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Full Length Research Paper

Temporal and spatial variations of phytoplankton in the Caspian Sea

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Geographic information system (GIS) can be used to perform a number of fundamental spatial analysis operations. Its major advantage is that it allows the user to identify the spatial relationships between various map features. In this study, phytoplankton cell abundance, biomass and species composition were evaluated in the Iranian coasts of the Caspian Sea during 1996 to 1997 and 2005 to 2006. Totally 1562 water samples were collected in Southern part of Caspian Sea (SCS) for durations of 1996 to 1997 and 2005 to 2006. There were changes in the highest seasonal means of phytoplankton biomass. While maximum phytoplankton biomass were recorded in spring and summer during 1996 to 1997, after the invasion of *Mnemiopsis leidyi* shifted to a winter period and biomass shifted to winter-spring during 2005 to 2006. Maximum cell abundance was observed in 2005 to 2006, contributed mostly by small size of phytoplankton, although its population decreased in 1996 to 1997 while maximum biomass was observed in 1996 to 1997, belonged to big size of phytoplankton such as *Rhizosolenia calcaravis*. Its population aggregated at the depth of 0 to 20 m more than 87% of the total cell abundance, due to some favorable conditions such as higher water temperature, light, dissolved oxygen and nutrient concentration. Phytoplankton was vertically distributed until the depth of 20 m, and the population decreased at the lower depths.

Key words: Phytoplankton, seasonal variation, biomass, geographic information system (GIS) and Caspian Sea, Iran.

INTRODUCTION

The Caspian Sea is the largest inland water body in the world, with a surface area of about 380,000 km^2 (the northern area 25%, middle 36% and Southern area 39%) and a volume of approximately 78,000 km3. The coastal length of the sea is about 6,380 km. It measures 1200 km from north to south and 200 to 450 km from east to west. The Southern Caspian Sea coast (Iranian part) is 900 km (Dumont, 1995). The Southern Caspian has the largest volume (64% of the total volume), and its area amounts to 35% of the total area of the sea. It is the deepest part of the sea with the maximum depth reaching 1025 m. According to Zonn (2000), the area is from 144690 up to 151018 km^2, and the average volume 48300 km^3. The average depth is 300 m.

The hydrobiology of the CS has been systematically studied since 1934 (the first All- Caspian expedition). After the Second World War, the Caspernikh (Institute in Russia) initiated regular seasonal annual observations in Northern Caspian and in the following years throughout the CS (except in Iranian waters). The Zoological and Botanical Institute of the USSR Academy of Science and other scientific institutions of the former Soviet Union carried out these expeditions periodically. A number of

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monographs and review articles dedicated to diversity of species, distribution, number and biomass of phytoplankton, zooplankton and benthos in the CS have been published (Proshkina-Lavrenko and Makarova, 1968; Birstein and Nauka, 1968; Kasymov and Bagirov, 1983; Salmanov, 1987; Kasymov, 1994). The survey of Southern part of Caspian Sea (SCS) (Iranian parts) started with the collaboration of the Caspian Sea Research Institute in Ecology (Sari, IRAN) and Fisheries Research Center of Giulan (Anzali, IRAN), existed between the 1991 to 1993 periods. From 1994 to 1996, these two institutes in collaboration with the USSR (KaspNIRKH Institute) conducted the survey. In 1997 and 1999, the survey reverted back to the above two institutes. Up till now, the monitoring project has been conducted on a yearly basis by the Caspian Sea Research Institute in Ecology (Sari, IRAN) for the Southern part of the Caspian Sea.

The abundance, composition and seasonality of phytoplankton communities can eventually determine the structure and function of marine ecosystems (Edwards and Richardson, 2004; Widdicombe et al., 2010). Recently, with the invasion of *Mnemiopsis leidyi*, phytoplankton species composition were flactuated widely (Roohi et al., 2008b). 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 ;Ganjian et al 2010k).

