TEMPORAL DISTRIBUTION AND COMPOSITION OF PHYTOPLANKTON IN THE SOUTHERN PART OF CASPIAN SEA IN IRANIAN WATERS FROM 1994 TO 2007

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by

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LIST OF ABBREVIATIONS

Abbreviation	Description
APHA	American Public Health Association
SCS	Southern part of Caspian Sea (Iranian waters)
CS	Caspian Sea
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
Sp	Species
SD	Standard Deviation
SE	Standard Error
PCA	Principal Component Analysis
CDFA	Canonical Discriminant Function Analysis
CSRIE	Caspian Sea Research Institute for Ecology
CEP	Caspian Sea Environmental Programme
IFRO	Iranian Fishery Research Organization

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
t	Ton
ppt	Parts Per Thousand
km^2	square kilometer
kg	Kilogram
$ind.m^{-3}$	Individual per cubic meter
$g.m^{-3}$	geram per cubic meter
µM	micromolar
$µg\ L^{-1}$	Microgram per Liter
ind.L-1	individual per Liter
$mg.L^{-1}$	Milligram per Liter
rpm	Rounds Per Minute

TABURAN RUANG MASA DAN KOMPOSISI FITOPLANKTON DI BAHAGIAN SELATAN LAUT CASPIAN DALAM PERAIRAN IRAN DARI 1994 HINGGA 2007

ABSTRAK

Laut Caspian merupakan permukaan air dalam terbesar di dunia yang mengalami perubahan ekosistem yang amat ketara sejak beberapa dekad lalu. Perubahan ini berlaku disebabkan faktor semula jadi eg. transgresi paras laut, perubahan cuaca, peningkatan aliran masuk air sungai dan juga faktor antropogenik seperti pencemaran, serangan ktenofor *Mnemiopsis leidyi* dan perikanan sturgeon secara haram di laut. Kesemua ini mendorong kepada perubahan yang signifikan dalam hidrologi, merubah asas makanan, kelimpahan dan biojisim daripada sumber biologi, dan juga bioproduktiviti laut. Ciri-ciri kualitatif dan kuantitatif jangka panjang struktur komuniti fitoplankton dan biojisim dikaji sepanjang tempoh 1994-2007. Sepanjang kajian dijalankan, sebanyak 4556 sampel fitoplankton dikumpul dalam 33 pelayaran yang dilakukan di bahagian selatan Laut Caspian (SCS). Sejumlah 334 spesies (88 genera) fitoplankton ditemui di SCS, yang merangkumi Bacillariophyta, Chlorophyta, Cyanophyta, Pyrrophyta, Euglenophyta, Chrysophyta, Xanthophyta dan Cryptophyta. Bacillariophyta dan Pyrrophyta hadir dalam semua kumpulan ekologi. Kumpulan ekologi fitoplankton terdiri daripada spesies air sungai (34%), spesies air payau - sungai (18%), spesies air payau (14%), spesies air payau – laut (4%), spesies laut (8%) dan spesies lain (22%). Kumpulan fitoplankton dominan daripada data sepanjang 1994 - 2007 adalah Bacillariophyta yang membentuk kelimpahan sel dan biojisim sebanyak 37 %, dan 52%,

masing-masing. Min kelimpahan sel dan biojisim tertinggi adalah masing-masing $249.1\times10^6 \pm 22.4\times10^6$ sel/m^3 dan 1034.17±117.81 mg/m^3; dan populasi yang lebih tinggi adalah disebabkan kehadiran Pyrrophyta, Bacillariophyta dan Cyanophyta di antara tahun 2001–2002. Kelimpahan sel dan biojisim populasi fitoplankton menunjukkan perbezaan yang signifikan dalam tahun 1994-2007 ($p<0.001$). Kelimpahan sel maksimum (9.7×10^6 sel / m^3) dan biojisim (83.8 mg/m^3) masing-masing diperhatikan dalam air payau dan air laut. Perubahan jangka panjang daripada kelimpahan sel dan biojisim dalam 5 kumpulan ekologi dan spesies dominan diperhatikan pada tahun yang berbeza. Dalam tahun 2001-2002, fitoplankton yang dominant adalah spesies *Exuviella cordata* dan *Rhizosolenia fragilissima*; dan ketumpatan yang tinggi adalah berkaitan dengan Bacillariophyta dan Pyrrophyta dalam musim sejuk. Dalam tahun 1999-2007, selepas serangan ktenofor *Mnemiopsis leidyi*, kelimpahan sel yang tinggi tidak lagi direkodkan dalam musim bunga tetapi dalam musim sejuk dan luruh, manakala biojisim yang lebih tinggi bertukar dari musim panas ke musim sejuk dan bunga. Indeks kepelbagaian fitoplankton yang tinggi adalah berkait dengan tahap kejernihan dan kemasinan yang tinggi. Populasi fitoplankton beragregat pada kedalaman 0 - 20 m, dengan lebih daripada 87% kelimpahan sel, yang disebabkan suhu air yang tinggi, cahaya, oksigen terlarut dan kepekatan nutrient. Taburan menegak limpahan sel dan biojisim fitoplankton didapati berkurangan dengan kedalaman air. Kualiti air di SCS dapat dikelaskan sebagai air tecemar organik dalam tahap yang sederhana dan tinggi. Dalam kajian ini, genus alga dan indeks pencemaran spesies (API) adalah disebabkan ayunan jumlah komposisi spesies fitoplankton. Indeks eutrofikasi (EI) menunjukkan suatu trend peningkatan daripada oligotrofik kepada eutrofik, yang nilai rendahnya diperhatikan bagi oligotrofik tipikal (0.21) pada 1994 dan yang tertinggi pada 2005-06

