ECOLOGICAL ASSESSMENT OF PLANKTON COMMUNITY AND EFFECTS OF ALIEN SPECIES IN THE SOUTHWESTERN CASPIAN SEA

by

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LIST OF ABBREVIATIONS

Abbreviation	Descriptions
ANOVA	Analysis of Variance
CEP	Caspian Sea Environment Programme
CSBP	Caspian Sea Biodiversity Project
DIN	Dissolved Inorganic Nitrogen
DIP	Dissolved Inorganic Phosphors
DSi	Dissolved Silicate
GWRO	Guilan Water Resource Organization
JICA	Japan International Corporation Agency
IFGO	Iranian Force power Geography Organization
IFO	Iranian Fisheries Organisation
IFRO	Iranian Fisheries Research Organistion
IT IS	Integrated Taxonomic Information System
MarBEF	Marine Biodiversity and Ecosystem Functioning
METU	Middle East Technical University
MVSP	Multi Variate Statistical Package
SD	Standard Deviation
SE	Standard Error
SPSS	Statistical Package for the Social Sciences
UPGMA	Unweighted Pair Group Method Average
TPN	Transparent Plastic Nansen
WoRMS	World Register of Marine Species
TSI	Trophy State Indicator

LIST OF SYMBOLS

Symbol	Descriptions
cells L^{-1}	Cells per liter
°C	Degree Celsius
d	Day
°E	Degree east
g	Gram
ha	Hectare
ind.m^{-3}	Individual per cubic meter
kg	Kilogram
km^2	Square kilometer
km^3	Cubic kilometer
m^3	Cubic meter
ml	Milliliter
mm	Millimeter
°N	Degree north
ppt	Parts per thousand
PSU	Practical Salinity Units
s	Second
y	Year
µM	Micromole
µm	Micrometer
%	Percentage

PENAKSIRAN EKOLOGI KOMUNITI PLANKTON DAN KESAN SPESIES ASING DI BARAT DAYA LAUT CASPIAN

ABSTRAK

Ekosistem Laut Caspian dengan aras pengelasan endemik yang tinggi telah mengalami pencemaran antropogen, perubahan dalam kuantiti nutrien dan kesan spesies invasif semenjak tahun 1980. Dua belas stesen kajian telah dikaji secara bermusim untuk melihat perubahan temporal komuniti fitoplankton dan zooplankton di barat daya Laut Caspian dari 1996 sehingga 2010. Daripada 158 spesies fitoplankton yang telah dikenalpasti, spesies yang dominan adalah diatom *Thalassionema nitzschioides*, *Dactyliosolen fragilissimus*, dinoflagelat *Prorocentrum cordatum*, dan sinofit daripada genus *Oscillatoria*. Peningkatan bilangan fitoplankton telah diperhatikan selepas tahun 2000 dan telah berlanjutan sehinga 2010. Kecuali bagi tahun 2001 dan 2002, diatom mendominasi sepanjang kajian ini. Sepanjang kedua-dua musim kemarau (2001 dan 2002), pengurangan kadar aliran sungai dan aras silikat, digandingkan dengan penambahan suhu air dan kemasinan merupakan faktor-faktor utama yang menyebabkan pertumbuhan dinoflagelat *P. cordotum* dan sinofit *Oscillatoria* sp. di barat daya Laut Caspian.

Sebanyak 61 taksa zooplankton telah ditemui di kawasan kajian. Tiga belas daripadanya merupakan meroplankton dan 48 merupakan holoplankton. Pengurangan dalam spesies zooplankton telah diperhatikan sebelum tahun 2000 dan berlanjutan sehingga 2010. Hanya satu daripada sembilan spesies Cladocera yang telah direkod sepanjang tahun 1996/1997 dijumpai pada tahun 2010. Daripada lima spesies Copepoda yang telah direkod sepanjang tahun 1996/1997, hanya satu spesies iaitu *Acartia tonsa*

yang direkod selepas tahun 2000. Larva dwicangkerang juga turut berkurangan sebanyak satu magnitud order sejak tahun 1996/1997. Larva dwicangkerang ini menghasilkan terdiri lebih daripada 50% jumlah bilangan zooplankton sebelum 2000. Spesies dominan zooplankton adalah *A. tonsa* selepas tahun 2000. Hasil penemuan menunjukkan tiada pengurangan jumlah *A. tonsa*, *Balanus* sp., *Nereis* sp., *Synchaeta* sp. dan *Tintinnopsis* sp., dikesan sepanjang tempoh blum *Mnemiopsis leidyi* selepas 2001 sehingga 2010. Populasi *M. leidyi* di barat daya Laut Caspian kebanyakannya merupakan individu yang mempunyai panjang kurang daripada satu sentimeter. Purata kelimpahan dan biojisim *M. leidyi* adalah antara 200 hingga 400 individu m^{-3}, dan 30 hingga 40 gram jisim basah m^{-3} sepanjang tempoh penyelidikan ini. Puncak kelimpahan bermusim dan biojisim *M. leidyi* di barat daya Laut Caspian berbeza dari tahun ke tahun. Purata suhu permukaan air semasa musim panas dan luruh adalah 20.0 ± 4.5°C, dan kajian mendapati *M. leidyi* lebih cenderung untuk hidup berhampiran permukaan air (sehingga kedalaman 20 meter).

Tiada impak *M. leidyi* terhadap zooplankton dan spesies fitoplankton yang dapat disahihkan dengan membandingkan purata tahunan kelimpahan fitoplankton dan zooplankton, terutamanya *A. tonsa*, pada tahun 1996/1997, sebelum serangan *M. leidyi*, dan selepas serangan semasa 2001 sehingga 2010. Kehilangan spesies Copepoda dan spesies Cladocera adalah tidak disebabkan oleh permilihan permakanan oleh spesies *M. leidyi* kerana spesies *M. leidyi* tidak memilih makanannya. Perubahan iklim, kemarau, aktiviti antropogenik, perikanan berleluasa, dan peningkatan bebanan pencemaran yang disebabkan oleh saliran sungai memainkan peranan yang penting dalam pengembangan populasi fito-zooplankton dan kehilangan spesies endemik di selatan Laut Caspian.