Geographical information systems (GIS) are implementations of computer-based techniques for managing, mapping and analysing geo-referenced data. GIS technology integrates common database operations, such as queries and statistical analyses, with the unique visualisation and geographic analysis benefits offered by maps. Such systems can yield information, on the spatio-temporal structure and relationships of variables, which would otherwise not have been apparent in the source data sets (Pierce et al., 2002).

Environmental research is frequently concerned with the measurement of variables whose magnitude and spatial distribution vary over time. Geographic information systems (GIS) are powerful tools for the analysis of such spatial changes (Johnson, 1990).

MATERIALS AND METHODS

Samples were collected during 6 cruises carried out on board the R/V Guilan in the Southern part of Caspian Sea (SCS) at 18 transects (from 1996 to 1997) and 6 transects (from 2005 to 2006) (Figure 1). The citation of study area was conducted according to a hydrological and hydro biological project by Iranian Fishery Research Organization (IFRO).

Phytoplankton samples collection

Phytoplankton samples were collected along the southern coasts of Caspian Sea using a Van Dorn water bottle sampler (Ruttner) (Vollenweider, 1974) from the surface, 5, 10, 20, 50 and 100 m of the water column. A total of 1562 phytoplankton samples were collected (1296 samples in 1996 to 1997 and 266 samples in 2005 to 2006) and held in 0.5 L bottles, preserved using buffered formaldehyde to obtain a final concentration of 4% (Sourina, 1978). 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). The micro and nanophytoplankton present in a subsample of 0.1 ml were taken from the 30 ml sample, to be counted using a Sedgewick–Rafter chamber under a phase contrast binocular microscope (Vollenweider, 1974; Newell, 1977; APHA, 2005; Ganjian et al., 2010i).

Spatial analysis

In natural resources the point field sampling is often used for spatially oriented projects and interpolation methods are implemented to predict the values in an unsampled location and to generate maps. In this study for spatial distribution of phytoplankton biomass in the surface water of south of Caspian Sea, 72 and 26 stations for 1996 to 1997 and 2005 to 2006, respectively.

According to the two selected years and different seasons all data was selected and compiled into a new data base. Data processing and statistics were carried out with the geographic information system (GIS). Though there are a number of spatial modeling techniques available with respect to application in GIS, spatial interpolation technique through Inverse Distance Weighted (IDW) approach with optimize power was used in the present study to delineate the spatial distribution of phytoplankton biomass. The simplicity of the method, and the credibility of interpolated surfaces form any type of data, have led to a wide application of this weighting method. The inverse distance weighting (IDW) method estimates the values of an attribute at unsampled points using a linear combination of values at sampled points weighted by an inverse function of the distance from the point of interest to the sampled points. The assumption is that sampled points closer to the unsampled point are more similar to it than those further away in their values. All spatial interpolation methods use the same general estimation formula, as follows:

$$z^{\wedge}(x_0) = \sum_{i=1}^{n} \lambda_i \, z(x_i)$$

where $z^{\wedge}$ is the estimated value of an attribute at the point of interest x_0, z is the observed value at the sampled point x_i, λ_i is the weight assigned to the sampled point, and n represents the number of sampled points used for the estimation.

The weights can be expressed as: (Li and Heap, 2008)

$$\lambda i = \frac{1/d_i^p}{\sum_{i=1}^{n} 1/d_i^p}$$

Where d_i is the distance between x_0 and x_i, p is a power parameter, and n represents the number of sampled points used for the estimation.

The main factor affecting the accuracy of IDW is the value of the power parameter (Isaaks and Srivastava, 1989). Weights diminish as the distance increases, especially when the value of the power parameter increases, so nearby samples have a heavier weight and have more influence on the estimation, and the resultant spatial

