entire sampling area (580 ± 690 $\mu g\ l^{-1}$) is also higher than the mean biomass obtained in the southern Black Sea for the same month (170 ± 91 $\mu g\ l^{-1}$; Eker et al., 1999; Eker-Develi & Kideys, 2003).

The increase in phytoplankton biomass (particularly as revealed by chl values from satellite data, Fig. 6) could be due to both eutrophication and the invasive ctenophore *Mnemiopsis leidyi*. After comparing data between 1934 and 1983, Kosarev & Yablonskaya (1994) could not see an apparent increase in nutrient concentrations along the water column over the years. Although some increase in nutrient input after 1983 is possible, the lack of widely accessible, published data from the Caspian prevents a sound evaluation. The ctenophore, which was noted in significant quatities in the Caspian by the early 2000, preys voraciously on mesozooplankton which is the major consumer of phytoplankton. Thus the levels of the latter woud be expected to increase as was revealed by the remote sensing data (Fig. 6). Similar increase in phytoplankton due to predation on zooplankton of *M. leidyi* was reported by Deason & Smayda (1982) during 1972–1977 in Narragansett Bay, Rhode Island, USA. These authors suggested that ctenophores may control phytoplankton blooms indirectly through their predation on herbivorous zooplankton and directly by the nutrient excretion accompanying such grazing. We suggest that the major increase in chl-*a* values observed during 1988–1992 in the Black Sea by Yunev et al. (2002, see Fig. 4 therein) must also be due to the first peak development of this invasive species. In addition, after *M. leidyi* invasion, very significant increases in phytoplankton biomass have been observed in the southern Caspian Sea, concurrent with low zooplankton quantities particularly during warm months of the year when the ctenophore levels are highest (Bagheri & Kideys, in preparation).

There may be a differential impact of *Mnemiopsis leidyi* on phytoplankton dynamics due to its spatial distribution in the Caspian Sea. Although in our sampling period phytoplankton levels were quite high, possibly the eastern Caspian including its coastal strip is among the least fertile regions of this sea when one consider the entire year. It must be noted that Kideys & Moghim (2003) found the lowest biomass values of *M. leidyi* along the

Kazakhstan coasts (Middle eastern Caspian) in August 2001, while levels were quite high in the southern Caspian Sea. *M. leidyi* is well-known to be abundant or successful only in fertile areas (Kideys & Niermann, 1994). Therefore one expects a higher impact on zooplankton and consequently a change in phytoplankton composition particularly in the southern Caspian.

It has been shown in laboratory experiments that the hatching success of copepod eggs is reduced when copepods are reared on a diatom diet (Ianora et al., 1995, 2004; Miralto et al., 1999). However, it is not yet clear whether this apparent contradiction to good copepod growth in diatom rich seas results from experimental artefacts (Irigoien et al., 2002), from nutritional inadequacy of diatoms (Jonasdottir et al., 1998) or from adverse chemical properties of diatoms (Ianora et al., 1999; Miralto et al., 1999). Nutritional inadequacy might result from a shortage of the essential fatty acid C22:6ω3, which is abundant in flagellate and protozoan biomass. If we consider that zooplankton preferably consume dinoflagellates rather than diatoms (Sommer et al., 2002) it is an expected situation to find high dinoflagellate numbers in the southern part in this study, since *Mnemiopsis leidyi* possibly consumed more zooplankton here.

It will be very important to gather data on major components, including phytoplankton, of the Caspian Sea ecosystem to evaluate potential changes occuring due to both anthropogenic impacts and particularly due to the invasive ctenophore *Mnemiopsis leidyi*.

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