ECOLOGICAL ASSESSMENT OF PLANKTON COMMUNITY AND EFFECTS OF ALIEN SPECIES IN THE SOUTHWESTERN CASPIAN SEA

ABSTRACT

The Caspian Sea ecosystem, with its high level of endemic taxa has suffered from anthropogenic pollution, changes in the quantity of nutrients, and the effects of invasive species since the 1980s. To study the temporal changes in phytoplankton and zooplankton communities, seasonal surveys were undertaken at 12 stations in the southwestern Caspian Sea from 1996 to 2010. Among 158 phytoplankton species identified, the dominant species were the diatoms *Thalassionema nitzschioides, Dactyliosolen fragilissimus,* the dinoflagellate *Prorocentrum cordatum*, and the cyanophyte of genus *Oscillatoria*. An increase in phytoplankton abundance was observed after 2000, and has continued until 2010. Except in 2001 and 2002 diatoms predominated thoughout the study. During these two drought years (2001 and 2002), a decrease in river discharge and silicate levels, coupled with an increase in water temperature and salinity were the main factors causing a bloom of dinoflagellate *P. cordotum* and cyanophyte *Oscillatoria* sp. in the southwestern Caspian Sea.

A total of 61 zooplankton taxa were found in the study area. Thirteen of them were meroplankton and 48 holoplankton. A decline in zooplankton species was observed before 2000 and continued until 2010. Only one of nine Cladocera species recorded during 1996/1997 were again, found in 2010. Of the five Copepoda species recorded during 1996/1997, only one, *Acartia tonsa*, was recorded after 2000. Bivalvia larvae have also declined by one order of magnitude since 1996/1997. Bivalvia larvae formed more than 50% of the total abundance of zooplankton before 2000. The

dominant zooplankton species was *A. tonsa* after 2000. The findings revealed no decrease of *A. tonsa, Balanus* sp., *Nereis* sp., *Synchaeta* sp. and *Tintinnopsis* sp. detected during the blooming period of *Mnemiopsis leidyi* after 2001 until 2010. *M. leidyi* populations in the southwestern Caspian Sea consisted mainly of individuals less than 1 cm in length. The average number and biomass of *M. leidyi* varied from 200 to 400 individual m^{-3}, and 30 to 40 g wet weight$\cdot m^{-3}$ during the study period. Seasonal peaks of abundance and biomass of *M. leidyi* were varied in the southwestern Caspian Sea from year to year. The average water surface temperature during summer and autumn was about 20.0 ± 4.5°C, with the results that *M. leidyi* preferred to settle in upper water layers (at the surface to 20 m depth). No impact of *M. leidyi* on the zooplankton and the phytoplankton species could be verified by comparing the annual average of the abundance of phytoplankton and zooplankton, especially that of *A. tonsa*, in 1996/1997, before the invasion of *M. leidyi,* and after the invasion during 2001 to 2010. The reason for the disappearance in Copepoda and Cladocera species is not owing to selectivity for feeding of different species by *M. leidyi,* as the *M. leidyi* is non-selective feeding. Climate change, drought, anthropogenic activity, overfishing, and increase pollutants loading by river run-off can be played an important role in the enhancement of phyto-zooplankton population and loss of endemic species in the Southern Caspian Sea.

CHAPTER 1

GENERAL INTRODUCTION

1.1 Features of the Caspian Sea

Iran lies between latitudes 25°N and 40°N and longitudes 44°E and 63°E which is located on the Eurasian plate and bordering the Arabian plate. The Zagros Mountains are the Thrust Mountains formed on its northern border (JICA, 2010). Iran is the second major nation in the Middle East, with a region of 1,648,000 km^2; it grades fourteenth in the world, being almost as large an area as the United Kingdom, France, Italy and Spain combined (Firouz *et al*., 1970; Coad, 2008).

The Caspian Sea is a huge internal water body. Even though it is not connected to any marine system, it is too large to be called a lake (Putans *et al.*, 2010). The Caspian Sea can be divided into three areas: Northern, Central and Southern. The capacity is 78,100 km^3, representing 44% of the total amount of internal lakes of the planet (Figure 1.1).

Volga river is estimated to pour almost 76.3% of its inflow into the Caspian Sea, while the Kura, Ural and Terek rivers contribute 4.9%, 3.7% and 3.2% respectively. The other rivers along the Iranian seashore, account for the remaining 11.9% of the river input (Coad, 2008).

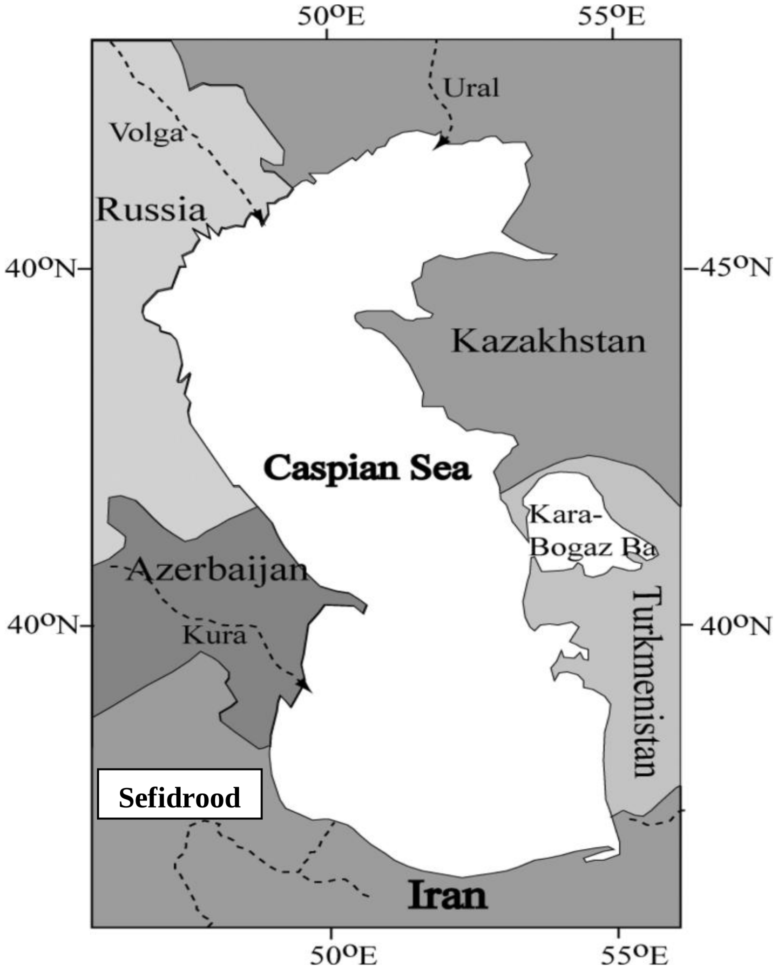

Figure 1.1 Caspian Sea with the adjacent countries and main freshwater rivers (from Kazemi & Tsunogai, 2009).

