DISTRIBUTION, ABUNDANCE AND BIOMASS OF PHYTOPLANKTON IN THE SOUTHERN PART OF CASPIAN SEA (IN IRANIAN WATERS)

By

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LIST OF ABBREVIATIONS

Abbreviation	Description

DO	**Dissolved Oxygen**
NO_2	**N- Nitrite**
NO_3	**N- Nitrate**
N-Total	**Total Nitrogen**
NH_4	**Ammonia**
SiO_2	**Silicate**
P-total	**Total phosphorus**
P-organic	**Organic phosphorus**
Lis	**Lisar**
Anz	**Anzaly**
Sef	**Sefidrod**
N	**Nooshar**
B	**Babolsar**
Am	**Amirabad**
Sp	**Species**
SD	**Standard Deviation**
PCA	**Principal Component Analysis**
CDFA	**Canonical Discriminant Function Analysis**
CSRIE	**Caspian Sea Research Institute for Ecology**

LIST OF SYMBOLS

Symbol	**Description**

°S	**Degrees south**
°N	**Degrees North**
°C	**Degree Celsius**
%	**percentage**
ml	**Milliliters**
m^3	**Cubic meter**
Cell	**Cell abundance**
mg	**Milligram**
m	**Meter (depth)**
μg/L	**Microgram/Liter**

TABURAN, KELIMPAHAN DAN BIOJISIM FITOPLANKTON DI BAHAGIAN SELATAN CASPIAN SEA

ABSTRAK

Kajian penyebaran bermusim fitoplankton dan parameter fiziko-kimia di Lautan Caspian telah dijalankan di 6 transek, 26 stesen pada kedalaman 0 meter (permukaan), 5, 10, 20, 50 dan 100 meter. Sejumlah 260 sampel fitoplankton telah dikumpulkan daripada strata kolum air semasa persampelan di sepanjang pesisir pantai (bahagian selatan) Lautan Caspian.

Sebanyak 163 spesies fitoplankton (71 Bacillariophyta, 21 Pyrrophyta, 31 Chlorophyta, 27 Cyanophyta dan 13 Euglenophyta) telah dikenalpasti. Bacillariophyta menyumbang 43% daripada kelimpahan spesies. Sebanyak 77 spesies fitoplankton telah direkodkan pada musim sejuk (Januari-Februari), 91 spesies pada musim bunga (Mei), 101 spesies pada musim panas (Julai) dan 86 spesies pada musim luruh (Oktober-November). Bilangan spesies phytoplankton semakin berkurang dari musim luruh ke musim sejuk.

Bacillariophyta mencatatkan kelimpahan sel dan biojisim yang tinggi di tengah Laut Caspian, manakala dinoflagelat mempunyai kelimpahan tinggi di kawasan barat dan tengah. Analisis PCA menunjukkan Bacillariophyta dan Pyrrophyta menyumbang sebanyak 53.64% daripada jumlah varians. Analisis CDFA yang telah dijalankan untuk kumpulan fitoplankton yang berlainan menunjukkan plot pembolehubah kanonikal dengan perkumpulan yang lebih tertumpu di bahagian barat disebabkan oleh kepadatan Bacillariophyta dan Pyrrophyta yang tinggi, manakala kawasan tengah mengalami pengasingan kerana biomas spesies Pyrrophyta yang paling tinggi.

Bacillariophyta dan Pyrrophyta merupakan kumpulan paling dominan sepanjang tempoh satu tahun kajian ini dijalankan. Purata untuk keseluruhan kelimpahan sel dan biojisim fitoplankton masing-masing adalah $11x10^6 \pm 9x10^6$

sel/m^3 dan 44.26$\pm$52.83 mg/m^3. Keseluruhan sumbangan oleh biojisim Pyrrophyta dan kelimpahan sel diatoms masing-masing mencatatkan peratusan sebanyak 53% dan 47%. Kehadiran Bacillariophyta telah menyumbang kepada kelimpahan sel fitoplankton semasa musim sejuk manakala biojisim yang maksimum pada musim bunga adalah disebabkan kehadiran Pyrrophyta. Suhu yang tinggi, 29°C direkodkan pada musim panas dan suhu terendah ialah 9.9°C pada musim sejuk. Saliniti berubah-ubah antara 9.1 dan 12.6 ppt.

Ketumpatan maksimum bagi Bacillariophyta berlaku pada musim sejuk dan musim luruh kerana kehadiran *Thalassionema nitzschiodes*, *Cyclotella menenghiniana* dan spesies dari genus *Nitzschia* dan *Chaetoceros* yang lain. Biojisim maksimum didapati semasa musim bunga kerana spesies dominan adalah Bacillariophyta yang bersaiz besar, contohnya *Rhizosolenia calcar-avis*, *Rhizosolenia fragilisima* dan *Nitzschia sigmoidea*. Phyla kedua dominan dari segi kelimpahan sel dan biomas adalah Pyrrophyta. Kelimpahan sel maksimum pada lapisan dan transek yang berbeza adalah disebabkan olah kehadiran *Exuviaella cordata* (Pyrrophyta) manakala biojisim tertinggi diperolehi daripada spesies *Prorocentrum praximum* dan *Prorocentrum scutellum.*

Exuviaella cordata mencatatkan pertumbuhan paling tinggi di semua musim, transek dan tersebar dilapisan yang berbeza berbanding spesies fitoplankton yang lain. Cyanophyta adalah kumpulan yang dominan semasa musim panas kerana kehadiran *Oscillatoria limosa*. Spesies dominan bagi Chlorophyta dan Euglenophyta masing-masing adalah *Binuclearia laterbonii* dan *Trachelomonas*. Kelimpahan maksimum bagi sel dan biojisim fitoplankton didapati pada kedalaman kurang daripada 20 meter. Kajian ini menunjukkan bahawa kelimpahan sel phytoplankton semakin berkurang dengan peningkatan kedalaman air.