(1.22). EI jangka panjang yang berjulat di antara 0.26 hingga 1.22 dalam 1994/1996 dan 1996/1997 dikelompokkan sebagai oligotrofik tipikal (O) dan 1999/2000 dikelompokkan sebagai mesotrofik standard (M) dan 2003/2004, 2004/2005, 2005/2006 dan 2006/2007 dikelompokkan sebagai eutofik tipikal (E). Cyanophyta diwakili terutamanya oleh *Aphanothece elabens*, *Microcystis* spp, *Oscillatoria limosa*, *Spirulina laxissma* dan *Anabaena* spp. sepanjang tahun yang dikaji. Kelimpahan sel dan biojisim tertinggi diperhatikan pada musim panas dan luruh. Pemantauan biologi jangka masa panjang di SCS adalah diperlukan untuk pengurusan sumbernya yang lestari dan mengelakkan kerosakan alam sekitar.

TEMPORAL DISTRIBUTION AND COMPOSITION OF PHYTOPLANKTON IN THE SOUTHERN PART OF CASPIAN SEA IN IRANIAN WATERS FROM 1994 TO 2007

ABSTRACT

Caspian Sea is the largest inner water body on the earth underwent sharp changes in its ecosystem during the recent decades of the twenty century. They were caused by natural eg. transgression of the sea level, climate change, increase of fresh water inflow and anthropogenic factors eg. pollution, invasion of ctenophore *Mnemiopsis leidyi* and illegal fishing for sturgeons at sea. All that led to significant change in hydrological regime; modify the food base, abundance and biomass of biological resources and bio-productivity of the sea. Long-term qualitative and quantitative characteristics of phytoplankton community structure and biomass were investigated in from 1994 to2007. During the study period, 4556 samples of phytoplankton were collected during 33 cruises in the southern part of the Caspian Sea (SCS). A total of 334 species (88 genera) of phytoplankton were identified in the SCS, which comprised of Bacillariophyta, Chlorophyta, Cyanophyta, Pyrrophyta, Euglenophyta, Chrysophyta, Xanthophyta and Cryptophyta. Bacillariophyta and Pyrrophyta were present in all ecological groups. The phytoplankton ecological groups were fresh water species (34%), fresh – brackish – water species (18%), brackish-water species (14%), brackish-marine-water species (4%), marine species (8%) and other species (22%). The dominant groups of phytoplankton from 1994 to 2007 were Bacillariophyta which constituted the major cell abundance and biomass (37 % and 52%, respectively). The highest annual mean phytoplankton cell abundance and biomass were $249.1\times10^6 \pm 22.4\times10^6$ cells/m^3 and 1034.17±117.81

mg/m^3, respectively; and higher population was due to the presence of Pyrrophyta, Bacillariophyta and Cyanophyta between 2001–2002. The cell abundance and biomass of phytoplankton population showed significant difference in years 1994-2007 ($p<0.001$). The maximum cell abundance (9.7×10^6 cells / m^3) and biomass (83.8 mg/m^3) were observed in brackish-water and marine water forms, respectively. Long-term changes of cell abundance and biomass in five ecological groups and dominant species were observed in different years. In 2001-2002, the dominant phytoplankton were *Exuviella cordata* and *Rhizosolenia fragilissima*; and high density was due to Bacillariophyta and Pyrrophyta in winter. In 1999-2007, after the invasion of ctenophore *Mnemiopsis leidyi*, higher cell abundance was no longer recorded in spring but in winter and autumn; while higher biomass shifted from summer to winter and spring. High diversity index of phytoplankton was associated with high level of transparency and salinity. Phytoplankton population aggregated at the depth of 0 - 20 m with more than 87% of total cell abundance due to some favorable conditions such as higher water temperature, light penetration, dissolved oxygen and nutrient concentrations. Vertical distribution of phytoplankton cell abundance and biomass decreased with increasing depth. Water quality in SCS was classified as moderately and highly organically polluted. In the present study, algal genus and species pollution indices (API) were due to the oscillation in the number of phytoplankton species composition. The eutrophication index (EI) showed an increasing trend from oligotrophic to eutrophic, with its lower value was observed for the typical oligotrophic (0.21) in 1994 and the highest in 2005-06 (1.22). Long term EI ranged from 0.26 to 1.22 in 1994/1996 and 1996/1997 were grouped in the typical oligotrophic (O) and 1999/2000 were grouped as the standard mesotrophic (M) and 2003/2004, 2004/2005, 2005/2006 and 2006/2007 were grouped with the typical eutrophic (E). Cyanophyta were represented mainly by *Aphanothece elabens*, *Microcystis* spp., *Oscillatoria limosa*, *Spirulina laxissma* and *Anabaena* spp. throughout the years. The highest cell abundance and biomass were observed in summer and autumn. Long term biomonitoring in the SCS is required to manage its sustainable resources and to prevent environmental degradation.

