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Mnemiopsis leidyi Invasion and Biodiversity Changes in the Caspian Sea

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1. Introduction

1.1 Caspian Sea

The complex history of the Caspian Sea formation has lead to a variety of different habitats. Like Australia, the Caspian Sea became isolated thousands of years ago (Plate 1). This isolation led to the speciation of many rare animals in particular the sturgeon.

The Caspian Sea is the biggest enclosed body of water on Earth, having an even larger area than that of the American Great Lakes or that of Lake Victoria in East Africa. It is situated where the South-Eastern Europe meets the Asian continent, between latitudes 47˚.07́N and 36˚.33́N and longitudes 45˚.43́E and 54˚.20́E. It is approximately 1,030 km long and its width ranges from 435 km to a minimum of 196 km. It has no connection to the world's oceans and its surface level at the moment is around _26.5 m below MSL. At this level, its total coastline is some 7,000 km in length and its surface area is 386,400 km^2. The water volume of the lake is about 78,700 km^3.



Plate 1. Caspian Sea area

The Caspian can be considered as divided into three parts, the northern, middle and southern parts. The border between the northern and middle parts runs along the edge of the North Caspian shelf (the Mangyshlak threshold), between Chechen Island (near the Terrace River mouth) and Cape Tiub-Karagan (at Fort Shevchenko). The border between the middle and southern parts runs from the Apsheron threshold connecting Zhiloi Island in the west to Cape Kuuli in the east (north of Turkmenbashi). The northern part covers about 25% of the total surface area, while the middle and southern parts cover around 37% each. However, the water volume in the northern part accounts for a mere 0.5%, while the volume in the middle part make up 33.9%, and in the southern part 65.6% of Caspian waters. These volumes are a reflection of the bathymetry of the Caspian. The northern part is very shallow, with average depths of less than 5m. In the middle part, the main feature is the Derbent Depression with depths of over 500m. The southern part includes the South Caspian Depression with its deepest point being 1025m below the surface (plate 2).

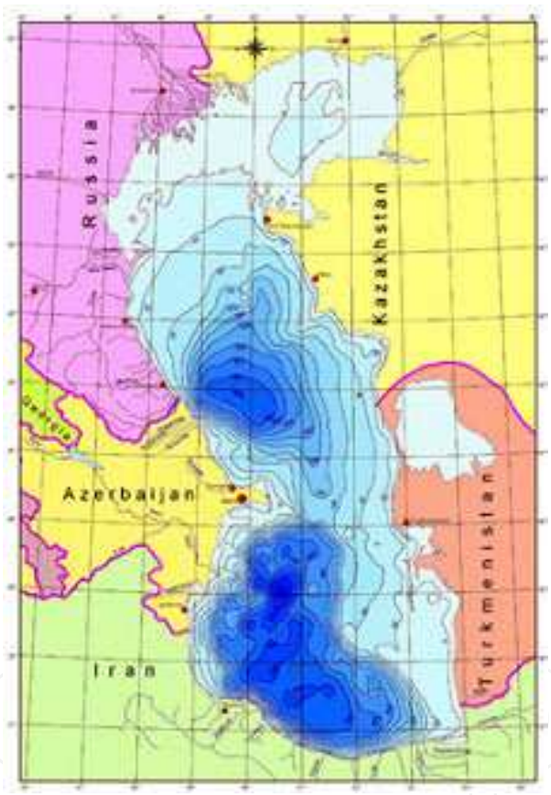


Plate 2. Caspian Sea riparian countries

Approximately 130 large and small rivers flow into the Caspian, nearly all of which flow into the north or west coasts. The largest of these is the Volga River that drains an area of 1,400,000 sq. km and runs into the northern part of the Caspian. Over 90% of the inflowing freshwater is supplied by the 5 largest rivers: Volga – 241 km3, Kura – 13 km3, Terek – 8.5 km3, Ural – 8.1 km3 and Sulak 4 km3. The Iranian rivers and the smaller streams on the western shores supply the rest, since there are no permanent inflows on the eastern side.
Apart from the extensive shallows of the northern part, the other two physical features that characterize the Caspian are the Volga and the Kara Bogaz Gol gulf.