Variasi komposisi dan penyebaran phytoplankton menandakan perubahan fizikal dan kimia di regim Laut Caspian.

DISTIBUTION, ABUNDANCE AND BIOMASS OF PHYTOPLANKTON IN THE SOUTHERN PART OF CASPIAN SEA

ABSTRACT

Seasonal distribution of phytoplankton and the physico-chemical parameters of the Caspian Sea were investigated at 6 transects with 26 stations, at the depths of surface 5,10, 20, 50 and 100m from winter (January-February), spring(May), summer(July), autumn (October-November) in 2005. A total of 260 phytoplankton samples were collected from the stratified water column during the sampling along Iranian coasts (southern part) of the Caspian Sea.

A total of 163 phytoplankton species were identified (71 Bacillariophyta, 21 Pyrrophyta, 31 Chlorophyta , 27 Cyanophyta, 13 Euglenophyta). Bacillariophyta contributed 43 % of phytoplankton species abundance.

The number of phytoplankton species recorded were 77 in winter (January-February), 91 in spring (May), 101 in summer (July) and 86 in autumn (October-November). They decreased from autumn to winter.

Due to the supply of SiO_2 ,nitrate and nitrite, cell abundance and biomass of Bacillariophyta were recorded high in the middle of Caspian Sea, while dinoflagellates were recorded abundant in the west and middle regions. PCA analyses showed that Bacillariophyta and Pyrrophyta contributed 53.64% of the total variance. CDFA analysis performed on different groups of phytoplankton resulted in the canonical variable plot with a thick cluster at the west, due to high concentrations of Bacillariophyta and Pyrrophyta, whereas the middle region was separated because of the highest biomass of Pyrrophyta species.

During the 1-year study, the most dominant groups were Bacillariophyta and Pyrrophyta. The overall average of cell abundance and biomass of phytoplankton were $11\times10^6 \pm 9\times10^6$ cells/m^3 and 44.26±52.83 mg/m^3

respectively. The overall contribution of Pyrrophyta biomass and Bacillariophyta cell abundance were 53% and 47% respectively. The presence of Bacillariophyta contributed to the phytoplankton cell abundance in winter and the Pyrrophyta maximum biomass occured in spring. The highest and lowest temperatures recorded were 29.0 ºC (summer) and 9.9 ºC (winter) respectively. The salinity fluctuated between 9.1 and 12.6 ppt.

The maximum density of Bacillariophyta was recorded in winter and autumn due to the presence of *Thalassionema nitzschiodes*, *Cyclotella menenghiniana*, and other different species of *Nitzschia* and *Chaetoceros*. Maximum biomass was observed in the spring as dominant species were the large size of Bacillariophyta *e.g. Rhizosolenia calcar-avis, Rhizosolenia fragilisima* and *Nitzschia sigmoidea*. The second dominant phyla in terms of cell abundance and biomass were Pyrrophyta. Maximum cell abundance in the different layers and transects were due to the presence of *Exuviaella cordata* (Pyrrophyta) while the dominant biomass belongs to P*rorocentrum praximum* and P*rorocentrum scutellum.*

Exuviaella cordata had the highest growth in all seasons, transects, and spread at different layers, compared to other species of phytoplankton. Cyanophyta was the dominant group in summer due to the presence of *Oscillatoria limosa*. The dominant species of Chlorophyta and Euglenophyta were *Binuclearia laterbornii* and *Trachelomonas* respectively. Maximum phytoplankton cell abundance and biomass was concentrated at the depth of less than 20m. In this study, it is found that cell abundance of phytoplankton decreased with increasing water layer (depth).

The changes in the physical and chemical regimes of the Caspian Sea influenced the variations of phytoplankton composition and distribution.

CHAPTER1

INTRODUCTION

The Caspian Sea or one commonly known as Caspiyskoye Morye, Caspyi, Caspian Lake, Khazar, Greek - Káspion pélagos, Latin - Caspium mare is located in the southeastern part of Europe (Figure 1) at its border with Asia between 30-47^{o}N and 46.5-55^{o}E, is the world's largest water body. It straddles the territories of Russian Federation, Republic of Kazakhstan, Azerbaijan Republic, Turkmenistan and Islamic Republic (I.R) of Iran.

The coastlines of the various countries are uneven, but the lengths are approximately as follows: Russian Federation: 1460 km, Kazakhstan: 2320 km, Azerbaijan: 825 km, Turkmenistan: 1200 and I.R. Iran: 1000 km. The total length of Caspian coast is nearly 7000 km (Aubrey *et al*.,1994b; Kosarev and Yablonskaya 1994).

The Caspian Sea is divided into three basins: the northern (27% of surface area), middle (38% surface area) and southern (39% surface area) (Stolberg *et al*., 2003) (Figure 1). It has a surface area of about 400 000 km^2 and water volume of about 78,700km^3 is the largest inland water body on earth. The surface area and water volume of the Caspian Sea are both dependent on the level at which the sea stands. It is located at the far end of southeastern Europe, bordering Asia (Kosarev and Yablonskaya, 1994). The length of the Caspian (north-south) is approximately 1200 km while its greatest breadth from east to west is 466 km. The average breadth of the Caspian from the west to the east is 330 km. 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 ppt in the north to 13ppt in the south. The low salinity in the northern part is due to the existance of significant river inflows. The Volga River supplies 82% of the annual riverine input in the Caspian Sea (Sur *et al*., 2000).