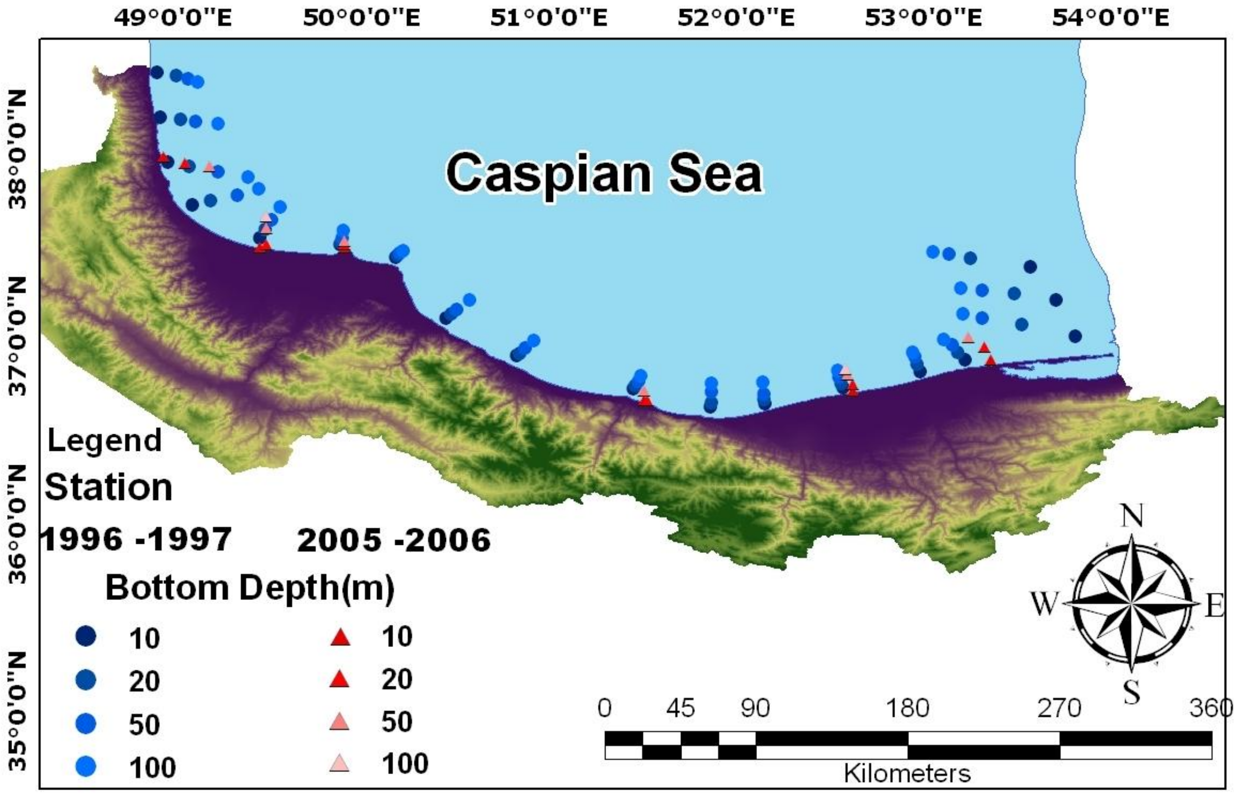


Figure 1. Sampling transects and stations position in the southern part of Caspian Sea.

interpolation is local (Isaaks and Srivastava, 1989).

RESULTS

Maximum cell abundance was observed in 2005 to 2006 (Figure 2b), contributed mostly by small size of phytoplankton, although its population decreased in 1996 to 1997 (Figure 2a) while maximum biomass was observed in 1996 to 1997 belong to big size of phytoplankton such as *R. calcaravis* (Figure 3a, b). Phytoplankton in the water column of southern Caspian Sea for the period of 1996 to 1997 and 2005 to 2006 were sampled to determine the vertical distribution of phytoplankton at the depths of 0, 5, 10, 20, 50 and 100 m. Its population aggregated at the depth of 0 to 20 m more than 87% of the total cell abundance, due to some favorable conditions such as higher water temperature, light, dissolved oxygen and nutrient concentration. Phytoplankton was vertically distributed until the depth of 20 m, and the population decreased at the lower depths (Figures 2a, b, 3a, b and 4).