CHAPTER1

INTRODUCTION

The greatest world lake - the Caspian Sea (other local names: Caspiyskoye Morye, Caspyi, Caspian Lake and Khazar) is noted for its sturgeon, oil and gas resources, and for the recent sea-level rise problem, in contrast to the drying out of Aral Lake, its eastern neighbour. These problems include the flooding of townships, oilfields, agricultural areas, radioactive and toxic waste sites pollution of the Volga, Ural, Kura, Terek and other rivers and destruction of the spawning grounds of sturgeons which signalize a forthcoming collapse in the world caviar market.

The Caspian Sea (CS) is a non outlet lake and has shores with five countries: Russian Federation, Republic of Kazakhstan, Azerbaijan Republic, Turkmenistan and Islamic Republic (I.R) of Iran (Figure 1.1). It is located on a vast continental depression on the border between Europe and Asia, between 47º07´ and 36º33´and 45º43´ of eastern longitude. The level is 28.3 m below the World Ocean's level; its fluctuation depends on the water balance. If the balance is positive then the level rises, if negative it decreases (Aladin and Plotnikov, 2004).

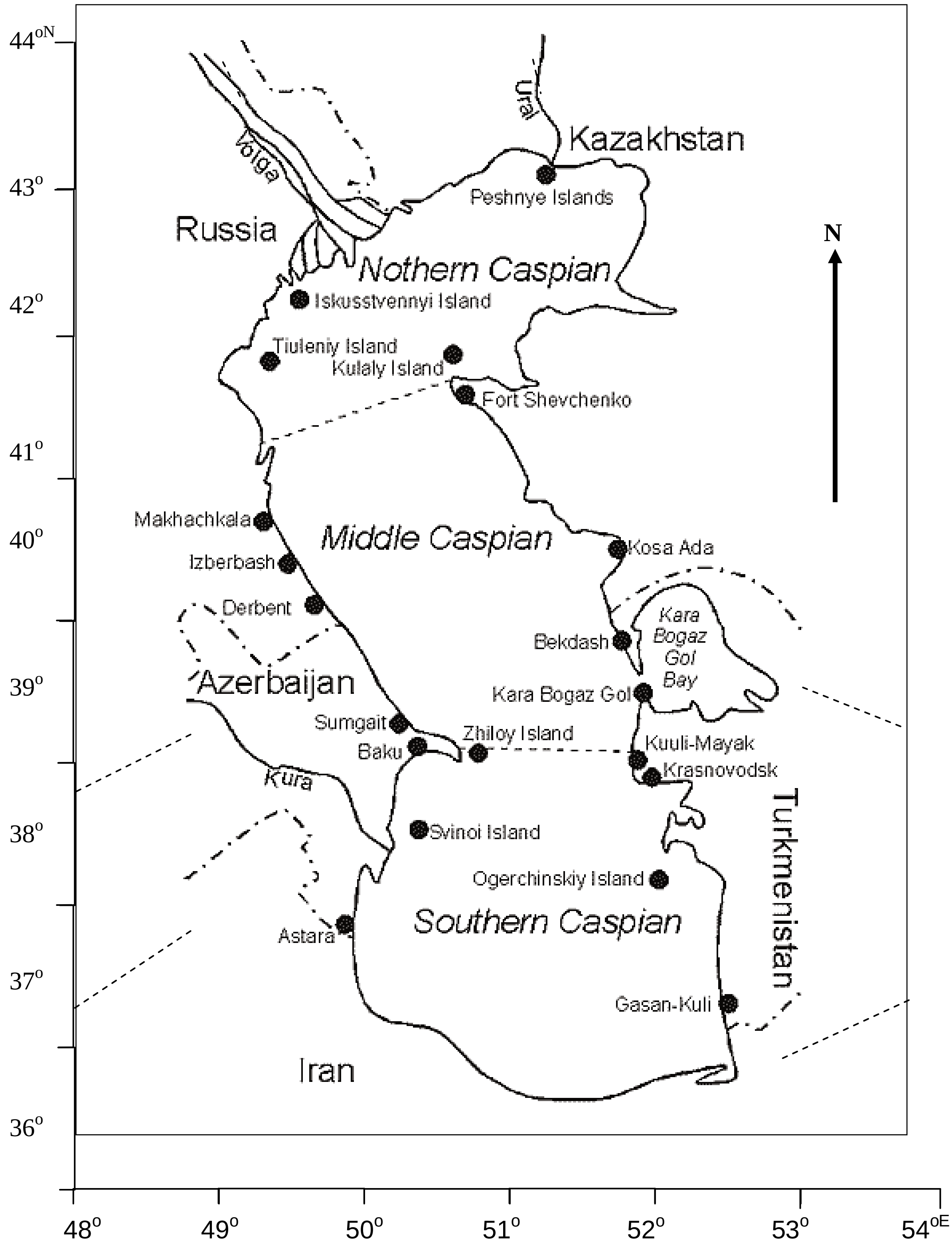

Figure 1.1 The Caspian Sea water area (modified from Rodionov, 1994)