The northern part of the sea covers about 80,000 km^2. It is relatively shallow, averaging about 5-6 m in depth. The Ural Furrow is a slightly deeper (8-10m) structure extending to the Ural River trend across the shallow northeast shelf. The middle part of the Caspian Sea is a separate depression totalling about 138,000 km^2 in area. The western slope of this depression is quite steep, whereas the eastern slope is more gradual. The bottom is a gentle slope plain with depths of 400-600 m. The average depth of the Middle Caspian is 190 m, and its greatest depth is 788 m. The southern part of the Caspian Sea, with a total area of about 168,400 km^2, is separated from the middle by the Absheron ridge which is a continuation of the main Caucasus range. The deepest (1025 m) part of the Caspian Sea is in the South Caspian (Kosarev and Yablonskaya 1994) (Table 1). The northern basin is highly influenced by freshwater inflow from the Volga and Ural rivers and has a very low salinity (0.1‰) while in the middle and southern basins the water is consistently brackish, and salinity varies between 10-13 ‰ (Stolberg *et al* 2003). The water balance in the Caspian Sea is determined primarily by river inflow and surface evaporation (Stolberg *et al* .,2003).

The Caspian Sea is a sea that contains unique flora and fauna, including many endemic species. The majority of the world reserves of sturgeon are concentrated here (more than 90% according to data from the 1970s). The

Caspian coastline intersects a variety of geographical and climatic zones, including the steppe, the desert zones, and the subtropics, thus creating internationally significant habitats and ecological corridors for migratory waterfowl. Four coastal areas have been assigned as world important Ramsar sites (wetlands of international importance): the Volga delta, Kyzylagach, Krasnovodsk and the Northern Cheleken gulfs (Aubrey *et al*.,1994b; Kosarev and Yablonskaya, 1994 ; CEP,1998; CEP, 2001).

The Caspian Sea is famous for its rich natural resources; such as oil, natural gas and fish, 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 accidental introduction of ctenophore *Mnemiopsis leidyi* (Ivanov *et al*., 2000) has left a tremendous impact 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).

Figure 1. The Caspian Sea water area (Rodionov, 1994).

Table 1: Summary of Caspian Sea Characteristics

Bordering Countries	Azerbaijan, I.R. Iran, Kazakhstan, Russian Federation, Turkmenistan
Location	Located between 47^o 13' and 36^o 34' North latitude and 46^o 38' and 54° 44' East longitude
Total sea area	436,000 km^2
Volume	78,000 km^3
Mean depth	184 m
Max depth	1,025 m
Coastal length	7,000 km
Catchments area	3.5 million km^2
Major rivers	Volga, Ural, Terek, Sulak, Kura, Atrek, Sefid-Rud Annual riverine input ca. 300 km^3
Salinity regime	Salinity varies sharply in the North Caspian Sea, ranging from 0.1 ppt at the mouth of the Volga and Ural rivers up to 10-11 ppt near the border of the Middle Caspian. The middle and southern parts of the sea have only small fluctuations of salinity; surface salinity is about 12.6 to 13.5 ppt, increasing from north to south and from west to east. There is also a slight increase in salinity with depth (0.1 to 0.2 ppt).
Temperature regime	Water temperature varies considerably with latitude. This difference is the greatest (about 10^{o}C) in the winter when temperatures in the north are 0-0.5^{o}C near the ice and 10-11^{o}C in the south. Freezing temperatures are found in the north and in shallow bays along the eastern coast. The water temperature of the west coast is generally 1-2^{o}C higher than along the east coast. In the open sea, the water temperatures are higher than near the coast by 2-3^{o}C in the Middle Caspian and by 3-4^{o}C in the southern portion.
Tidal regime	In the North, inorganic phosphate (0.12-0.8 μM), phosphorus in organic form (2-2.5 μM), nitrogen (10-25 μM ,nitrates (5 μM) in spring and in summer, 7-10 μM in winter), silica 60 μM in winter, 20 μM in summer (Kosarev and Yablonskaya 1994, Dumont

	1998).	
Seabed types	On the shallow north shelf, sediments are predominantly terrigenous shell and oolitic sands. Aleurolites and silt sediments with high calcium carbonate content cover the deeper areas. On some parts of the bottom, there are hard rock outcrops of Neogene age. The sediments of the Caspian Sea contain rich oil and gas deposits.
Primary Production	North Caspian 22.7 mil. tons of organic carbon / year, Middle 50.9 mil. tons, South 41 mil. tons (Kosarev and Yablonskaya 1994).

1.1 Hydrology and Hydrobiology of the Caspian Sea

1.1.1 Temperature of water surface

Due to the north-south orientation of the Caspian Sea, the temperature of the water is subject to sizeable latitudinal changes. This is most distinctly expressed in winter when the temperature changes from 0-0.5^{o}C on the edge of the icy north of the sea to 10-11^{o}C in the south, such that the difference in water temperatures is nearly 10^{o}C. This difference decreases to 1-2^{o}C in summer, when dissimilarity occurs from east to west. During summer water surface temperature is 24-25^{o}C in the north and about 25-26^{o}C in the south, but the temperature on eastern coast is 1-2^{o}C lower than that on the western coast. (Kosarev and Yablonskaya, 1994).