Mean water temperature at different depths was in the range of 8.1 to 19.1°C. The highest temperature was recorded at the depth of 0 to 20 m (19.1 to 17.5°C) and lowest at the depth of 50 to 100 m (12.2 to 8.1°C) (Figure 5). In general, the overall average cell abundance and biomass of phytoplankton were in 2005 to 2006 due to small size and in 1996 to 1997 due to big size of phytoplankton, respectively (Figures 6a, b and 7a, b). The most cell abundance of phytoplankton was observed in 2005 to 2006, while high density was due to Bacillariophyta and Pyrrophyta in transect 2 (Figures 2b and 6). High biomass of phytoplankton was observed in 1996 to 1997 and Bacillariophyta represented the most abundant biomass. Cyanophyta reached its highest biomass in summer (Figures 3a and 7).

DISCUSSION

In addition to the marked changes in the abundance observed in the phytoplankton over the study period, there was 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 dominate the plankton for a shorter or longer period of time and then are replaced by another set of species (Nybakkhen, 1993; Ganjian et al., 2010j). Caspian Sea phytoplankton community structure consists of representatives of warm-requiring, moderate-thermophilic and moderate cold-requiring species. In summer the temperature at the surface water of the SCS changes from 23°C up to 30°C,

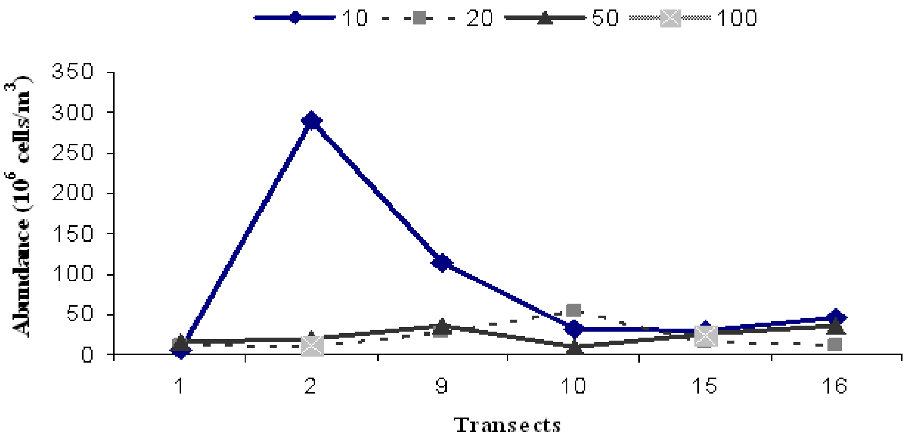
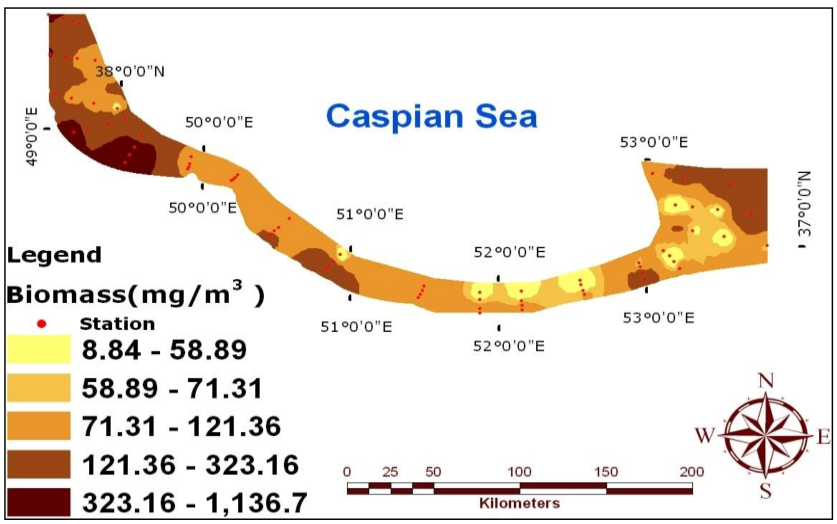


Figure 2. Annual changes total of phytoplankton cell abundance (10^6cells/m^3) at different transects in (a) 1996 to 1997 (b) 2005 to 2006 in the Southern part of Caspian Sea.