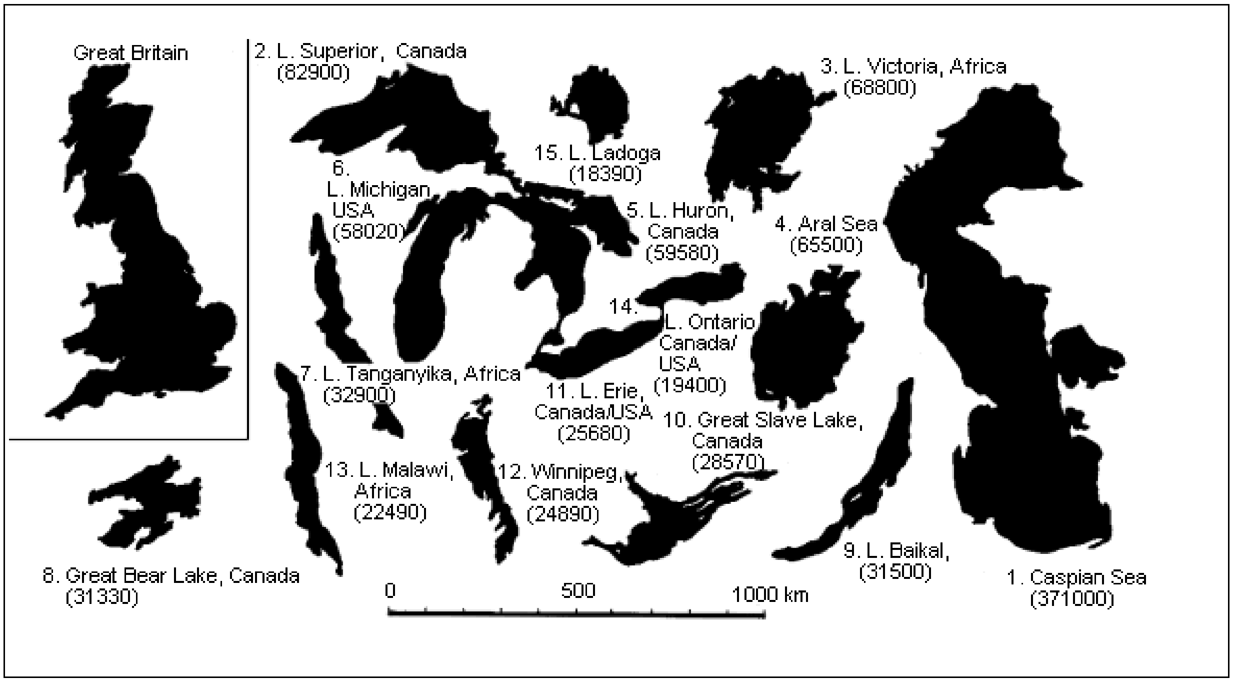

Figure 1.2 The 15 largest lakes in the world (insert is outline of Great Britain) all drawn to same scale. The numbers indicate the rank in area, while the figures in brackets denote surface area in square kilometers (after Ruttner, 1963; in Burgess and Morris, 1987)

The CS is unique in its size and characteristics. It is the largest inland water body (with no connection to world oceans) in the world (Figure 1.2), having been isolated from the world oceans at the end of the Pliocene epoch (1.8 million years ago), its ecosystem incorporates remnants of the fauna of the larger regional seas (mainly the Mediterranean and the Arctic biogeographic complexes). A major difference between the Caspian and other large inland water bodies is its meridian orientation and great length (1,200 km) so there are large climate differences among different areas of the sea. The northern shores are exposed to the extremes of the continental climate, while the southern and southwestern coast is sub-tropical (CEP, 2002).

The CS lies between 47º13´ and 36º34´35´´ north latitude and between 46º38´39´´ and 54º44´19´´ east longitude. The north-south length is approximately 1,200 km and the greatest east-west breadth is 466 km. The average breadth of the Caspian from the west to the east is 330 km but in the region of the Absheron peninsula, the breadth is only 204 km. The surface area of the CS is about 436,000 km^2, and the volume is about 77,000 km^3. The maximum depth is 1,025 m, with an average of 184 m (CEP, 2002). The CS 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 1.1). The surface area and water volume of the CS 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 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 CS ranges from 3 ppt in the north to 13ppt in the south. The low salinity in the northern part is due to the existence of significant river inflows. The Volga River supplies 82% of the annual riverine input in the CS (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 CS is a separate depression totaling 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 (SCS), 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 CS is in the South Caspian (Kosarev and Yablonskaya 1994) (Table 1.1). 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 CS is determined primarily by river inflow and surface evaporation (Stolberg *et al.*, 2003).

The CS 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.*, 1994; Kosarev and Yablonskaya, 1994; CEP, 1998; CEP, 2001).

Table 1.1 Summary of Caspian Sea Characteristics

Bordering Countries	Azerbaijan, I.R. Iran, Kazakhstan, Russian Federation, Turkmenistan
Location	Located between 47° 13' and 36° 34' North latitude and 46° 38' and 54° 44' East longitude
Total sea area Volume	436,000 km^2 78,000 km^3
Mean depth Max depth	184 m 1,025 m
Coastal length Catchments area	7,000 km 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°C) in the winter when temperatures in the north are 0-0.5°C near the ice and 10-11°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°C higher than along the east coast. In the open sea, the water temperatures are higher than near the coast by 2-3°C in the Middle Caspian and by 3-4°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).		
Numbers of species and subspecies in the Caspian Sea	Natural marine resources	No of species and subspecies	Endemic species
	Phytoplankton	450	
	Zooplankton	315	
	Phytobenthos	64	
	Zoobenthos	379	
	Fish	126	115
	Mammals	1	1
	Birds	466	
	Sources:CEP, 1998; Aubrey *et al*.,1994; Dumont, 1998		