1.1.2 Air temperature

The average annual air temperature over the Caspian Sea varies from 10^{o}C in the north to 17°C in the south. The monthly average air temperature in

January is between –5 to 10°C in the northern part of the sea and the near eastern coast of the Middle Caspian, and is –1 to 5°C in the area near Makhachkala. The coldest month in the southwestern and central areas is February when the approach of the coldest air temperatures typically occurs.The largest difference in monthly average air temperatures during the summer is slightly higher at the South Caspian shoreline (22°-24°C) while, near the western coast it is 21°-24°C (22-25°C at the shoreline), near the northeastern coast, temperatures is about 24- 25°C (increases up to 28°C at the shoreline) (Kosarev and Yablonskaya, 1994).

1.1.3 Salinity of water

The salinity of the Caspian Sea changes from the north to the south within a range of 1.0 to 13.5 (ppt) with average salinity in the Northern Caspian measuring 5-8 (ppt). Based on the Venetian classification of water salinity, this area should be referred to oligo-mesohaline water bodies. In the open regions of the Middle and Southern Caspian, salinity is more stable in comparison with the Northern Caspian and ranges from 11 up to 14 (ppt). The average salinity of the Middle Caspian is 11-12 (ppt), and the Southern Caspian 12-13 (ppt). Thus, both these areas of the Caspian, based on the Venetian classification, should be referred to as zones of mesohaline water bodies (Aubrey, 1994).

Such variable salinity conditions strongly increase the biodiversity of the Caspian. In fact the saline conditions allow freshwater, brackish, euryhaline and hyperhaline hydrobionts to inhabit the sea. Besides this, the chemical variablity in the Caspian waters promote the proliferation of many marine organisms. It should be noted that three ecosystems coexist in parallel within the borders of the Caspian i.e. freshwater, brackish and hyperhaline and this too promotes biological diversification within the lake.

The vertical stratification of water salinity in the Caspian is poorly expressed and the water salinity of the sea floor hardly differs from that on the surface. Under the present of very weak vertical stratification of water salinity, good intermixing of waters is observed in this lake, and the existance of waters rich in oxygen in the bottom level. In ancient days when the Caspian was much higher than now, and when there was a strong vertical stratification of bottom salinity, oxygen was practically absent at the bottom (Kosarev and Tuzhilkin, 1995; Dumont, 1998; Fedorov**,** 1983; Rubanov, *et al*.,1987).

1.1.4. River

The water resources of the Caspian Sea include river flow (of up to 660 large and small rivers), The total annual river runoff (340km^3/year – long-term average value) into the Caspian Sea is distributed between the many rivers flowing directly into the sea. The main rivers are the Volga (Russia), Kura (Azerbaijan/Georgia), Ural (Kazakhstan/Russia), Emba (Kazakhstan), Kuma (Astrakhan/Kalmik, Russia), Terek (Dagestan, Russia), Sumgayit (Azerbaijan), Atrek (Iran/Turkmenistan), Sulak (Dagestan, Russia), Samur (Azerbaijan/Russia), Shiroud (Iran) and Sefidrod (Iran) (CEP, 1998a).

1.1.5 Pollution

Water pollution poses a serious threat to Caspian biodiversity (Dumont, 1998; Ivanov, *et al*.,2000). The sources of pollution are from: industrial, agricultural and household discharges, as well as emergency emissions such as pesticides, oil and natural gas . Most of the essential pollutants are found in the waters of the Volga River. This is because the Volga carries into the Sea everything that comes from the territories within its basin. Discharges from the Azeri sector are basically from offshore operations. Pollutants produced by industrial activities of Baku and Sumgait, contributed to the flows of the Kura River. In Turkmenistan, oil enterprises, located in Turkmenbashi and oil operations in the Cheleken area contribute considerably to Caspian pollution. Kazakhstan too contributes to this marine pollution to a lesser extent. Such pollution is due to the flooding of former oil exploration sites during rises in sea levels and discharges from the Ural River.

The typical toxicants found in the Caspian Sea are oil hydrocarbons, heavy metals, phenols, synthetic surface-active substances, and chlorine-organic pesticides. Oil pollution also poses considerable danger. It is well known that the interaction of hydrobionts with oil hydrocarbons results in physiological, biochemical and morphological changes. In some cases, these changes are of reversible in nature while in others, they cause persistent pathological disorders leading to destruction of flora and fauna.

The above factors make it clear why it is crucial to study and protect biodiversity. Mankind would not survive without living organisms as they provide not only food and primary products but supply our planet and all living creatures with oxygen.

1.1.6 Phytoplankton

Phytoplankton occupy the first notch in the biological chain of every aquatic environments. They are known as primary producers of food and are mostly composed of single-celled algae in fresh and marine ecosystems. Since phytoplankton have photosynthetic pigments (*e.g* chlorophyll *a*) they can absorb energy and transfer it to higher fauna. Phytoplankton creates edible materials such as carbohydrates, proteins and fats from CO_2, H_2O and minerals via photosynthesis. They obtain from the seawater nutrients that released after the decomposition of waste and dead tissue by bacteria. As they are not motile, their locomotion is dictated by sea currents. They are even consumed by some predators directly or to serve as base food for higher organisms (Lalli and Parsons, 1993; Stout, 2005, Ward and Whipple, 1959; Boyed,1981; Walsh *et al*., 2001).

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 (Priddle *et al.,* 1994; Walsh *et al*., 2001; Moore and Abbott, 2002). This variability in the structure of the phytoplanktonic community has important implications for the entire ecosystem, since phytoplankton, as the autotrophic component of the marine ecosystem, affects the structure and efficiency of the food web, global biogeochemical cycles and carbon sedimentation in deep waters (Priddle *et al*., 1992; Smetacek, 1996; Walsh *et al*., 2001).