Iranian territorial waters are within the southern Caspian basin, occupying an area of 148,700 km^2, and separated from the middle Caspian Sea by the Apsheron Bank. The south Caspian Sea holds over 65% of the water body, while the northern Caspian holds only 1% of the water (Kazemi & Tsunogai, 2009).

1.2 Meteorology of the southwestern Caspian Sea

Annual precipitation in the southwestern Caspian Seais estimated at between 1,500-2,000 mm per year (Jafari, 2009). More than 90% of the average annual precipitation in the area occurs between November and May (JICA, 2010). Annual evaporation in the area is less than 1,500 mm.

1.3 Catchment area and river discharge in the southwestern Caspian Sea

The Caspian drainage basin in Iran covers an area of 185,000 km^2, encompassing the whole of the northern part of Iran (Lahijani, 2004). The rivers in northwestern and northeastern Iran flow into the sea through Azerbaijan and Turkmenistan respectively. Rivers that flow to the Caspian Sea through the Iranian coast have a dominant drainage basin, most of which is located on the northern flank of the Elborz mountain range (Lahijani *et al*., 2008). There are more than 80 rivers in the Guilan Province that flow into the southwestern Caspian Sea. The Sefidrood river is the largest river in Iran entering the Caspian Sea with a 67,000 km^2 catchment area and a discharge of 4,037 million m^3 per year. The Sefidrood river constitutes a major route of sturgeon migration for reproduction and spawning (CEP, 2007). The rivers that flow into the southwestern Caspian form a delta in the area and encompass 135,000 km^2 of that catchment's basin (Lahijani *et al*., 2008). Annual discharge of the main river (Sefidrood river) in the southwestern Caspian Sea varies between 30-300 million m^3 per year and is shown in Figure 1.2.

Figure 1.2 Long-term fluctuation of the Sefidrood river discharge in the Caspian Sea during 1985- 2009 (GWRO, 2010).

The Anzali wetland is the other freshwater source. The Anzali complex is located in Guilan Province, and constitutes the most important wetland in the southwestern Caspian region. The catchment area is 3,740 km^2, and the wetland contributes about 2,400 million m^3 freshwater per year (Sharifi, 2006; JICA, 2010). The Anzali wetland is of great importance to Iran owing to its diversified habitats and designation as an international wetland, established by the Ramsar Convention (Jafari, 2009). The average length of the wetland is about 30 km and average width about 3 km, although in some places it exceeds 12 km. The wetland includes a passage to the Caspian Sea with an average width of 426 m (Figure 1.3). Eleven tributary rivers flow into the Anzali wetland (Khodaparast, 2004). Total precipitation in the area is 2000 mm per year (Jafari, 2009). The main wetland is drained by the Sowsar, Pir Bazar, Raste-Khaleh, Nahang and Kolver Rogas over a distance of about 4 km to the southwestern Caspian Sea(Mirzajani *et al.*, 2010).