The CS 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 (Bagheri & Kideys, unpublished data), pelagic fish stocks and other higher components of the ecosystem (Shiganova *et al*., 2001; Kideys, 2002; Kideys *et al*., 2004). During the past 30 years the environmental status of the CS has changed significantly in response to impacts of various factors, such as fluctuations in sea level, pollution from different of toxicants (Ivanov and Sokolski, 2000; Salmanov, 1999), and invasive species. The biological introduction of foreign organisms from ballast waters of vessels taken aboard in the Black Sea, entering the Caspian has had serious ecological impacts (Ivanov, 2001). In particular, the invasive jellyfish (Ctenophora, *Mnemiopsis leidyi*), that became apparent in November 1999 (Ivanov *et al*., 2000) has subsequently affected all components of the ecosystem used by the three kilka (Kideys and Moghim, 2003).

1.1 Hydrology and Hydrobiology of the Caspian Sea

Temperature of water surface: Water temperatures show a similar north-south gradient, caused by a climate-depth interaction. In summer, when strong thermoclines develop down to 60-80 m, north-south gradients are significant because the shallow northern basin heats up rapidly such that the middle basin is then slightly cooler than both other zones (Fig 1.3) (Dumont, 1998). During winter, the north cools strongly, whereas the middle and south basins, because of their volume and warmer climate, remain warmer. The south basin never cools below 10ºC, while the north and the lateral shelves typically freeze for several months during winter (Fig 1.3) (Dumont, 1998). 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°C. This difference decreases to 1-2°C in summer, when dissimilarity occurs from east to west. During summer water surface temperature is 24-25°C in the north and about 25-26°C in the south, but the temperature on eastern coast is 1-2°C lower than that on the western coast. (Kosarev and Yablonskaya, 1994).

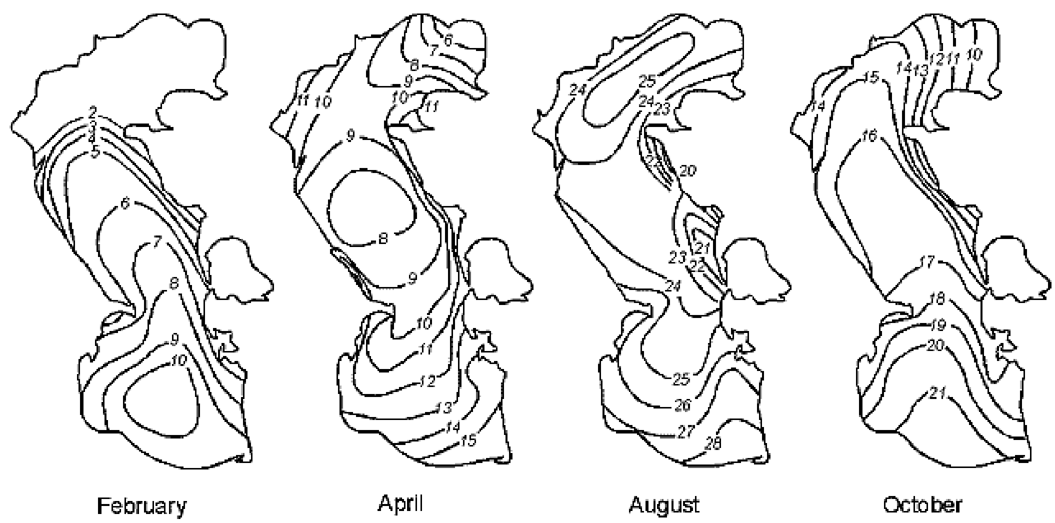

Figure 1.3 Surface water temperature in the Caspian Sea (After Dumont, 1998)

Air temperature: The average annual air temperature over the Caspian Sea varies from 10°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).

Salinity of water**:** The salinity of the Caspian Sea changes from the north to the south within a range of 1.0 to 13.5ppt 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 14ppt. The average salinity of the Middle Caspian is 11-12ppt, and the Southern Caspian 12-13ppt. Thus, both these areas of the Caspian, based on the Venetian classification, should be referred to as zones of mesohaline water bodies (Figure 1.4) (Aubrey, 1994; Aladin and Plotnikov, 2004).

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 variability in the Caspian waters promotes 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 existence 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; Rubanov, *et al*., 1987).

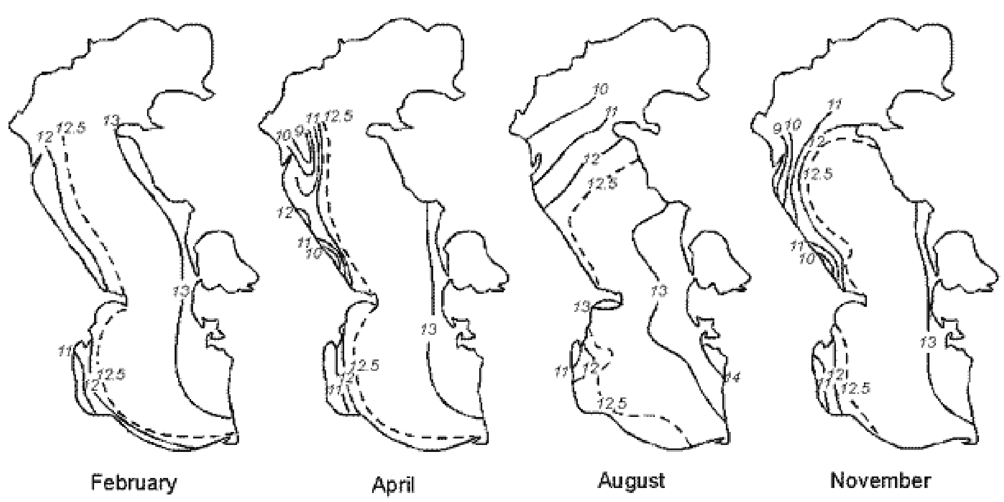

Figure 1.4 Mean salinity (g/l) in the Caspian Sea: April, June, August, and October (After Dumont, 1998).