The Volga Delta is situated in the Prikaspiisk lowlands covering around 10,000 km2 and the delta has a width of about 200 km. A feature of the delta region are the so-called Baer knolls which are hillocks, between 3m and 20m in height, formed by the action of onshore winds on the river sediments. These sediments are discharged into the delta at a rate of 8 million tones per year. Numerous small lakes can be found between the knolls and there is a complex system of channels with many islets. The Volga-Caspian shipping canal traverses the delta and is dredged to maintain a depth of no less than 2m (Aladin and Plotnikov, 2004).

2. Biodiversity in the Caspian

The biodiversity of the Caspian aquatic environment is a product of thousands of years of isolation from the world's oceans, allowing ample time for speciation. The biological diversity of the Caspian and its coastal zone makes the region one of the most valuable ecosystems in the world. The Caspian harbors some 147 species of fish, 450 species, varieties, or forms of phytoplankton, 87 species of algae, and 315 species of zooplankton. One of the most important features of the Caspian's biodiversity is the relatively high level of endemism among its fauna. Recent studies suggest the actual endemism may be even higher than what is already known. To date, there are 331 known endemic species in the Caspian. They are represented by the following: UNDP, www.caspianenvironment.org/newsite/Data-MajorDocuments.htm.

Four (4) species of *Spongia*	One (1) species of *Isopoda*
Two (2) species of *Coelenterata*	Sixty-eight (68) species of *Amphipoda*
Twenty-nine (29) species of *Turbellaria*	Nineteen (19) species of *Cumacea*
Three (3) species of *Nematoda*	One (1) species of *Decapoda*
Two (2) species of *Rotatoria*	Two (2) species of *Hydracarina*
Two (2) species of *Oligochaeta*	Fifty-three (53) species of *Mollusca*
Four (4) species of *Polychaeta*	Fifty-four (54) species of fish
Nineteen (19) species of *Cladocera*	One (1) species of marine mammal
Three (3) species of *Ostracoda*	Twenty (20) species of *Mysidacea*
Twenty-three (23) species of *Copepoda*	One (1) species of *Isopoda*
Twenty (20) species of *Mysidacea*	

Tran boundary Diagnostic Analysis for the Caspian Sea, Caspian Environment Programme. September 2002. Baku. www.caspianenvironment.org/newsite/Data-MajorDocuments.htm.

Table 1. Known endemic species in the Caspian Sea.

The decline in bioresources and biodiversity are closely linked through food chains and feeding patterns. A disturbance in the phytoplankton-zooplankton and benthic communities caused by invasive species for instance may impact species at higher trophic levels, such as sturgeon or seals. With the invasion of ML (*Mnemiopsis leidyi*) as well as introductions of other species the naturally occurring food web may have undergone or be undergoing potentially significant disruptions particular when under concurrent stresses.

The sturgeon species existed 200 million years ago at the same time as dinosaurs and can therefore be called living fossils. At that time sturgeon inhabited many ancient seas. Later on in the process of evolution, possibly due to competition with bony fish species, the

sturgeons started to become extinct but managed to survive in the Caspian Sea. This gigantic lake contains more than 90% of the world resources of sturgeon. Furthermore, the Caspian Sea is also home to many other rare species of crustaceans and mollusks (Birstein et al., 1968).

Due to its unique and diverse habitats, the Caspian Sea has become home to many rare species of flora and fauna. In connection with an increase of the Caspian Sea level during the period of 1994 – 1996, habitats for rare species of aquatic vegetation have drastically decreased. This can be attributed to a general lack of seeding material in newly formed coastal lagoons and water bodies (Aladin and Plotnikov, 2004).