The distribution pattern of phytoplankton in different ecosystems are of major scientific importance. Phytoplankton belongs to different groups such as Bacillariophyta, Pyrrophyta, Chlorophyta, Cyanophyta and Euglenophyta and their abundance and biomass, will determine the quality and quantity of other aquatic animals. There are more brackish and freshwater forms of phytoplankton than marine species in the Caspian Sea. Nevertheless, species richness in this enclosed sea is lower than that in 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 cell abundance (EXXON, 2001).

Ecological and environmental alterations are also important at the phytoplankton level as they can affect its distribution patterns and biomass. There are very few studies available on phytoplankton of the Caspian Sea (Kosarev & Yablonskaya, 1994; CEP, 2000). Ecological and environmental alterations may trigger changes in the phytoplankton species number, abundance and biomass. These phenomena are related with the high levels in the biomass of the ctenophore, *Mnemiopsis leidyi* observed in last years. Voracious feeding on zooplankton (mainly copepods, cladocerans and meroplankton which are the major consumer of primary producers) by this ctenophore led to an abnormal increase in total phytoplankton quantity (Kideys & Moghim, 2003).

1.2 Objectives of the study

The objectives of this study are:

(i) To determine the species composition and diversity of phytoplankton.

(ii) To study the distribution, cell abundance and biomass of phytoplankton at different regions and seasons.

(iii) To examine the physicochemical parameters which influences phytoplankton distribution.

CHAPTER2
LITERATURE REVIEW

The hydrobiology of the Caspian Sea 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 Caspian Sea (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 monographs and review articles dedicated to diversity of species, distribution, number and biomass of phytoplankton, zooplankton and benthos in the Caspian Sea have been published (Proshkina-Lavrenko and Makarova, 1968; Birstein *et al*., 1968; Kasymov and Bagirov, 1983; Salmanof, 1987; Kasymov ,1994) .

After the collapse of the Soviet Union, the Caspian littoral states could not afford to carry out further research in 1990. Therefore, the most complete and compiled materials are related to the period of 1950–80s. The biological survey in each ecosystem has an important role related to the amount of aquatic stocks in the system. Phytoplankton investigation is an essential element that helps to achive our goal and indicate which phytoplankton constitute the main part of primary production.

The collaboration between the Fisheries Research Center of Mazandaran-Sari (Ecological Academy of Caspian Sea) with Fisheries Research Center of Gillan province existed between the 1991-1993 period. From 1994 to 1996, the survey was conducted by the the Fisheries Research Mazandaran and Gilan in collaboration with the USSR Kasperninikh Academy. In 1997 and 1999 the survey conduct reverted back to the Fisheries Research of Mazandaran and Gilan. Up till now, the monitoring project has been conducted on a yearly basis by Mazandaran Fishery Research Center for the Southern part of the Caspian Sea.

The total number of phytoplankton species recorded during 1962–1974 period in the Caspian Sea was 449. These species comprises of 163 diatoms, 139 Chlorophytes, 102 Cyanophytes, 39 Dinofagellates, 5 Euglenophytes and 1 Chrysophyte (Kosarev & Yablonskaya, 1994 ; Proshkina- Lavrenko, 1963; Proshkina –Laverenko and Makrova, 1968) while the number of phytoplankton species decreased from the north (414 species) to the middle (225 species) and south (71 species) zones mainly due to the disappearance of fresh water forms towards the south. Diatoms and Pyrrophyta are dominant in the Caspian Sea. These two groups have an important role in primary production in this sea (Salmanov, 1987; Kasymov and Bagirov, 1983; Kasymov, 1987; Ganjian & Hossaini, 1998; Ganjian and Makhlogh 2003; Ganjian, *et al*.,2004a; Ganjian,*et al*., 2004b).

Diatom are the most dominant phytoplankton throughout the year with the highest cell density and biomass. They are widespread on the surface layer of the Caspian Sea and reach peak density in autumn (Salmanof, 1987; Kasymov and Bagirov, 1983; Ganjian & Hossaini, 1998; Ganjian, and Makhlogh, 2003; Ganjian *et a*l., 2004b). The highest amount of phytoplankton in the Caspian Sea are diatoms and Pyrophyta, and the highest abundance of blue-green algae (Cyanophyta) occur in late summer (Draganov,*et al*.,1968;

Draganov,*et al*., 1984; Inaov, 1969; Salmanof, 1987; Bagherof and Ghasemof , 1983,Dowing, 2001, Ganjian *et al*, 2004a; Ganjian, *et al* 2004b).

The phytoplankton of the Northern Caspian is different from that of the Middle and Southern Caspian, resembling estuarine plankton (Proshkina-Lavrenko and Makarova, 1968). The phytoplankton of the Northern Caspian in 1986-1994 consisted of 230 species while the Middle and Southern Caspian comprised of 82 and 83 species, respectively. According to the latest data pertaining to the composition of plankton microalgae, the Northern Caspian alone recorded more than 400 species (Cyanophyta - 90, Chrysophyta - 1, Bacillariophyta - 149, Pyrrophyta - 58 Euglenophyta - 7, Chlorophyta - 138). However, despite this diversity, only a few species are predominant. In relation to salinity, algae are subdivided into some ecological groups: freshwater, brackish and marine species, and halophobes (Levshakova, 1971).