Transparency: The waters of the Caspian Sea are characterized by high transparency. The most transparent area are the open waters of the Southern Caspian. In the Middle Caspian, the transparency of open waters is a little bit lower. In the Northern Caspian, because of the large inflow river drifts, the transparency is very low and is usually less than 1 m, and only at a great distance from the deltas, the transparency increases up to 7-8 m (Kosarev and Yablonskaya, 1994).

River: The water resources of the Caspian Sea include river flow (of up to 660 large and small rivers), ranging from 218.7 to 495.8 km^3 annually. Large rivers such as Volga, Emba, Ural and Terek discharge waters into the northern part of the Sea with the total annual flow making 88% of all rivers flow into the Caspian Sea. Other large rivers such as Sulak, Samur, Kura and a number of small ones inflow into the western part (the total flow - about 7%). The rest 5% of the total flow is produced by Iranian rivers (Gorgan, Kheraz, Sefidrua). There are no permanent watercourses in the eastern coast including the Kara-Bogaz-Gol Bay (CEP, 1998a; CEP, 2001).

Phytoplankton: Phytoplankton occupies the first notch in the biological chain of every aquatic environment. They are known as primary producers 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 patterns 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).

The Caspian has about 450 species, varieties, or forms of phytoplankton. The dominant forms are Cyanophyta, Bacillariophyta, and Chlorophyta. Middle and South

Caspian phytoplankton are a mixture of marine, brackish, and freshwater forms. By contrast, North Caspian phytoplanktons are all freshwater forms (CEP, 2002).

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 the 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 richness or abundance and biomass. (Kideys & Moghim, 2003).

1.2 Threats to the biodiversity of the Caspian Sea

Environmental problems of the CS are multiple and various in their origin. On one hand, they are caused by the commercial use of the sea; on the other hand, human activity impacts on coastal areas, including input from rivers in the Caspian. Anthropogenic impact on the Caspian ecosystem occurs concurrently with various natural endogenous and exogenous processes. It is primarily sea level changes, periodical seismic activity, surges and retreats, mud volcanoes and neo-tectonics. Special features of the Caspian include constant alterations of its area, volume, configuration of the coastline and water column structure. Anthropogenic activity, as well as a natural impact, can have a chronic (long term) or acute (short term) effects. The most important threats and/ or problems of the CS are summarized as follow:

1.2.1 Rivers regulation

At present the Caspian lacks about 12% of river input. During the period of water reservoir infill water loss was even higher. During the construction and operation of large hydrotechnical facilities on rivers, the Caspian lost 350 cubic kilometers of river water, or over 25 km^3 per year. Regulation of river flow has chronic and acute impacts. Chronic impact can be described as a shoaling of river deltas. For instance, lack of river input reduced the area of delta vegetation, and loss of vegetation resulted in loss of aquatic and coastal fauna (Sonne, 2000). The impact of dam construction on sturgeon and salmon was the most severe due to the loss of natural spawning grounds resulted in almost complete loss of the Caspian salmon population. Accidental discharges of hydropower plants have an acute impact on the Caspian. Therefore every hydropower plant makes significant damage to the biological diversity of the aquatic community. Caspian Rivers carry a high amount of pollutants from catchment areas produced by both industrial and agricultural anthropogenic impact. This can result in the Caspian becoming severely polluted.

1.2.2 Over-fishing and illegal fishing

The annual catch in the Caspian (without sprat) reduced from 283,000 tonnes in 1951-55 to 81,000 tonnes in 1990-95. However, reduced rate of catches of the majority of species in the Caspian cannot be related to the reduction of resources, but as a result of an economic recession in the fishing industry. At present there is a real threat to the survival of the species. Fishing along with river regulation and pollution resulted in the complete loss of some species of fish and Cyclostomata. Nowadays the catch of sturgeon in the Caspian has reduced from 25,000 tonnes per year to 1,000 tonnes. To recover the reserves of sturgeon with its long life cycle will take at least 30-50 years. The problem of over fishing affects other species. For example in Iran, trout, bream resulted in complete loss of these species. Over fishing is less dangerous for short life cycle species (Glukhovtsev, 1997).