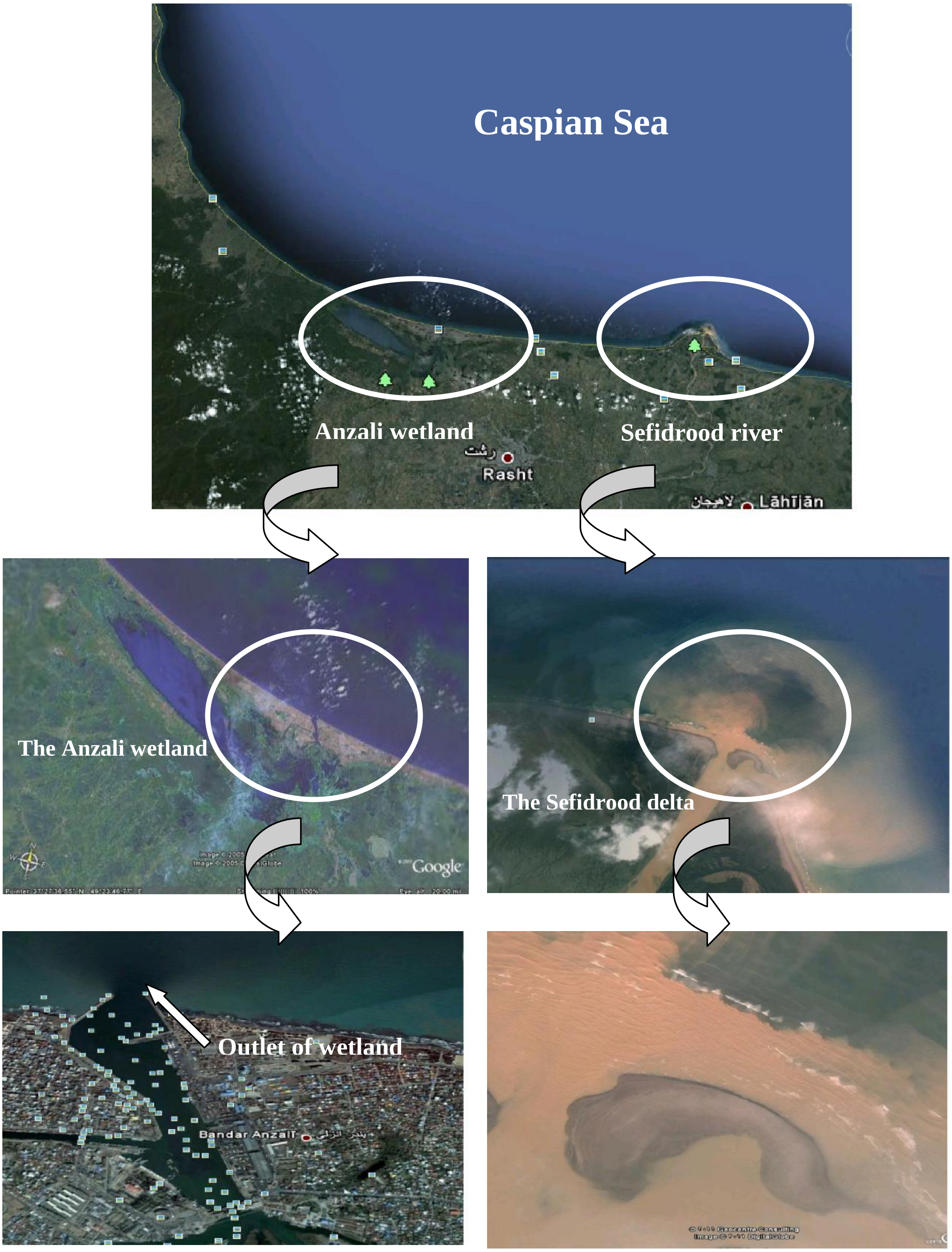

Figure 1.3 Images of the Anzali wetland (49° 27' 44" E & 37° 28' 30" N) outlet and the Sefidrood river (49° 56' 81" E & 37° 28' 96" N) discharge into the southwestern Caspian Sea (Google Earth, 2011). E = east, N = north

1.4 Environmental degradation in the Caspian Sea

1.4.1 Water pollution

The salinity of the Caspian Sea ranges from 0.10 to 13.50 from north to south. There is also a slight increase in salinity with depth (Kosarev & Yablonskaya, 1994). In the northern Caspian Sea, inorganic phosphate levels are on average 0.12-0.80 µM. Nitrogen is largely present in organic form (10.0-25.0 µg L^{-1}). Nitrate concentration can reach up to 0.50 µM in spring and summer and 10.0 µM in winter. Silicate concentration shows a strong seasonal cycle and decreases from 60.0 µM in winter to < 20.0 µM in summer, when diatom blooms were observed (Dumont, 1998).

Over the last thirty years, the Caspian Sea has undergone significant ecological alterations. Besides being inconsistently separated from other marine (Rodionov, 1994), the Caspian Sea has also been subjected to major anthropogenic impacts on its ecosystem due to local pollution (e.g., phosphorous-containing detergents), industrial (e.g., heavy metals and other industrial by products), and agricultural discharges (e.g., nitrogen-containing fertilizers and pesticides). In addition, the development of oil and gas fields provided extra pressure on the ecosystem, particularly the fish species (Salmanov, 1999; Ivanov, 2000; Aladin & Plotnikov 2003; Ayati, 2003).

Several cities, industries and factories surround the Iranian shores of the Caspian Sea. Urban sewage from more than 10 million poeple is the main contaminant in the area. Sewage from the manufacturing sector contributes approximately 31% of the total pollution loading. The main developed zone is in the region of Rasht (the capital of Guilan Province) with wastes discharging into the surrounding rivers and ultimately ending up in the southwestern Caspian Sea. In the Guilan District, 32 main cities and 90 industries discharge untreated wastewater directly into the surrounding rivers (Coad, 2008). For example, the Sefidrood river and the Anzali wetland suffer seriously from various major sources of pollution such as agrochemicals, sewage, and industrial effluents (Khodaparast, 2004; CEP, 2007; Safaei, 2008; Kazemi & Tsunogai, 2009; JICA, 2010). Judging by the rapid growth of agriculture, urbanization, and industry, together with the lack of environmental management, the overall environmental quality of the rivers and the Anzali wetland have probably been declining steadily during the past few decades (CEP, 2007). Talebi (1998), Mirkou (2001), Ayati (2003), Ghandi *et al.* (2005) each detailed agro-chemical usage along the Caspian shore, which includes various fertilizers, and a chlorinated pesticide diazinon that has been used throughout Iran in its anti-malarial campaigns. Herbicides and pesticides are extensively used in paddy fields (the rice field area in the Guilan Province comprises about 190,000 ha) in the southern Caspian Sea basin (JICA, 2010).

Half of Iran's fishery is from the Caspian Sea and the other half is through inland fishery in the Guilan District, totaling 18,000 tonnes and 19,900 tonnes, respectively. About 91% of the inland fishery involves fish culture (JICA, 2010). There are numerous aquaculture ponds in the Guilan region, with a total area of 3,500 ha, and fish culture (common carp, silver carp, grass carp, bighead and rainbow trout) activities practiced (JICA, 2010). These fisheries all use antibiotics, formaldehyde, copper sulphate, and malachit green. Iran was the first country to export high quality caviar, but the annual harvest of caviar has decreased drastically in the Caspian Sea. The Iranian Fisheries Organisation (IFO) is apprehensive about the recent rapid degradation of water quality in the Caspian Sea (Dumont, 2000).

1.4.2 Invasive species

The diatom *Pseudosolenia calcar-avis* first appeared in the Caspian in the mid-20th century, and rapidly became established to the point where it often represented more than 90% of the phytoplankton biomass. *Pseudosolenia calcar-avis* is a very large diatom (length: 300 µm), and is almost certainly too large for the native zooplankton species to consume. Consequently, this may have contributed to a progressive decline in zooplankton production, with resultant effects on planktivorous fish species (Shiganova *et al.*, 2005; CEP, 2007).

Acartia tonsa is a widespread copepod. It is common in coastal areas, and sometimes occurs in huge abundance. Native populations inhabit the Indian Ocean, and the Atlantic and Pacific coasts of both North and South America. It was introduced to the Black Sea in the mid-1970s with the first record on 1976. Surprisingly the same species was found in Mediterranean Sea, but much later in 1985. In the Caspian Sea, *A. tonsa* appeared in early 1980s. In the north Caspian Sea it was observed in 1982, and in the middle Caspian in the 1983. Today *A. tonsa* is found throughout the Caspian and has become an dominant organism in the zooplankton communities of the south and middle Caspian Sea (Shiganova *et al.*, 2005; Plotnikov *et al*., 2006; CEP, 2007).

Mnemiopsis leidyi originated off the east coast of the Americas and is classified as a very successful invader-species. It was transported most possibly in ballast water to Europe in the mid-1980s. It started its procession in the Black Sea towards the end of the 1980s, invaded certain areas of the Mediterranean Sea at the beginning of 1990s, and was found throughout almost the whole basin by 2009 (Mutlu, 2009; Galil *et al*., 2009; Boero *et al*., 2009; Fuentes *et al*., 2009). By the late 1990s *M. leidyi* had expanded to the Caspian Sea (Esmaeili *et al*., 1999; Ivanov *et al*., 2000; Shiganova *et al*., 2004) and has now also become very frequent in the North Sea and Baltic Sea since 2006 (Faassel & Bayha, 2006; Oliveira, 2007; Javidpour *et al*., 2009a; Hintikainen, 2009).