(b)

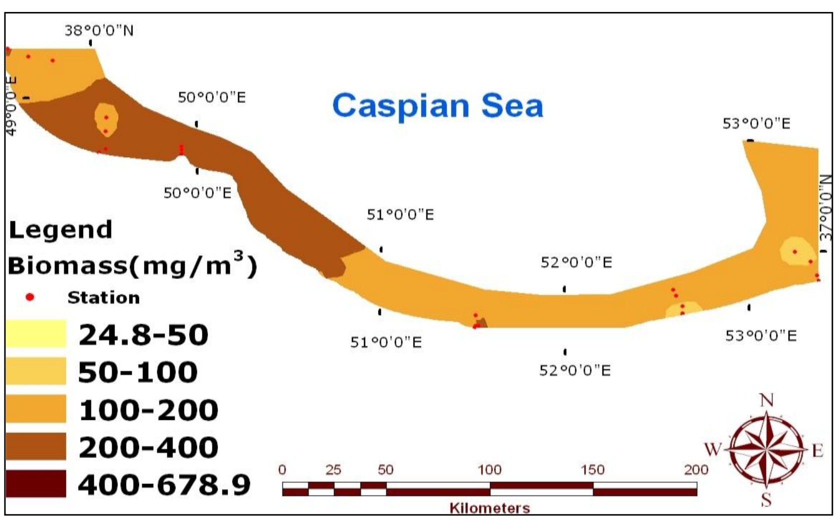


Figure 3. Annual changes mean of phytoplankton biomass (mg/m^3) at different transects in (a) 1996 to 1997 (b) 2005 to 2006 in the southern part of Caspian Sea.

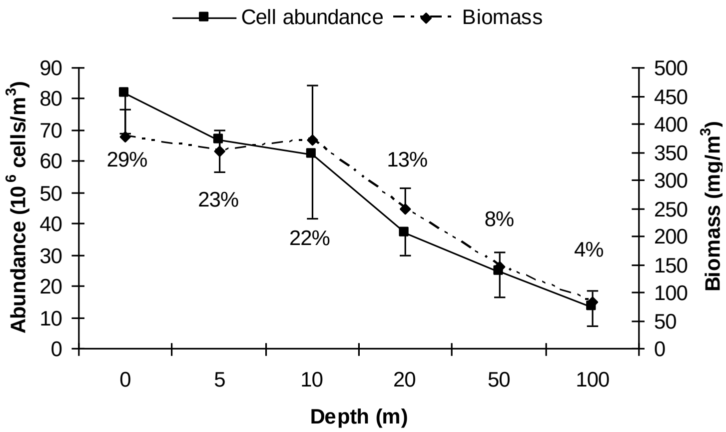


Figure 4. Phytoplankton cell abundance (10^{6}cells/m^3) and biomass (mg/m^3) (mean ± SE) at different depths (m) in the Southern part of Caspian Sea.

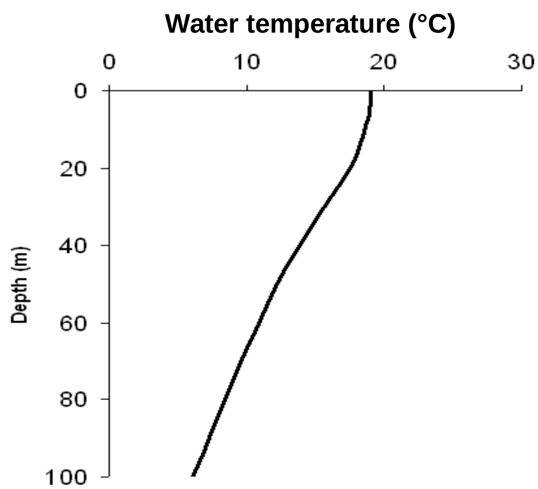


Figure 5. Water temperature (°C) at different depths (m) in the Southern part of Caspian Sea.

and goes down to 6 to 9°C of deep water in winter (maximum Temp in winter surface layer is 13°C). Thus water temperature in various parts of SCS is inconsistent and it plays an important role in seasonal changes of phytoplankton (Kasymov, 2004).