1.2.3 The Caspian Sea water level changes

The CS water level change is one of the most important natural impacts on the biodiversity of this huge water body (Dumont, 1995). The impact can be both chronic (long-term) and acute (short-term). A chronic impact is historically natural sea level fluctuations, can be attributed to climate changes and river discharge into the Caspian. Acute (short-term impact) is seasonal or wind-induced changes of level. It is obvious that a continuous decrease of the CS level has a negative impact on aquatic life and a positive impact on onshore organisms. Lowering of the CS level created problems for navigation. It is clear that construction of the dyke in the head of the Kara Bogaz Gol Bay had a negative impact on both the biodiversity and economical activity of the area. It is obvious that the drying of the Bay resulted in the death of its inhabitants such as salt-loving Crustaceans, algae and bacteria. In 1992 the dyke was totally destroyed, and within 9 years the Bay became partially rehabilitated. A population of *Artemia salina* in the Bay was rehabilitated. Therefore flamingo returned to Kara Bogaz Gol. Production of cysts of *A. salina* also re-commenced. After Turkmenistan claimed its independence in the middle of 1990's, a Turkmen-Belgian company specializing in *A. salina* cysts producing was founded in the area. The Company is operating successfully and profitably (Atamuradov, 1999). Production of mineral at Kara Bogaz Gol is also successful again. Not only is the surface and the volume of the Bay restored but also its biodiversity. In addition to *A. salina* a salt-loving Crustacean *Molina mongolica* was found in the Bay. In the shallow waters of Kara Bogaz Gol salt loving water larvae of flies and mosquitoes were found. Water of the Bay is full of bacteria and algae. The most abundant are algae *Aphanothece salina* that form multiple mucous colonies at the coast, and flagellates *Dunaliella viridis* and *D. salina* that bloom during the period of mirabilite settlement. One gram of firm salt contains about 0.5 million of *Dunaliella* cells, 1 cm^3 of water contains 21 million of bacteria in average. Thus, re-establishing the natural discharge of the Caspian water in Kara Bogaz Gol allowed the biodiversity of the bay to rehabilitate. A continuous sea level rise made significant damage to plant life in deltas of Caspian Rivers. Trees cannot be constantly flooded, so dead forests can be found in all river deltas. Fast sea level rise for more than 2 m within less than 20 years had a negative impact on many plant communities; some of them were lost due to flooding. Animal communities also disappeared with the loss island. It can be concluded that sea level rise does not allow endemic Caspian aquatic life to spread to the north due to desalination of the Caspian. When sea level reduces, its salinity increases and the abundance of true Caspian endemics increases.

1.2.4 Pollution

Pollution is a significant threat to the biodiversity of the Caspian. The sources of pollution are industrial, agricultural and accidental discharges and sewage. The main flow of pollution comes from Volga. The Volga input contains discharges from other sources that did not accumulate in reservoirs and its delta. The most typical toxicants in the Caspian are petroleum hydrocarbons, heavy metals, phenol, surfactants, and chloral-organic pesticides. Oil pollution is the most dangerous one. Interaction of aquatic life with petroleum hydrocarbons causes various physiological, biochemical and morphological changes in organisms. In some cases the changes can be reversible; otherwise they cause chronic pathological effects that result in death of fish. The sources of oil pollution of the Caspian are primarily offshore wells during the drilling and production phases, accidental pipeline breaking, and cleaning of effluent of oil refineries. The other sources of pollution are toxicity of heavy metals, pesticides and some other organic pollutants. General toxicity of water at the same level of pollution varies highly and depends on ecosystem condition (hydrochemistry, eutrophication etc.). Water of the Middle and South Caspian is described as moderately polluted or polluted. As a result, the biodiversity of benthic fauna reduced by a factor of 3 to 10. The pollution is mainly related to Turkmenbashi oil refinery and transfer terminal, marine transport, and operation of oil wells. Eutrophication is a direct implication of water pollution by industrial and household organic effluents. Enclosed water bodies of wetlands (gulfs, lagoons, delta lakes) in the deltas of the Volga and the Kura are highly susceptible to eutrophication, which stems from a high density of population in the catchments of these rivers. Information on blooms and development of hypoxic zones is not available (Dumont, 1998; Ivanov, *et al*., 2000; CEP, 2001).

1.2.5 Introduced species (Some invader species)

The impact of introduced species on the biological diversity of the CS falls into two groups: chronic (long term) or acute (short term) impact. Acute impact is identified during first years after the introduction of the new species into the Caspian. All present resident species in the Caspian can be described as introduced. The only difference is the time of introduction. Some of the species were introduced so long ago that now can be considered 100% resident species.

Aquatic organisms of the Caspian can be divided into four groups. The first group is the 'indigenous', which is the most ancient introduced species. The second group is Arctic introduced species, which is known as 'glacious relicts'. The third group is 'Atlantic introduced species', which includes introduced species from the Black and Mediterranean Seas. The fourth group includes species introduced from fresh waters (Ivanov *et al*., 2000). As the above-mentioned species were introduced into the Caspian long ago, so they can be divided into ancient and recent species. The comb-jelly *Mnemiopsis leidyi* has invaded the Caspian recently. This species of comb-jellies has negatively influenced industrial fisheries in the Black sea and first of all on catches of plankton-eating fishes. The Ctenophore (*Mnemiopsis leidyi*), were introduced into the Caspian with ballast waters at the end of the 20th century. This species is an example of a negative impact on the biodiversity of the Caspian.

The species eats out zooplankton and causes starvation for the plankton-feeding fish. All the cases of introduction were related to anthropogenic activity. In 1920's four species were accidentally introduced into the Caspian: algae *Rhizosolenia calcar-avis*, bivalve *Mytilaster lineatus*, and two species of shrimps*: Leander squilla* and *L. adspersus.* There is no reliable information about the way the species were introduced. During the first years following the introduction, the abundance of the species was quite high; they suppressed the Caspian species. For instance, in 1936 the biomass of algae *R. calcar-avis* was several millions tonnes which was about 65% of the total plankton biomass. A short raise of abundance and further reduction was recorded for bivalve *M. lineatus*, and the two species of shrimps (Ivanov *et al*., 2000; Aladin and Plotnikov, 2000).