Many rare and endemic plant species of Russia are associated with the intra-zonal communities of the Volga delta and riparian forests of the Samur River delta as well as to the Sarykum barkhan which is a unique refuge for flora adapted to the loose sands of the ancient Central Asian Deserts. The principal limiting factors to successful establishment of plant species are hydrological imbalances within the surrounding deltas, water pollution, and various land reclamation activities. The water level change within the Caspian Sea is an indirect reason for which plants may not get established. This affects aquatic plants of the Volga delta, such as: *Aldrovanda veiculosa* and *Nelumbo caspica*. About 11 plant species are found in the Samur River delta, of which some form a unique liana forest that dates back to the Tertiary period.

Different factors are involved in decline of biodiversity in the Caspian Sea.

1. One of the factors contributing to depleted fisheries and ecosystem resilience is the separation of anadromous fish from their natal river systems in the Caspian. Reduced access to sturgeon spawning sites began in the 1930s with the construction of irrigation weirs, followed by the construction of large dams on the Kura River in the 1950s, the Volga River in the 1960s, and the Sefidrud River in the early 1970s. In the past 50 years, anadromous fish migrations have been blocked to up to 90% of natural spawning grounds on rivers like the Volga and the Kura. As summarized above, anadromous fish such as sturgeon, salmon or herring develop genetically distinct sub-populations in response to environmental variability. Dams without fish passages block migration up rivers for spawners and down rivers for fingerlings. This loss of connectivity and natural selection cannot be replaced by hatcheries and has had the effect of drastically reducing the biological diversity of the Caspian's fish species and populations. It has led to reduced numbers of fish overall and reduced numbers of genetically distinct populations of fish (Aladin and Plotnikov, 2004).
2. Invasive species are also factors thought to be contributing to ecosystem stress, loss of biodiversity and depleted fisheries. Invasive species have been shown the world over to have direct and indirect impacts on many ecosystem components, including productive fisheries and the economy. Ecosystems often contain cascading feeding interactions that respond in unpredictable ways to introductions. Invasive species affect individuals, populations, and assemblages of populations in the ecosystems where they occur. One assemblage-level impact is a substantial shift in relative abundances, resulting in declines and losses among native fishes, for example. This is widely believed to have happened in the Caspian with respect to the native species of fish called the Kilka among others. *Mnemiopsis lediyi*, an invasive species of jellyfish, is thought to have affected the cascading feeding interactions that the Kilka relied upon, possibly causing the Kilka populations to decline dramatically, which in turn is thought

to have impacted the Caspian seal, for whom Kilka are an important food source. Clearly, to restore depleted fisheries, ecosystems and the processes and interactions that occur within them must be protected.

3. The presence of POPs (in particular pesticides) and PTS from exploitation of oil in some parts of the Caspian Sea is a major source of concern, especially their accumulation in the long-lived species – mollusks, seals, and sturgeons (UNDP, www.caspianenvironment.org/newsite/Data-MajorDocuments.htm).

3. *Mnemiopsis leidyi* problem in the Caspian

In the early 1980s, the comb jelly *Mnemiopsis leidyi*, a ctenophore that normally resides off the eastern United States, was accidentally introduced into the Black Sea via ballast waters from cargo ships. This voracious zooplanktonic predator (with extremely high rates of reproduction and growth) reached enormous biomass levels (a few hundreds million tons for the entire basin!) devastating the pelagic (i.e. in water column) food chain in the entire Black Sea basin by the end of 1980s (Vinogradov et al., 1989). Inevitably, such high biomass of this comb jelly consumed a considerable fraction of the zooplankton that had been the food for pelagic fish and their larvae before its arrival. One of the dramatic consequences of the *M. leidyi* invasion was the sharp drop (from about 630,000 tons in 1988 to steadily 150,000 tons in 1991) in commercial catches of planktivorous fish (mainly the anchovy Engraulis encrasicolus L.) in the Black Sea (Kideys 1994; Prodanov et al., 1997). The yearly economical damage to the fisheries sector alone were estimated to be about 250-500 million USD during this period. Although merely one or two researchers pointed out the overfishing as the major cause, the concurrent sharp decrease in zooplankton quantity from different regions in the Black Sea (Kovalev et al., 1998; Gubanova et al., 2002; Gordina et al., 2004) was a conclusive evidence. Indeed one would expect much higher quantities of zooplankton (due to decreased predation) at low levels of planktivorous fish occurence. The decreased levels of the pelagic fish must have also affected the abundance of top predators (several species of predator fish as well as the three species of dolphins) in the Black Sea. Although there are no systematic data on dolphins, they were noted to be scarcer by fishermen and mariners at this period.