Of the freshwater algae, the green algae are the most common in term of the number of species. In shallow areas, filamentous algae of genera *Zygnema* and *Spirogyra* recorded the highest biomass. Blue-green algae consist of freshwater and marine species. There are also presense of marine and brackish forms, but their role is insignificant. Diatoms are widespread all over the Caspian Sea and are equally diverse in all ecological habitats. They occure in high number of species and their specific composition is the most stable during the reproduction period. *Rhizosolenia calcar-avis,* a marine algae is the most dominant, and recorded the highest in biomass. Perydine algae are represented by mainly marine and brackish water forms. *Exuviaella cordata* plays a special role, which dominates by numbers and is inferior to *R. calcar-*

avis by biomass, due to its cells which are ten times smaller. This species increased southward due to the decrease of freshwater forms as the contribution of marine species increases from 7 % in northern part of the sea to 27 % in more southerly regions (Proshkina-Lavrenko 1963; Proshkina-Lavrenko and Makarova, 1968; Salmanof, 1987).

A marine diatom, *Rhizosolenia calcar-avis* is the dominant phytoplankton of the Middle and Southern Caspian. At present, its density is stable in the Middle Caspian. In the 90-s, in the Middle Caspian the eastern region should have the richest concentrations of phytoplankton species and also their population. The phytoplankton population of the Southern Caspian along the coast of Azerbaijan is represented by 171 species. Diatoms are also widespread in this part of the sea and have the most diverse species composition (75 species of 22 genera). In terms of specific diversity, the genus *Chaetoceros* has 16 species and subspecies (varieties and forms) of which 3 are endemic to the Caspian Sea *(Chaetoceros winghamii, Chaetoceros subtilis* and *Chaetoceros rigidus*). The second most widespread genus in terms of species is *Thalassiosira* consisting of 11 species and subspecies (varieties and forms) of which 5 are endemic. Genus *Coscinodiscus* comprised of 8 species, varieties and forms followed by genera *Melosira* and *Nitzschia* consisting up to 6 species and subspecies (varieties and forms). In the genus *Coscinodiscus*, the species *C. jonesianus* and *C. granii* are the most abundant. It is important to note that the marine genus *Rhizosolenia*, *Actinocyclus, Scletonema* and *Thalassionema* are abundant though they represented in a small number of species. Their representatives are widely distributed in the Caspian and play an important role in marine life. (Proshkina-Lavrenko,1963; Proshkina-Lavrenko and Makarova, 1968; Salmanof, 1987,).

Blue-green algae in the Southern Caspian are represented by 55 species and 13 genera. The genus *Oscillatoria* is the most diversely represented, from which the genus *Oscillatoria* is clearly distinguished by its specific diversity (Proshkina-Lavrenko and Makarova, 1968; Salmanof, 1987). The blue-green and perydine algae are indigenous inhabitants of the Caspian. Their qualitative composition are poorer than diatoms, found all over the sea and are represented by 23 species, and 9 genera. In terms of abundance, pyridines occupy second places after diatoms which being one of the most widespread species. Some of dinoflagellate *e.g. Exuviealla cordata, Prorocentrum scutellum, Prorocentrum micans, Glenodinium capsicum* also among the dominant species occur from spring to autumn.

In the Southern Caspian, the green algae are represented by 15 species of 8 genera. *Pediastrum simplex, P. boryanum, Scenedesmus quadricanda* etc. are abundant in fresh water coastal areas. *Binuclearia lauterbonii* is also widespread. Yellow-green and Euglenas algae are represented by 2 species. Presumably, 13 species of Caspian endemics occur (Proshkina-Lavrenko and Makarova, 1968), but in recent years only 3 species were found - *Thalassiosira inserta, Thalassiosira caspica* and *Thalassiosira parvula*.

Long-term changes in the development of phytoplankton in the Northern Caspian are naturally related to the amount of nutrients brought in by the Volga River. The dependence of diatom biomass on the amount of silicon, and the whole primary production of a community on phosphorus brought in by freshwater has been established. Due to the damming of the Volga River

(Figure 1), the abundance of diatoms has decreased although the population of *Rhizosolenia* has increased. Green algae, particularly *Spirogyra*, predominant while species of brackish water and freshwater complexes have declined in number by the mid 1970s. The concentration of phytoplankton in the western half of the Northern Caspian is higher, than in the eastern half.

Species of freshwater and brackish water complexes are predominant with diatoms being the most ubiquitous. Blue-green and green algae occupy in the shallow regions, mainly, in the estuary of the Volga River. In contrast Pyrophytes occupy mainly in deep the areas of the sea, where salinity is higher. The yellow-green alga, *Dinobrion sertularia*, used to be found at outlets of fishways during certain years while Euglenas are found only in regions with fresher water. The species, which used to be found in the 1950-1960s (*Anabaena wariabilus* Kutz, A. Solitaria Kleb) were again found in 1986-1994 period, but the dominant species being *Thalassiosira inserta* and *Stephanodiscus astrae* (Proshkina-Lavrenko and Makarova, 1968; Senichkina, 1986; Salmanof, 1987).

Diatoms and dinoflagellates are the most abundant classes of marine phytoplankton (Lalli and Parsons, 1993; Carter *et al*.,2005). Diatoms generally have rapid growth rates (Furnas, 1990) and tend to thrive in upwelling conditions that provide not only high nutrient concentrations for rapid growth, but also provide the vertical mixing required by the non-motile diatoms to maintain their position in the euphotic zone (Margalef, 1978; Mann, 1993; Carter *et al*., 2005). Dinoflagellates typically prosper in stratified conditions as their motility enables them to exploit both the overlying euphotic zone and the underlying nutrient-rich waters (Margalef, 1978; Cullen, 1982; Mann, 1993;

Carter *et al*.,2005). The motility of dinoflagellates also enables them to maintain their position under the weakly turbulent conditions of a stratified water column (Margalef, 1978 ; Mann, 1993; Carter *et al*., 2005).