1.2.6 Climate change (global warming)

Climate changes induced the sea level and salinity changes of the ancient Caspian. These changes significantly altered the biodiversity of the water body. The fall of temperature increase the sea level, while temperature rise decrease the sea level and increase the salinity. Thus, during the period of transgressions at the Caspian, fresh-water and originally fresh-water species dominated, while the abundance of marine salt-loving species reduced. There is no doubt that global warming is a reality of the 20th century and a new coming millennium. The sudden sea level raise at the end of the 20th century induced suggestions that the global warming process is more complicated and non-linear, and the general anthropogenic warming can have unstable periods and even cooling. Global anthropogenic warming must cause reduction of the sea level, even at an early stage of global warming cyclones will carry more rains into the CS that will increase the Caspian Rivers input. However, the increase of the global temperature increase the evaporation which would not only compensate increase of rivers discharge but even will exceed it (Ivanov *et al*., 2000).

Caspian Sea is the largest inner water body on the earth which underwent sharp changes in its ecosystem during the recent decades of the twentieth century. They were caused by natural (transgression of the sea level, climate softening, increase of fresh water inflow) and anthropogenic factors (pollution, unintended invasion with ctenophore *M. leidyi*, illegal fishing for sturgeons). However, nowadays the precious Caspian ecoystem is in a catastrophic condition due to an invasive jellyfish species (the ctenophore *Mnemiopsis leidyi*). This species, transported via ballast waters from the northeastern American coasts, first to the Black Sea and later to the Caspian, is outcompeting the native pelagic fish through voracious feeding on their food items (i.e. zooplankton). Some of the documented impacts from this event are decreased zooplankton (both in quantity and in biodiversity), increased eutrophication, almost ceased pelagic fishery, mass mortalities of fish as well as of some top predators (e.g. Caspian seal) due to malnutrition, havoc for the fishing community and severe economic damage of riparian countries (Kideys *et al*.,2005; Mamedov, 2006, Roohi *et al*., 2010). All that led to significant changes in hydrological regime, state of food base, abundance and biomass of biological resources and finally in bio-productivity of the Sea The phytoplankton studies in the SCS are few, usually less rigorous and are often in less accessible literature sources as compared with similar studies done in the Black Sea and even European Seas. Previous studies have involved only short time periods and species identification was either not included or only to higher taxonomic levels (Rezvani *et al*., 1991; Hossieni *et al*., 1996; Laloei *et al*., 1999; Roohi, 2000; Roohi *et al*., 2001, 2003; Bagheri and Kideys 2003; Kideys and Moghim 2003). Hence, these long-term data (1994-2007) was conducted to identify the fluctuation in different years, and to relate the phytoplankton community with changes in SCS water quality regimes. The assessments of biological indices for classification of water quality in the SCS have not been previously studied in Iran. The use of phytoplankton as bioindicators of aquatic degradation is important to detect bio accumulation and biomagnifications of pollutions and invasive species in SCS.

The hypotheses of the study are summarized as:

(I) SCS has spatial and temporal distribution of physical, chemical and biological properties that will affect the phytoplankton species composition. Changes in SCS ecosystem can be reflected by phytoplankton species composition and distribution.

(II) The invasion of comb-jelly *Mnemiopsis leidyi* negatively influenced the biodiversity in the SCS. As an ecologically important group in aquatic ecosystem, alteration and shift in the species composition and productivity of phytoplankton assemblage will affect the food web intractions and other ecosystem composition.

(III) The impacts of *M. leidyi* on the major biological components of the ecosystems can be evaluated by gathering long-term data from different regions in the Caspian Sea. This assessment includes nutrient, phytoplankton and physichochemical parameters.

(IV) The long-term data which is provided in this study, is possible to show the role of phytoplankton and also physicochemical parameters to predict the biodiversity changes in the future.

1.3 Objectives

Based on the hypothesises, it is important to carry out a biomonitoring study by utilizing phytoplankton as indicator of anthropogenic stress on SCS ecosystem health. Hence, the objectives of this study are:

1) To determine the physico-chemical parameters of the SCS that affect phytoplankton species composition, distribution and abundance.

2) To investigate the toxic phytoplankton in the southern part of Caspian Sea and the effect of physicochemical parameters on phytoplankton population.

3) To determine the effect of *M. leidyi* on phytoplankton species composition and diversity fluctuation.

4) To determine the species diversity of phytoplankton, as an indicator of trophic changes and the assessment of biological indices for classification of water quality in the SCS.

5) To study the correlation between physical, chemical and biological parameters of water quality based on the changes in phytoplankton in order to find out the trends for monitoring water quality in the southern part of Caspian Sea.

CHAPTER2

LITERATURE REVIEW

Researches on phytoplankton of the CS started to be carried out only from the beginning of Nineteen century. A review of the literature on phytoplankton for 1900-1965 was in detail expounded in the book of Proshkina-Lavrenko and Makarova (1968) who revised the species described, gave a geographical distribution and the ecology of species (Kasymov, 2004).

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 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).

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