M. leidyi did not only affected the quantity of animals but also of plant organisms, known as phytoplankton. These (mainly) photosythetic organisms are the food for zooplankton. Due to decreased levels of zooplankton, phytoplankton had a chance to over-grow in the Black Sea (Yunev et al., 2002) during the peak period in *M. leidyi* quantity. Such increase was deleterious particularly for some shallow regions in the Black Sea ecosystem (e.g. off Danube River) already badly suffering from eutrophication.

The situation in the Black Sea has been one of the most striking examples in marine bioinvasion history. Due to scale of the problem, UNEP intervened and gathered international experts in Geneva in 1994, for investigating methods for solving this problem (GESAMP, 1997). The futility of physical and chemical methods for this problem were noted and therefore, biological control seemed the only workable remedy. And, based on the literature knowledge of feeding specificity, another ctenophore species (*Beroe ovata*) rose as the best candidate for dealing with *M. leidyi* problem. Indeed, B. ovata reported feeding only on other ctenophore species (Kremer and Nixon 1976), most notably on *M. leidyi*. However, scientists from the Geneva meeting could not stress on using a new predator species for

dealing with the problem in the Black Sea, due to risk of unexpected problems: What if *B. ovata* start feeding on other species rather than *M. leidyi?*.

A warning that *M. leidyi* might also invade the Caspian Sea had been voiced during the Geneva meeting as well as by Dumont (1995). Unfortunately, at the end of the 1990s the invasion of *M. leidyi* in the Caspian Sea was already being reported (Esmaeili et al., 2000; Ivanov et al., 2000; Roohi, 2000). It must have also been transported in the ballast waters of ships traveling from the Black Sea (salinity 18 ppt) to the Caspian Sea (max. salinity 13-14 ppt) through the Volga Don Canal. Investigations in the Caspian Sea showed by September 2000, it was found everywhere including the northern Caspian where the salinity can be as low as 4 ppt (Shiganova et al., 2001a).

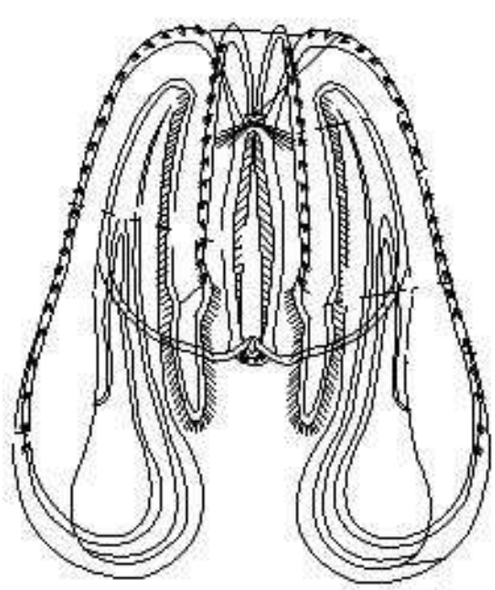
The impact of *M. leidyi* on the Caspian Sea ecosystem has been even worse than in the Black Sea due to the greater sensitivity of this enclosed basin. Adverse impacts from *M. leidyi* could be listed as the following:

1. Again the fish collapse was the most apparent problem in the ecosystem. Striking decreases were observed in the pelagic (mainly sprat *Clupeonella* spp.) fishery of all countries bordering the Caspian Sea: almost a 50% decrease in the kilka catches of both Iranian, Azerbaijan and Russian fisheries had occurred during 1999 and 2001. During spring and summer of 2001, mass (estimated as 250,000 tons, or 40% of the population) mortalities of sprat were reported at the sea surface (Davis et al., 2003). The fish catch value was halved again in 2002, resulting in great economic losses (Kideys et al., 2004, 2005). Fishermen even stopped fishing during most part of 2003, due to lack of fish (Fazli and Roohi 2003).
2. Sharp decrease in fish catch became a big problem for thousands people earning livelihood from sprat fishery. The economical loss from sprat fishery alone is hundreds million Euros per year. Most of the fishermen in Iran, who once took loans from banks for starting to a business with promising outlook, cannot now pay their debts and may even end up in prison. Their problem was even at headlines on BBC World TV in 23rd July 2001.
3. Not only pelagic fishes, but also some large predators feeding on these fish such as white sturgeon *Huso huso* and the endemic Caspian seal *Phoca caspica* are also suffering from significant population decrease. As reported by the media, the mass deaths of Caspian seals (*Phoca caspica*) occurred in the northern Caspian Sea during the spring of 2000. There is strong evidence that the epizootic disease observed in seals during the spring of 2000 was caused by under nourishment (Davis et al., 2003). Significantly decreased pregnancy and fat content inseal population were also reported. The white sturgeon, that is famous for the quality of its caviar, mainly depend on sprat as food (Hashemian and Roohi 2004).
4. Biodiversity of the Caspian is important as most of species occur only in this sea all over the world (i.e. endemic). Not only the quantity of zooplankton is reported to decrease sharply, but also the number of species. For example, number of zooplankton (copepod and cladocerans) species during 2001-2002 was only 3 compared to 22 species in 1995 or 1996!. The consequences of such reduction could be very significant for the ecosystem (Roohi et al., 2010)
5. Due to decreased levels of zooplankton, eutrophication (to much plant production) started to be a significant problem for this ecosystem. Global chlorophyll distribution

obtained via remote sensing display the Caspian Sea as one of the most eutrophic regions in the world in recent years, in contrast to years before *M. leidyi* invasion (Roohi et al., 2008a, b)

4. General aspect of *Mnemiopsis*

Mnemiopsis leidyi - is the lobate ctenophore. Two oral lobes are derivatives of the ctenophore body (spherosome). Four smaller lobes -auricules are situated under the principal two oral lobes. During their movements the lobes in fold completely its buccal orifice. The oral lappets carry tentacular rings. Its central part is situated above the lips of the mouth crevice. Both "lips" are extremely contractible (Agassiz, 1860; Seravin, 1994, plate 3).
Mnemiopsis **characteristics** in a glance are as follows:





Mnemiopsis leidyi photo by ROOHI, A.

Plate 3. *Mnemiopsis leidyi* images of the Caspian Sea

Luminescence- *Mnemiopsis* is remarkably phosphorescent. The seat of the phosphorescence is confined to the rows of locomotive flappers.
Ecological group- Macrozooplankton
Origin: North American species might be brought into the Black Sea with ballast water by Russian tankers driving oil to the ports at eastern coast of USA. From the Black Sea Mnemiopsis might be transferred into the Caspian Sea also by tankers driving oil though the Volga-Don Canal.
World distribution: The native habitat of the ctenophore, *Mnemiopsis*, is in temperate to subtropical estuaries along the Atlantic coast of North and South America (Harbison et al., 1978). In the early 1980s, it was accidentally introduced to the Black Sea (Vinogradov et al., 1989), where it flourished and expanded into the Azov, Marmara, eastern Mediterranean, and Caspian Seas (Studenikina et al., 1991, Shiganova et al, 2001a, Shiganova et al, 2001b).