The most prevalent group of phytoplankton are the diatoms, of which there are 20,000 species. Since major changes in an ecosystem can affect all the trophic levels in the food chain, any ecological and environmental alteration can have a significant impact on phytoplankton .

Phytoplankton is often categorized into groups based on their primary role in biogeochemical material fluxes and/or in primary production. For example, diatoms are considered the principal phytoplankton group contributing to primary production and carbon export in coastal areas while dinoflagellates are often regarded to be an important contributors to biomass in stratified or silica limited areas and are well examined in harmful algal bloom literature. In contrast, cyanobacteria are the dominant algal group in offshore continental shelf and oceanic waters (Margalef, 1978; Glover *et al.,* 1986; Smayda, 1989).

In spring diatoms bloom, dissolved silica levels will reach a concentration that limit diatom growth (Dokulil and Skolaut, 1986; Mei *et al*., 2005). This high production is strongly associated with the dynamics of ice and the physical properties of the water column, which are influenced by regional circulation and climate patterns (Barber *et al*., 2001; Mei *et al*., 2002; Mei *et al*., 2005; Melling *et a*l., 2001; Tremblay *et al*., 2002b; Rebecca, 2005).

Phytoplankton proliferation is accompanied by the uptake of major chemical elements such as nitrogen (N) and phosphorus (P), while diatoms growth is accompanied by silicon (Si) uptake.The long-term stoichiometry of nutrient consumption by marine phytoplankton is the same as the ratio of the principal elements in phytoplankton biomass, i.e. phytoplankton take up C, N and P at the approximate ratio of 106:16:1 (Redfield *et al*., 1963). As this stoichiometry data holds true over large oceanic regions and over long time scales, it is a critical parameter in global biogeochemical models that predict export production based on nutrient drawdown (Fasham *et al*., 1990; Fennel and Neumann, 2004; Mei *et al*., 2005).

It is generally assumed that the export of organic matter from the euphotic zone in a marine system is equal to NO_3 based new production, when the system is in a long-term steady state (e.g. Eppley and Peterson, 1979). Recent studies have shown that NO_3 uptake by phytoplankton is accompanied by significant production of dissolved organic nitrogen (DON) (Bronk *et al*., 1994). Low concentrations of nutrients result in extremely low values for all phytoplankton related variables, including chlorophyll *a*, primary production and cell abundance (Sournia, 1973; Berman *et al*., 1984a,b; Dowidar, 1984; Azov, 1986; Bonin *et al*., 1989; Psarra *et al*., 2000; Christaki *et al*., 2001),dominance of small-size phytoplankton (Li *et al*.,1993; Yacobi *et al*., 1995; Ignatiades, 1998; Ignatiadeset *et al*., 2002), and significantly low bacterial abundance and production (Robarts *et al*., 1996). Dominance of small-sized phytoplankton in the Levantine Basin has been reported even during the annual phytoplankton bloom (Vidussi *et al*., 2001; Carter *et al*.,2005), In winter, after the annual phytoplankton bloom, phosphate concentrations rapidly decrease to below detection limits while measurable nitrate remains in the surface waters (Kress and Herut, 2001;Stella *et al.,* 2005). This residual nitrate is isotopically heavy and the particulate organic nitrogen (PON) isotopically light, both characteristics of a phytoplankton bloom that ceased as a result of P-limitation (Struck *et al*., 2001; Stella *et al.,* 2005). Nitrogen is commonly the growth-limiting nutrient in estuaries but phytoplankton growth rate in response to enhanced nitrogen availability may induce phosphate limitations over phytoplankton growth, and possibly silica limitations over diatom proliferation (Ryther and Dunstan, 1971; Hecky and Kilham, 1988; Dortch and Whitledge, 1992; Ramirez *et al*., 2005). It is clear that phytoplankton succession and community composition reflect the environmental conditions of the ecosystem, among which nutrient availability plays a significant role (Kilham and Kilham, 1980; Smayda, 1980; Sommer *et al*., 1986). It has been found that nutrient additions to natural water potentially alter the existing balance among algae to compete for nutrients and consequently shape community structure (Tilman *et al*., 1982; Sommer, 1989; Ramirez *et al*.,2005).

CHAPTER 3

MATERIALS & METHODS

3.1 Sampling transects and stations

This study was conducted along 6 transects with 4 stations (2 extra stations at 100 m in some seasons) at the depths of surface, 5, 10, 20 and 50m located in the western(Lisar and Anzaly), central (Sefidrod and Nooshar) and eastern (Babolsar and Amirabad) zones of the southern parts of the Caspian Sea (Figure3.1). The distance between stations differs among transects (Table 3.1).