1.4.3 Climate change and overfishing

Unusual changes to the hydrological system and climate were detected in the North Atlantic to the Ponto-Caspian at the end of the 1980s (Bilio & Niermann, 2004). These changes in the system may have altered the plankton structure and pelagic fish stock in the Caspian Sea and Black Sea (Niermann *et al.*, 1999; Oguz *et al.*, 2003; Yunev *et al.*, 2005). The biomass of pelagic fish in the Caspian Sea, Bering Sea and the Black Sea, showed marked variations. For example, the entire stock of the pelagic fish catch dropped from 186,000 in 1996 to 12,000 tonnes in 2004 in the Iranian part of Caspian Sea (Fazli *et al.,* 2007). Almost 90% of the sturgeon world stock are concentrated in the Caspian Sea. The sturgeon landing dropped from 25,000 to 900 tonnes during 1980 and 2004 in the Iranian part of Caspian Sea (CEP, 2007). The latest findings documented that pelagic fish mass changed significantly irrespective of the Ctenophora blooms (Fazli *et al.*, 2007). Only in the Caspian Sea and Black Sea, the decrease of pelagic fish stocks was correlated with the invasive species *M. leidyi* (Bilio & Niermann, 2004).

1.5 Objectives of study

Since the 2000s, a long-term programme has been initiated by the Iranian Fisheries Research Organization (IFRO) to monitor the development of *Mnemiopsis leidyi*, mesozooplankton, phytoplankton and environmental parameters of the southern Iranian coast of Guilan and Mazandaran Provinces (Kideys *et al.*, 2001). Within the framework of this programme, Roohi (2009) documented population dynamics and effects of *Mnemiopsis leidyi* in the southern Caspian Sea. Nasrollahzadeh (2008) studied nutrient distribution in the Iranian coastal waters of the Caspian Sea and its influence on phytoplankton abundance and diversity. Nasrollahzadeh (2008) and Roohi (2009) concluded that the total abundance and biomass of *M. leidyi* decreased to a certain extent in the years after 2003 but that the impact of *M. leidyi* on nutrients, phytoplankton and zooplankton in terms of species composition and abundance was still evident and may remain for years.

In order to investigate the situation that has developed during 2001 to 2006 in the southern Caspian, a long-term survey on the phytoplankton, zooplankton, and *Mnemiopsis leidyi* community in the southwestern Caspian Sea was undertaken from 1996 to 2010. This study was designed according to the objectives:

1) To study annual and seasonal changes in phytoplankton and zooplankton community;

2) To investigate the annual and seasonal fluctuation of *Mnemiopsis leidyi*: distribution, abundance, and biomass and size composition;

3) To determine the relationship between phytoplankton and zooplankton abundance, and *Mnemiopsis leidyi* population and environmental variables; and

4) To assess correlation between phytoplankton and zooplankton abundance with *M. leidyi* population size.

CHAPTER 2

LITERATURE REVIEW

2.1 History of research

Several institutes of fisheries and marine science were launched in the Caspian Sea during 1932 to 1965 (Aladin & Plotnikov, 2003). In 1968, the Atlas of Invertebrates was published (Birshtain *et al.*, 1968), and have become an important manual for biodiversity studies. Many monographs and evaluations dedicated to species diversity, distribution patterns, abundance, and biomass of phytoplankton, zooplankton and benthos in the Caspian were published by Zenkevich (1963), Birshtain *et al.* (1968), Karpevich (1975), Bagirov (1989), Voynova & Alikperov (1992), Kosarev & Yablonskaya (1994), Dumont (1995), Kasimov (1982, 1994, 2000), Dumont (1995, 1998, 2000), Ivanov (2000), Ivanov & Sokolskiy (2000), Ivanov *et al.* (2000), Mamaev (2002), Aladin & Plotnikov (2003), Shiganova *et al.* (2005) and Plotnikov *et al.* (2006).

Studies on the Iranian section of the Caspian are few and none were carried out before the 1980s. The first investigation of the southern Caspian Sea was carried out by Barimani (1977) who reviewed the geography, hydrology and biology of the Caspian Sea. After this publication, there have been a rapid increase on the studies on hydrology and hydrobiology, water quality, phytoplankton, zooplankton, and benthos, along the Iranian coasts beginning in the 2000s. Mohammadjani (1991) identified the phytoplankton and zooplankton communities along the coast of Caspian Sea and the Anzali wetland. Fallahi (1993) examined the plankton communities of the Iranian waters. Hossieni *et al.* (1998) investigated the hydrology and hydrobiology of the southern Caspian Sea. Razavi (1999) gave an introduction to the ecology of the sea.

Since 2000 many studies were carried out in the Caspian Sea by the Iranian Fisheries Research Organization (IFRO) and the Caspian Sea Environmental Programme (CEP) such as Nezami *et al.* (2000), CEP (2001), Laloei *et al.* (2002), and CEP (2006, 2007). They provided an up-to-date general description of the Iranian Caspian coastal zone: the important rivers, wetlands, water quality, climate, pollutants, and fisheries. Several papers on phytoplankton, zooplankton, *Mnemiopsis leidyi*, and water quality in the southern Caspian Sea, have been published in recent years. These include the works of Kideys & Moghim (2003), Kideys *et al*. (2005b) Kideys *et al*. (2008), Nasrollahzadeh (2008), Roohi (2009), and Ganjian *et al*. (2010).

There are a few studies on the plankton community in the southwestern Caspian Sea (Guilan coasts), which include: harmful algal bloom in the southwestern basin of the Caspian Sea (Khodaparast, 2006); identification and distribution of phytoplankton in Anzali wetland and the coast of Caspian Sea, and the study on *Nodularia* sp. anomalous algal blooming in the southwestern Caspian Sea (Makaremi *et al*., 2006, 2007); identification of Copepoda and Cladocera in the Caspian Sea (Guilan Province) (Sabkara *et al.*, 2007); distribution and abundance of *Mnemiopsis leidyi* in the western Iranian coasts of the Caspian Sea (Bagheri & Kideys, 2003); and the study of the *Mnemiopsis leidyi* in the Iranian seashore of the Caspian Sea (Bagheri *et al.*, 2004).