Habitat: *Mnemiopsis leidyi* inhabits coastal areas and surface layers (above thermocline) open sea. Some large ctenophores can spread deeper and even can be found near the bottom in the coastal areas of the Caspian Sea.
Migrations: Transferred with the currents. Dial vertical migrations were not recorded, although it is more abundant near the surface at night where they feed and reproduce
Relation to salinity: Euryhalinic species. Salinity range from 2 to 38 (Kremer, 1993). In the seas of Mediterranean basin *M .leidyi* occurs in waters with salinities ranging from 3 in the Sea of Azov to 39 in the eastern Mediterranean. In the Caspian Sea its distribution is limited isohalines of 4 ‰.
Relation to temperature: Eurythermic species. Temperatures range from 0°C in northern native locations in the winter, to 32°C in the southern estuaries during the summer.
Feeding type: Heterotrophic, carnivorous
Feeding behavior: The larvae of *Mnemiopsis* can retract entirely their two tentacles into the tentacular sheaths on either side of the body, between the oral and aboral poles.
Reproduction type: *Mnemiopsis leidyi*- is a self-fertilizing hermaphrodite
Relation to environmental factors: The main factors, which are important for reproduction, are temperature and food concentration

5. Highlights of *Mnemiopsis* monitoring data in the Caspian

Invasion of the Caspian Sea by the comb-jelly *Mnemiopsis leidyi* (ML) since late 1990s has become one of the main environmental issue of this unique ecosystem. The adverse effects of this ctenophore was first visible on the pelagic fishery but also evident on other major compartments of the ecosystem, including, phytoplankton, zooplankton, benthos, Caspian Seal and even on some sturgeon species. Some endemic zooplankton species appear to have completely disappeared from samples of ongoing monitoring programs. ML invasion has had major impact on fisheries industry causing considerable economic damage, mostly to the coastal communities which depend on pelagic fisheries for their livelihood. The case of ML in the Caspian Sea is one of the largest invasion impacts ever occurred in a marine ecosystem all over the world.

6. A review of Mnemiopsis investigations of the Caspian Sea over the last decade

After *Mnemiopsis* invasion into the Caspian Sea via the ballast water from the Black Sea and/or the Sea of Azov in 1999 (Roohi et al., 2008a), some objectives of this alien ctenophore was taken into account in several local or national projects such as follows:

- Distribution and abundance of *Mnemiopsis leidyi* in the Caspian Sea (Iran- Russia – Azerbaijan)- in 2001-2004 and 2009
- Feeding, respiration, reproduction of *Mnemiopsis leidyi* in the Caspian Sea- in 2001-2009
- Comparative feeding study of *Mnemiopsis leidyi* and Kilka in the Caspian Sea- in 2003 - 2004 and 2008/9
- Zooplankton and phytoplankton changes after ML invasion

Mnemiopsis monitoring with the spatial and temporal investigations were conducted along the inshore and offshore of the Caspian Sea in Iran- Russia- Azerbaijan and Turkmenistan coasts. Fortunately, the main two countries (Iran and Russia) had established the favorable framework of the jelly study and achieved the appropriate results in which most of the discussion were based on two countries data analysis.

Ctenophore samples were collected with an METU (Medalist Technology University) net having a mouth opening of 0.2 m^2 and a screen with a mesh size of 500 m, from the same depths as the Juday net (Vinogradov et al., 1989; Kideys et al., 2001). On completion of each tow, the cod end was immediately passed into a container and ctenophores counted by eye. The body length of each individual with lobes was measured lying flat (out of water) onboard, and the density of *Mnemiopsis leidyi* (per m^2 and m^3) was calculated from the net diameter and tow depth. The ctenophores were sorted in length groups of 5-mm intervals to determine the abundance of different size groups. Length measurements were converted to wet weight using an appropriate equation (Kideys et al., 2001). Samples of M*nemiopsis* were collected from 20001 along few semi- transects perpendicular to the Iranian coast of the Caspian Sea (Fig. 1).