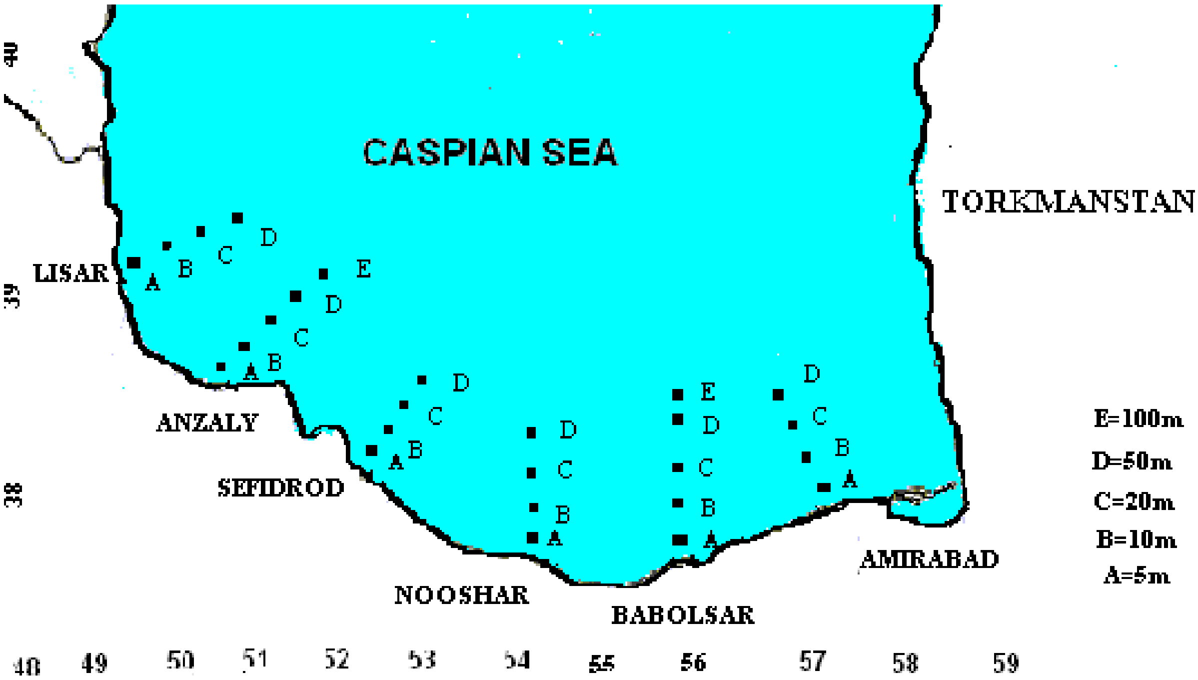

Figure 3. 1. Sampling transects and stations position in the southern part of Caspian Sea.

Table 3.1. Sampling locations.

Transect	Stations	Depth	Longitude	Latitude
Lisar	Lis1	5	48.57.00	37.57.50
	Lis2	10	48.58.00	37.57.5
	Lis3	20	49.05.00	37.57.5
	Lis4	50	49.12.30	37.57.20
Anzaly	Anz1	5	49.27.590	37.29.100
	Anz2	10	49.27.910	37.29.350
	Anz3	20	49.30.064	37.30.882
	Anz4	50	49.30.414	37.34.961
	Anz5	100	50.26.977	38.16.002
Sefidrod	Sef1	5	49.54.783	37.28..920
	Sef2	10	48.54.956	37.29.379
	Sef3	20	49.55.20	37.30.45
	Sef4	50	49.54.800	37.31.370
Nooshar	N1	5	51.30.704	36.40.042
	N2	10	51.31.177	36.40.261
	N3	20	51.32.075	36.40.976
	N4	50	51.33.429	36.42.968
Babolsar	B1	5	52.38.787	36.43.298
	B2	10	52.38.646	36.43.641
	B3	20	52.38.638	36.45.172
	B4	50	52.36.882	36.48.127
	B5	100	52.35.987	37.25.110
Amirabad	Am1	5	53.22.699	36.52.357
	Am2	10	53.23.306	36.53.661
	Am3	20	53.20.129	36.57.176
	Am4	50	53.16.350	37.00.750

3.2 Phytoplankton sampling

Phytoplankton samples were collected from the surface, 5, 10, 20, 50 and 100m of column waters (at 26 stations) and 260 samples of phytoplankton were collected from winter (January-February), spring (May), summer (July) and autumn (October-November) along the southern coasts of the Caspian Sea using a Van Dorn water bottle (Ruttner) (Vollenweider, 1974). These samples were held in 0.5L bottles and preserved using buffered formaldehyde to obtain a final concentration of 4% (Sourina, 1978) (Plate 3.1). The samples were kept stagnant for at least 10 days, to allow for complete sedimentation. The water in the upper level was siphoned off (using special siphon) and the remainder sample was treated in a few stages (Plate 3.2a) by the sedimentation and centrifuge method (5 minute with 3000rpm), so that the final concentration of the samples were 30ml (Plate 3.2b). A complete phytoplankton analysis consisted of two parts. The first part was an identification of phytoplankton species and to choose the final volume concentration for quantification and enumeration. If there was a few phytoplankton species in the samples, the volume was increased from 5ml to 10ml untill 25ml.

An approximate of time duration for settling the algal samples were as follow:

Volume 5 mL	5 hours
Volume 10 mL	10 hours
Volume 15 mL	15 hours
Volume 20 mL	20 house
Volume 25 mL	25 house

The second part was the enumeration and quantification of phytoplankton species. The micro and nanophytoplankton present in a subsample of 0.1 ml (Plate 3.3) were taken from the 30 ml sample, to be counted using a Sedgewick–Rafter chamber under a phase contrast binocular microscope (covering slip 24x24mm & with magnification of 10X, 20X and 40X) (Plate 3.4) (Vollenweider, 1974; Newell, 1977; Clesceri *et al*., 1989). The volume of each cell was then calculated by measuring its appropriate morphometric characteristics (i.e. diameter, length and width) and geometric shape (Appendix 4)(Kellar, *et al.,* 1989; Senichkina, 1986; Hillebrand *et al*., 1999). Finally, the volume values were converted to 1 m^3 biomass.

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Calculation of biomass (mg/m^3) and cell abundance ($cells/m^3$) were done according to the following formula:

Cell abundance ($cells/m^3$) = **VC × N**

Biomass (mg/m^3) = **VC × W**

VC = volume coefficient

W = weight

N = number (cell)

Volume of sample (mL)	**Coefficient**
5	100.000
10	200.000
15	300.000
20	400.000
25	500.000
30	600.000