2.2 Biodiversity feature

Endemism in the Caspian still rivals that of the Lake Baikal (Dumont, 1998; Plotnikov *et al.,* 2006). The first reliable report of the Caspian Sea ecosystem is that of Zenkevich (1963), which recorded 718 taxa, included protozoa (62 taxa), invertebrates (397 taxa), vertebrates (79 taxa), metazoan (476 taxa), and parasitic organism (170 taxa). Of these taxa, almost 46% were native to the Caspian Sea, although 66% also occupy nearby southern seas, 4.4% are of Atlantic and Mediterranean genera, and 3% are of Arctic genera (Aladin & Plotnikov, 2004).

Among the fish, several species of Gobiidae (35 taxa), Clupeidae (18 taxa), and Sturgeon (5 taxa) are either native to the Caspian Sea, or common only with the Black Sea. A feature of the Caspian biota is euryhalinity, freshwater taxa source tolerable of salinities up to 13 PSU and marine taxa source tolerable of salinities as low as 13 PSU organism current.

2.3 Phytoplankton

The northern Caspian Sea phytoplankton structure is quite different from that of the middle and southern Caspian, and contains characteristic marks of estuarine plankton, poor by marine species (Aladin *et al.,* 2009). Kosarev & Yablonskaya (1994), reported an early study of phytoplankton of the Caspian, listed a total of 449 taxa found between 1962 and 1974. The 449 taxa consisted of Bacillariophyta (163 taxa), Chlorophyta (139 taxa), Cyanophyta (102 taxa), Dinoflagellata (39 taxa), Euglenophyta (5 taxa), and Chrysophyta (1 taxa). The total phytoplankton taxa changed from 414 to 71, respectively in the north and south mostly owing to the declining of freshwater discharge in the south of the Caspian Sea (Dumont, 1998). Diatoms have the largest number of species in the marine ecosystem during bloom periods (Dumont, 1998; Eker, 2006). The diatom *Pseudosolenia calcar-avis* has the largest biomass, while Dinoflagellata is represented mainly by marine and brackish water forms and are of high importance to the food web. *Prorocentrum cordatum* is numerous but has a smaller biomass than *P. calcar-avis* because its cells are ten times smaller. The share of marine species increases from 7% in the northern part of the Caspian up to 27% in the more southern regions (Kosarev & Yablonskaya, 1994; Dumont, 1998; Aladin & Plotnikov, 2003). *Pseudosolenia calcar-avis* accounts for the bulk of the phytoplankton of the middle and southern Caspian. Long-term changes in development of phytoplankton of the northern Caspian are connected to the amount of nutrients brought in by the Volga river. Nasrollahzadeh (2008) reported the average abundance of phytoplankton in 2005 as significantly higher than in 1996. In spring 1996, both *Cyclotella meneghiniana* and *Skeletonema costatum* were the dominant species, accounting respectively for 29% and 30% of the total phytoplankton in the Iranian coast of Caspian Sea. During the summer of 1996, diatoms were still the dominant group, although *Anabaena spiroides* (cyanophyte) and *Binuclearia lauterbornii* (chlorophyte) increased in abundance. In autumn and winter of 1996, more than 50% of the phytoplankton abundance was accounted for by *Thalassionema nitzschioides*. Kideys *et al.* (2005a) noted that phytoplankton structure of the Eastern Caspian Sea was different from that of the Southern Caspian Sea. Among 45 phytoplankton taxa, only 21 taxa are common in these areas; with average phytoplankton abundance of 40,000 cells L^{-1} in the middle and southern Caspian Sea. The dinoflagellates accounted for 47% of the total abundance with *Prorocentrum compressum*, *P. cordatum* and *P. scutellum* (main species) and diatoms made up 70% of the total biomass of the phytoplankton (Kideys *et al*., 2005a), the most dominant being *Pseudosolenia calcar-avis,* which contributed 65.5% of the whole biomass.

In the spring of 2005, the composition of the major phytoplankton species was more evenly distributed, with *C. meneghiniana* and *T. nitzschioides* having slightly higher percentile of abundance (Nasrollahzadeh, 2008). During summer and autumn of 2005, *Oscillatoria* sp. and *Spirulina laxissma* were the dominant species, with *Chaetoceros* sp. (a diatom) having the second-highest percentile abundance in the southern Caspian Sea (Nasrollahzadeh, 2008). Between 2001 and 2006, 226 phytoplankton taxa were documented. Diatoms consisted almost 50% of the total taxa, Chlorophyta (20%), Cyanophyta (17%), Dinoflagellata (11%) and Euglenophyta (8%) were other contributors (Roohi, 2009). The maximum average phytoplankton abundance was recorded at 396,000 cells L^{-1} which occurred in January 2002. The minimum abundance was recorded during summer of 2003 (19,000 cells L^{-1}). Roohi *et al*. (2010) reported that diatoms were the main phytoplankton taxa in 1996, while after the 2000s (appearance of *M. leidyi*), the Cyanophyta and Dinoflagellata abundance exceeded the diatoms.

2.4 Zooplankton

Among 315 zooplankton taxa recorded for the Caspian Sea, 135 taxa were the Protista. Bagirov (1989) and Aladin & Plotnikov (2004) reported that number of zooplankton taxa were almost 200 in the northern Caspian Sea, Protista stand for almost 70 taxa, Rotatoria 50 taxa, Cladocera 30 and Copepoda more than 20 taxa.

Meroplankton, represented mainly by larvae of bivalves and crustaceans, contributes to the biodiversity of plankton communities. Changes of organisms complexes, from brackish to freshwater and marine are observed from the northern coast to the southern coast. A freshwater complex of rotifers and cladocerans occupy shallow water and estuaries with freshwater species of *Brachionus, Moina, Diaphanosoma,* and *Bosmina* (Kasimov, 2000; Aladin & Plotnikov, 2004; Aladin *et al.*, 2009).