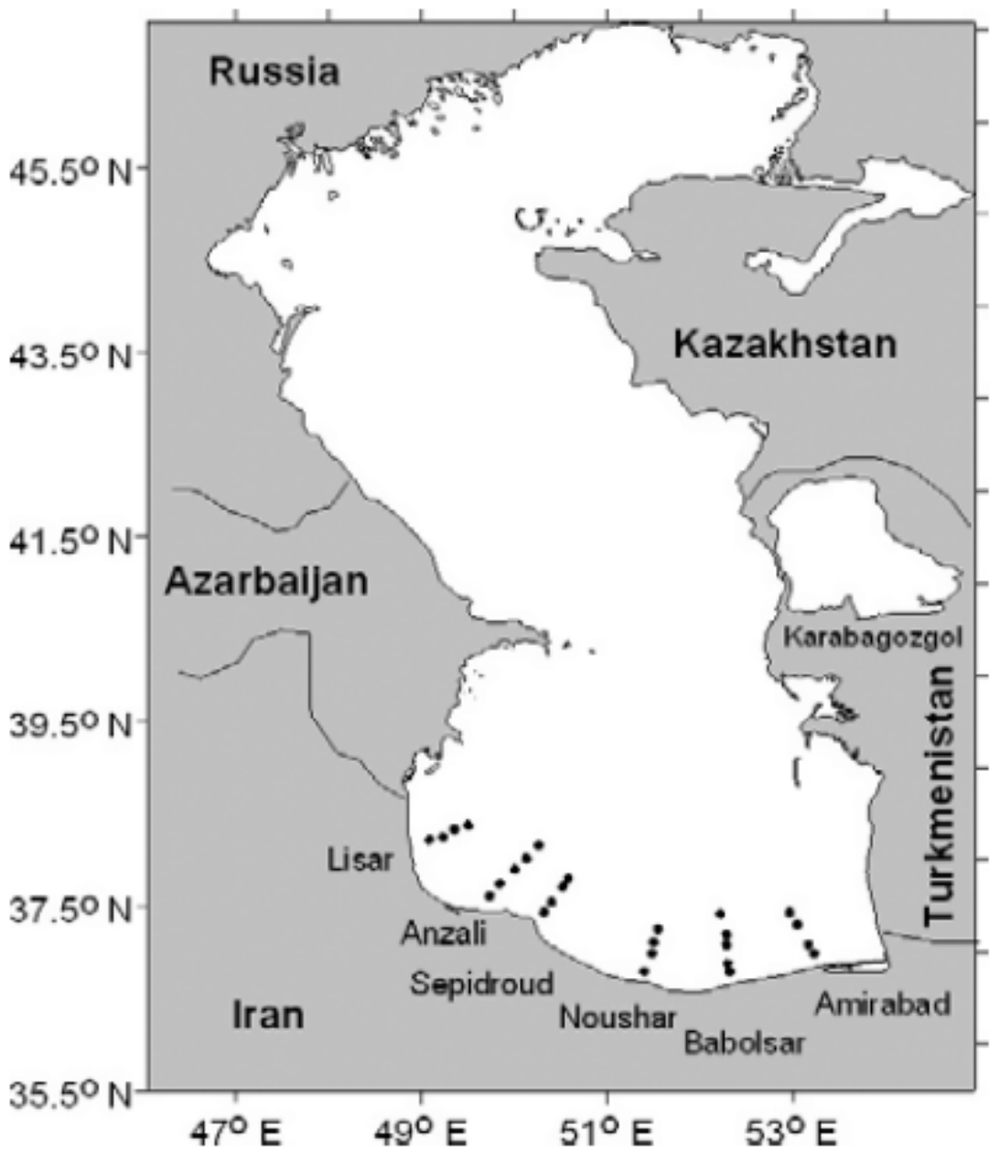


Fig. 1. Distribution of sampling stations in the southern Caspian Sea.

The ctenophore *Mnemiopsis leidyi* was found at all stations from 2001–2009. There was a seasonal succession of ctenophore densities every year, the maximum being observed in August and September, and the minimum density in the winter months. A significant correlation was found between the water temperature and the abundance of Mnemiopsis leidyi ($P < 0.005$). The highest summer– autumn average of Mnemiopsis leidyi abundance was observed in 2002 (760 ± 1148 ind.m^3), although the biomass during this period (23.2 ± 23.3 g.m^3) was lower than in 2001 (41.5 ± 44.3 g.m^3). In terms of monthly averages, October 2001 was the month of the maximum abundance and biomass (1157 ± 1614 ind.m^3 and 58.9 ± 40.0 g.m^3).