Numerous changes in the biodiversity have been observed in the Caspian Sea following the invasion of the ctenophore *M. leidyi* (Roohi et al., 2008a; Kideys et al., 2008). 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* (Roohi et al., 2009). Certainly other factors such as over fishing, 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* (Kideys et al., 2008; Ganjian, 2010i).

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 (Carter et al., 2005). The typical dominance of small-size phytoplankton in the Levantine Basin has been reported even during the annual phytoplankton bloom (Mohan et al., 2007; Vidussi et al., 2001).

A quite typical pattern of seasonal variation of phytoplankton in 1991 to 1993 was reported (Labry et al., 2001) that, higher abundance of phytoplankton was always observed at the end of winter, when the ice and snow cover attained its maximum thickness. Another survey showed (Kideys and Moghim, 2003) that one of the reasons for the diatoms prevalence was due to cold waters. Hereby, this studies also emphasis that the overall phytoplankton population was 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 phytoplankton) to an apparent dominance of opportunistic Pyrrophyta (45% biomass and 52% cell abundance) in spring.

Several factors act in performance to reduce that the nitrogen content of seawater was constant throughout the water column. Such is usually not the case. The upper layers of water usually have reduced concentration compared to lower waters, as will be shown subsequently. Also, due to only light absorption by water, the production at 100 m would be less than at 10 m. More important, the increasing numbers of phytoplankton cells have a profound effect. As the phytoplankton population grows in the upper 100m of water, the plants themselves