Representative zooplankton taxa in the shoreline zones of the middle and southern Caspian include *Calanipeda aquaedulcis, Acartia clausi, Heterocope caspia, Podonevadne camptonux, and P. angusta*. In the middle and southern Caspian, more than 50% of the total zooplankton biomass is formed by larvae of *Balanus* in spring, and by the larvae of Bivalvia in summer (Bagirov, 1989). Besides Cladocera was the most important zooplankton species (25–55% of the total number) in the western coast of the Caspian Sea. Among Copepoda, dominant species are: *Eurytemora grimmi, E. minor, Acartia clausi, Calanipeda aquaedulcis,* and *Limnocalanus grimaldii.* These species are found throughout the year. Of cladocerans, *Pleopis polyphemoides*, *Podonevadne trigona, Camptonyx macronyx, P. camptonyx podonoides, Evadne anonyx producta*, and *E. anonyx deflexa* were found here. *P. polyphemoides* is the dominant species in spring; *Podonevadne trigona* is constantly present in the summertime. The endemic *Cornigerius maeoticus hircus*, *C. maximowitschi*, and *C. Bicornis* are rare. The other representatives of cladocerans are freshwater crustaceans of the family Chydoridae and *Bosmina longirostris* (Kasimov, 2000).

Hossieni *et al.* (1998) documented that zooplankton community consisted of 36 taxa (86 and 14 %, respectively holoplankton and meroplankton), including Cladocera (24 taxa), Copepoda (7 taxa), and meroplankton (2 taxa) in the Iranian coastal of Caspian Sea. They reported that the average zooplankton abundance changed between 8,400 and 33,200 ind.m^{-3} during 1996.

Sabkara & Makaremi (2007) performed a survey in Anzali region in 1996 during which they identified 16 species of Cladocera, dominated by the group Polyphemidea. They noted that *Pleopis polyphemiodes, Polyphemus exigus, Cercopagis pengoi,* and *Podonevadne trigona* were prevalent. Sabkara *et al.* (2007) published results from a study of zooplankton distribution along the Anzali coast during 1999/2000, with greater taxonomic emphases. They noted the zooplankton taxa number was observed to be more than 50, of which more than 80% were holoplankton and the remainder meroplankton; the dominant zooplankton species were Rotifera (22 species). They also identified Copepoda taxa, and recorded seven species in Anzali inshore, of which the dominate taxa were *Acartia* sp. and *Euytemora* sp.

Roohi *et al.* (2008) noted that 18 zooplankton taxa discovered in the southern Caspian Sea, of which 5 taxa were holoplankton (4 Copepoda and 1 Cladocera) and the remainder meroplankton (13 taxa). The lowest zooplankton abundance (397 ind.m^{-3}) and biomass (1.8 mg m^{-3}) were recorded in autumn 2002. The main zooplankton abundance and biomass were Copepoda, and occurred at each station during 2001 to 2006. The maximum and minimum of zooplankton abundance changed between 3,400 and 9,000 ind.m^{-3} in 2001 to 2006 (Roohi, 2009).

Roohi *et al.* (2010) reported that the highest zooplankton abundance (22,000 ind.m^{-3}) was recorded during winter of 2001, while the peak zooplankton biomass (64.1 mg.m^{-3}) was during summer of 2004. Monthly variations of zooplankton abundance and biomass were similar during 2001 to 2006. There was a decrease (abundance and biomass) of 20–50% after the appearance of *M. leidyi* during 1996 to 2006 (Roohi *et al.*, 2010). Roohi *et al.* (2008) believed many changes in the species richness and diversity of plankton structure occurred after the appearance of *M. leidyi* in the southern Caspian Sea.

Zooplankton study of the coasts of Black Sea revealed an increase in abundance during 1984 to 1986, and a decrease in abundance in 1987 to 1989. Similar observations were recorded in other areas of the world (Niermann *et al*., 1999). Large copepod taxa as significant food source depleted while other opportunistic taxa such as A*cartia tonsa* rose in the Black Sea (Shiganova *et al*., 2004). The major food sources for pelagic fish such as kilka are Copepoda species; a shift in the Copepoda population and species composition has effect on the pelagic fish. Copepoda species, as the genus *Pseudocalanus*, *Paracalanus* and the species *Oithona similis*, and the appendicularian *Oikopleura dioica* were rather affected by increasing abundance of medusae, whereas the copepods *Centropages hamatus* and *Acartia* sp. showed no major difference in abundance during the study period (Niermann, 2004). Behrends & Schneider (1995) believed the cause for alerts in Copepoda taxa were not owing to the selectivity for the special Copepoda taxa, but linked to dissimilar ecological characteristics of the taxa. The changes in abundance and zooplankton composition during 1980s-1990s were observed in the North Sea, North Atlantic, Baltic Sea, and the North Pacific and in European inland waters

(Beaugrand *et al*., 2002; Oguz *et al*., 2003; Polonsky *et al*., 2004; Bilio & Niermann, 2004). Beaugrand *et al*. (2002) reported that the shifts in zooplankton species are linked to the rising in water temperature and anthropogenic activity.

2.5 *Mnemiopsis leidyi*

The first study on the *Mnemiopsis leidyi* in the southwestern Caspian Sea was carried out by Bagheri & Kideys (2003). They noted *M. leidyi* was present in all regions, at all depths, and during all seasons studied. There was a seasonal fluctuation of ctenophore abundance each year, with the highest abundance showed in summer and the lowest abundance in winter.

The highest biomass value (166 g.m^{-2}) was measured in July 2002 and the lowest biomass value (3.30 g.m^{-2}) was in December 2001. Abundance and biomass values of the ctenophore were low during winter and early spring, gradually increasing during summer and autumn. Minimum mean weight of specimens in the population was observed in March with a value of 0.03 g. The highest *M. leidyi* biomass occurred at 20 m depth, with the population sharply decreasing below 20 m depth. The lowest biomass of *M. leidyi* was observed at the deeper layer (20-50 m depth). Length-frequency distribution displayed that whilst 94 % of the size structure belonged to small individuals < 5 mm, the largest size that the ctenophore could attain in the southwestern Caspian Seawas 52 mm, measured in August 2001 (Bagheri & Kideys, 2003). The average abundance and biomass of *M. leidyi* were observed as 170 ind.m^{-2} and 60 g.m^{-2} during summer 2000 (Shiganova *et al.*, 2001a). The average *M. leidyi* biomass changed between summer 2001 (90 g.m^{-2}) and autumn 2001 (556 g.m^{-2}) in the middle of the Caspian Sea (Shiganova *et al.*, 2001b).

In August 2001 Moghim collected hand net samples of *M. leidyi* in the southern Caspian Sea. The highest biomass of *M. leidyi* (more than 350 $g.m^{-2}$) was showed in the middle and southern Caspian, while the eastern shores exhibited the lowest biomass of *M. leidyi* (less than 4.0 $g.m^{-2}$) (Kideys & Moghim, 2003).

The highest abundances (2,300 $ind.m^{-2}$) accounted in the western and southern shores, whilst the lowest abundance (60 $ind.m^{-2}$) observed in the eastern areas (Kideys & Moghim, 2003). The average biomass of *M. leidyi* from this study showed that the high biomass rates were owing to bigger *M. leidyi* in the southern and middle Caspian Sea. There was a regular model of *M. leidyi* abundance each year in the southern Caspian Sea, the highest showed in summer-autumn, and the lowest exhibited in winter. According to Roohi *et al.* (2008) the average of abundance and biomass were 340 $ind.m^{-3}$ and 20 $g.m^{-3}$, respectively during 2001 to 2006. Furthermore, they noted biomass of *M. leidyi* was 3,000 kg (area = 148,200 km^2) during the study in the southern Caspian Sea.

2.6 History of alien species

The abundance of exotic taxa by the Black Sea and Sea of Azov increased significantly after Volga–Don channel was launched in 1960s. This channel introduced a way, of which alien species from the Black Sea and Mediterranean Sea could come in the Caspian Sea with shipping. Furthermore, the Volga river is currently linked to the Baltic Sea through a compound drainage system, which lets the Volga–Don channel and its expansion, the Volga–Baltic channel, to cooperate the function of an invasive way for exotic species from the complete Ponto-Caspian Basin (Figure 2.1; Shiganova *et al*., 2005).

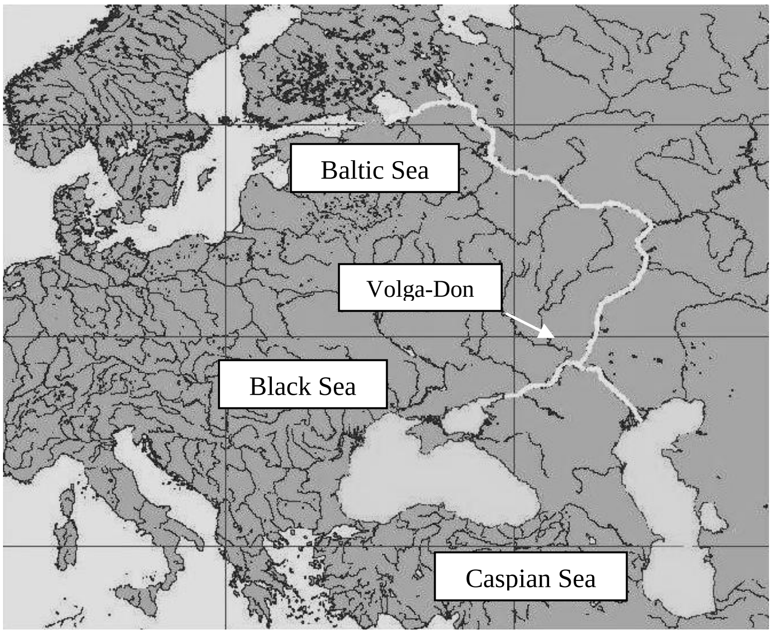

Figure 2.1 The Black Sea–Caspian Sea–Baltic Sea invasion corridor (from Shiganova *et al.*, 2005).

This invasive way introduces fauna and flora species exotic to the Caspian Sea (Shiganova *et al.*, 2005). For example, shipping permitted invasion of *Pleopis polyphemoides, Acartia tonsa, Pseudosolenia calcar-avis, Ceratium diaphanum, C. tenuissimum*, *Ectocarpus confervoides* and *Phlysiphonia variegatai*, which have not been observed previously in the Caspian Sea. Entrance of the Black Sea taxa to the Caspian Sea through the Volga–Don channel persists to date (Shiganova *et al.*, 2005).

Exotic species are one of the worst threats to not only the Caspian's biodiversity but also the functioning of its ecosystem. It is concrete that the Caspian ecology is under change which is caused by streaming jets of exotic species (CEP, 2007). Plankton communities have been severely changed by a chain of exotic species. For example, *Acartia tonsa*, which was introduced in the 1980s, has become extremely abundant. In several areas where once there were between 10 and 15 species of copepod, this copepod might be the only species recorded now (Grigorovich *et al.,* 2003; Aladin & Plotnikov, 2004; Plotnikov *et al.*, 2006; CEP, 2007). A detailed list of the Black Sea species that impulsively attacked the Caspian Sea is given in Table 2.1.

Table 2.1 The list of invasive species from the basin of Black and Azov Sea into the Caspian Sea (Shiganova *et al.*, 2005).

Taxanomic groups	**Ecology groups**	**Corridor of introduction**	**Year of introduction**
Coelenterata (Hydrozoa)			
Blackfordia virginica Mayer, 1910	Plankton-Benthos	Shipping	1956
Odessia maeotica Ostroumov, 1896	Plankton-Benthos	Shipping	1956
Bougainvillia megas Kinne, 1896	Fouling	Shipping	1962
Coelenterata (Scyphozoa)			
Aurelia aurita Linnaeus,1758	Plankton-Benthos	Shipping	1999
Ctenophora		Shipping	
Mnemiopsis leidyi Agassiz, 1865	Plankton	Shipping	1999
Polychaeta			
Nereis diversicolor Muller, 1776	Benthos	Acclimation	1939-1941
Ficopomatus enigmatica Fauvel, 1923	Fouling	Shipping	1959
Mollusca (Bivalvia)			
Mytilaster lineatus Gmelin, 1791	Fouling	Railway	1920
Dreissena rostriformis bugensis Andrusov, 1897	Fouling	Shipping	1992
Abra segmentum Recluz, 1843	Plankton-Benthos	Acclimation	1939
Hypanis colorata Eichwald, 1838	Plankton-Benthos	Shipping	1960
Mollusca(Gastropoda)			
Lithogliphus naticoides Pfeiffer, 1828	Plankton-Benthos	Shipping	1971
Tenellia adspersa Nordmann, 1845	Fouling	Shipping	1989