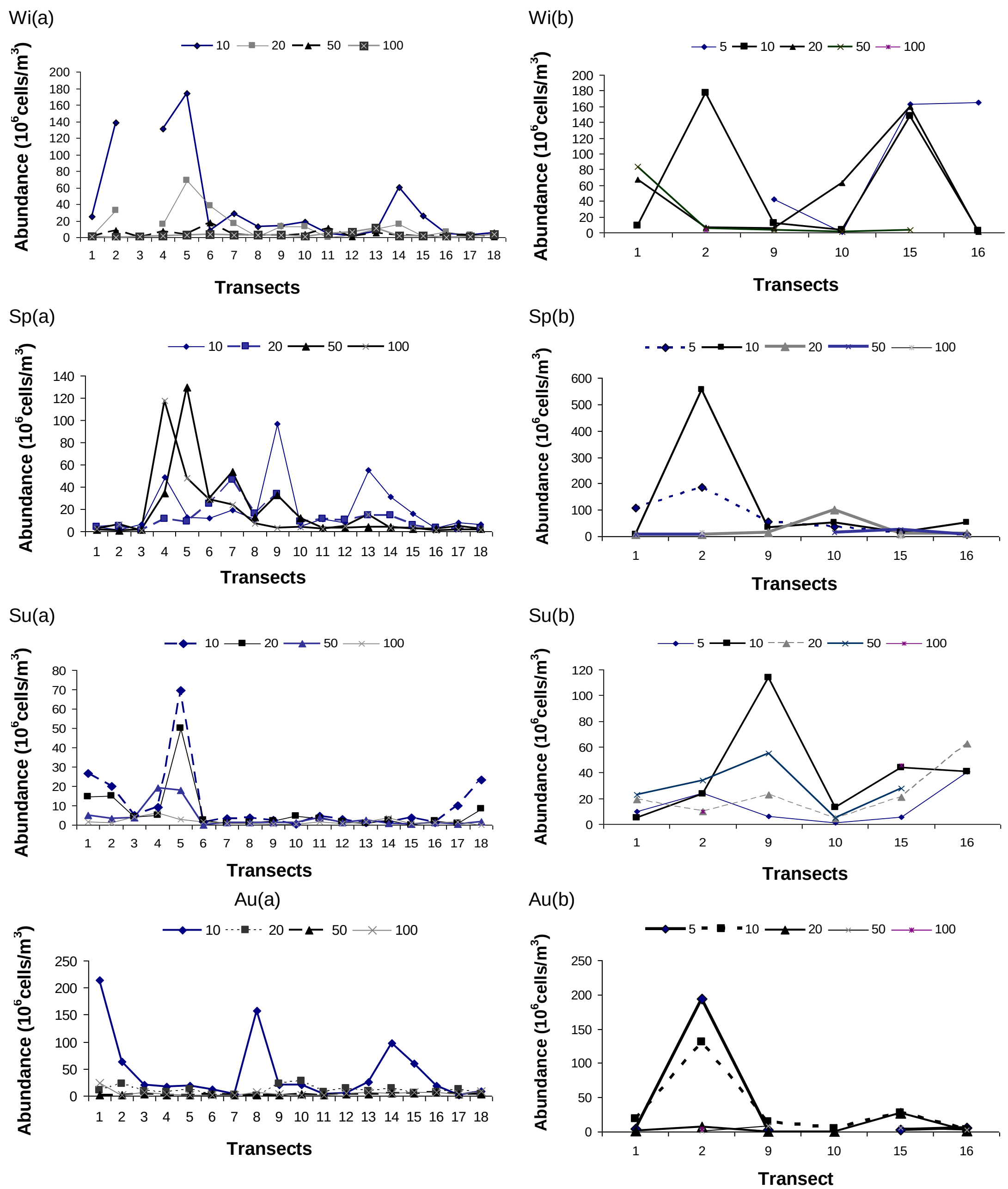


Figure 6. Seasonal changes mean of phytoplankton cell abundance (10^{6}cells/m^3) at different transects in (a) 1996 to 1997 (b) 2005 to 2006 in the southern part of Caspian Sea. Wi = Winter, Sp = Spring, Su = summer, Au = Autumn.

absorb more and more of the light. As a result, there is less and less light penetrating to the deeper levels. Less light means that the compensation depth begins to move upward and becomes shallower (Nybakken, 1993). The annual maximum phytoplankton cell abundance and biomass were distributed at the depths of less than 20 m (Figure 4). Phytoplankton density and biomass during blooming events were mostly aggregated in surface layers of 0 to 25 m. The observations in the present study agreed with the previous studies (1992 to 1993) and also concurred with that of Ganjian and Hossaini (1998).

Considering that the seasonal succession is most often and clearly seen in temperate seas, which have a marked change in temperature over the course of a year, temperature has been suggested as a cause. Certainly, this may be one of the factors, but it is unlikely to be solely responsible because certain dominant species recur at different temperature. Another suggestion reason

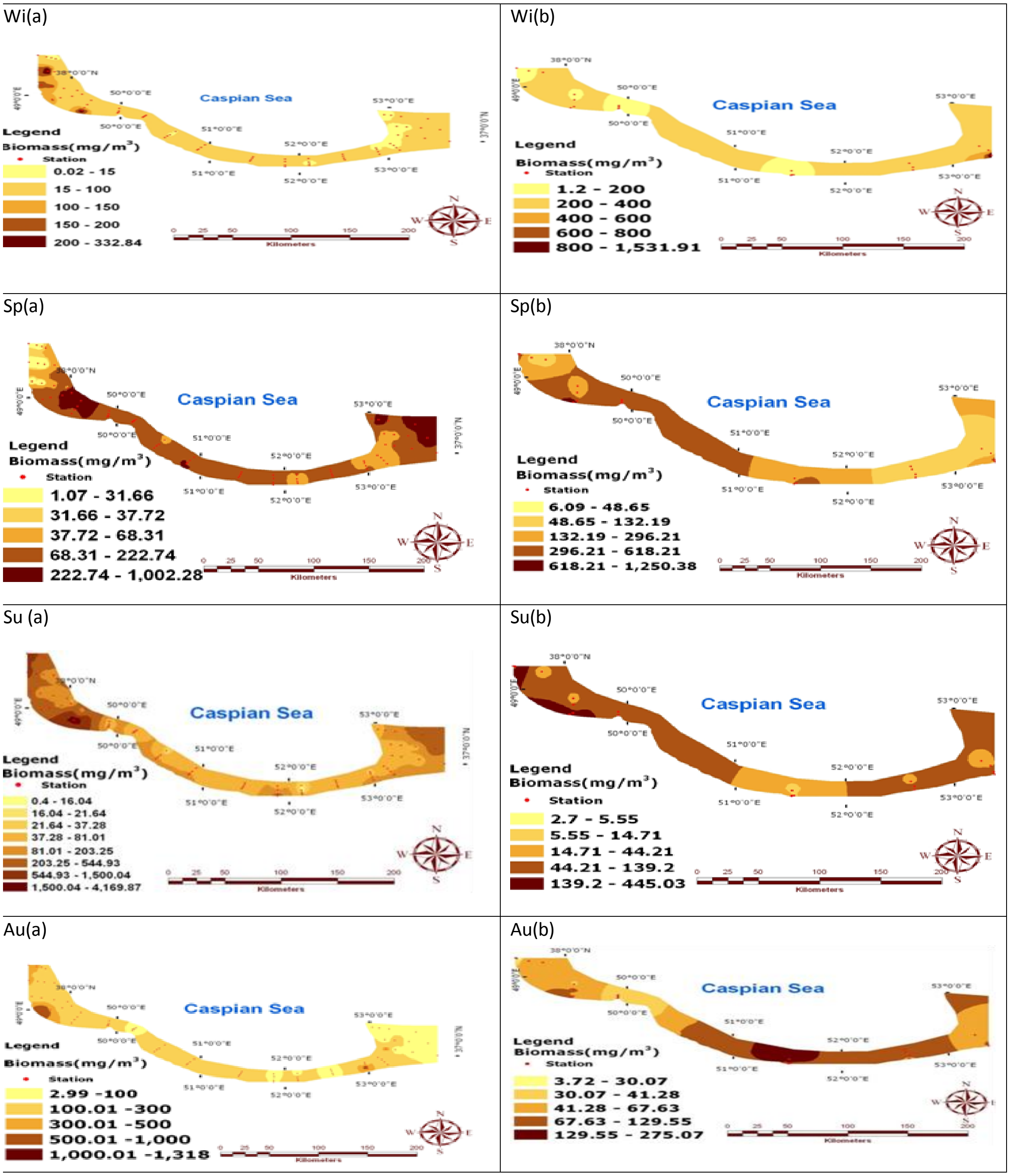


Figure 7. Seasonal changes mean of phytoplankton biomass (mg/m^3) at different transects in (a) 1996 to 1997 (b) 2005 to 2006 in the southern part of Caspian Sea. Wi = Winter, Sp = Spring, Su = summer, Au = Autumn.

is the change in nutrient level over the year, with different concentrations favoring different phytoplankton species (Nybakken, 1993). In temperate waters small-celled, rapidly dividing diatom species initiate the spring bloom. They are then succeeded first by larger diatoms in the late spring and then by a summer warm-water dinoflagellate community. In tropical and subtropical waters, diatoms and dinoflagellates are generally dominant all year, although they may be interrupted by periodic diatom blooms (Nybakken, 1993). There were also changes in the highest seasonal means of phytoplankton biomass. While maximum phytoplankton biomass were recorded in spring and summer during 1996 to 1997, after the invasion of *M. leidyi* shifted to a winter period and biomass shifted to winter-spring during 2005 to 2006 (Figure 7a and b). Dominant phytoplankton groups changed from diatoms to Pyrrophyta and Cyanophyta when *M. leidyi* abundance was at a maximum level during summer-autumn of 2001 to 2002 in the Southern Caspian Sea (Roohi et al., 2009, Ganjian, et al., 2010i). In the present study the highest of the total phytoplankton biomass in 1996 to 1997 was observed in the east region while after invasion *M. leidyi* maximum biomass of phytoplankton in 2005 to 2006 shifted to the west region (Figure 7a and b).

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