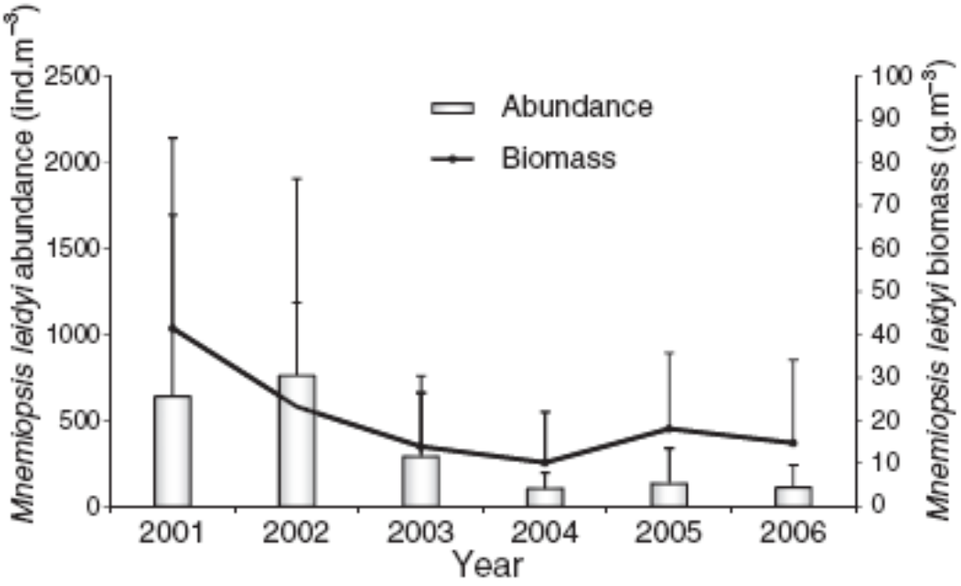


Fig. 2. Spatial and depth means of *Mnemiopsis leidyi* abundance and biomass in the Southern Caspian Sea during summer–autumn 2001–2006

In terms of spatial distribution, in spring the maximum abundance of *Mnemiopsis leidyi* (141 ind.m^3) was recorded in the coastal area of the southeastern Caspian Sea (Amirabad) and the minimum (3–14 ind.m^3) in waters 100 m deep. In summer, the highest abundance was again noted in the southeastern Caspian Sea, with values 763 ind.m^3. Likewise, in autumn, the maximum abundance was in the southeast at Babolsar (at the shallowest station of 5 m depth), with a value of 1235 ind.m^3. In addition, abundance was high at a station with a depth <20 m (500–700 ind.m^3. In winter the maximum abundance was recorded in the Anzali region, with a value of 653 ind.m^3 (Fig. 3).

In the Northern Caspian, *M. leidyi* was first found only in September 2000; its abundance increased in October, but values were not high: 108 ±65 ind. m-2 (21.6 ±9 ind. m^{-3}), biomass 140.4 ±42 g m^{-2} (28.1 ±8 g m^{-3}).

In May 2001, *M. leidyi* was recorded only in the Southern Caspian (Fig. 6A), where its abundance was 1972 ± 683 ind. m^{-2} (100 ± 34 ind. m^{-3}) and biomass 128 ± 57.5 g m^{-2} (6.4 ± 2 g m^{-3}) and in the southwestern part of the Middle Caspian, up to 43° N, abundance was 230 ± 144 ind. m^{-2} (12 ± 20 ind. m^{-3})and biomass was 20.0 ± 37 g m^{-2} (1.4 ± 2 g m^{-3}) (Fig. 4). *M. leidyi* was most abundant in the western and middle areas of the Southern Caspian, with maximum abundance at the Apsheron Swell and in the western slope waters. Mean size was

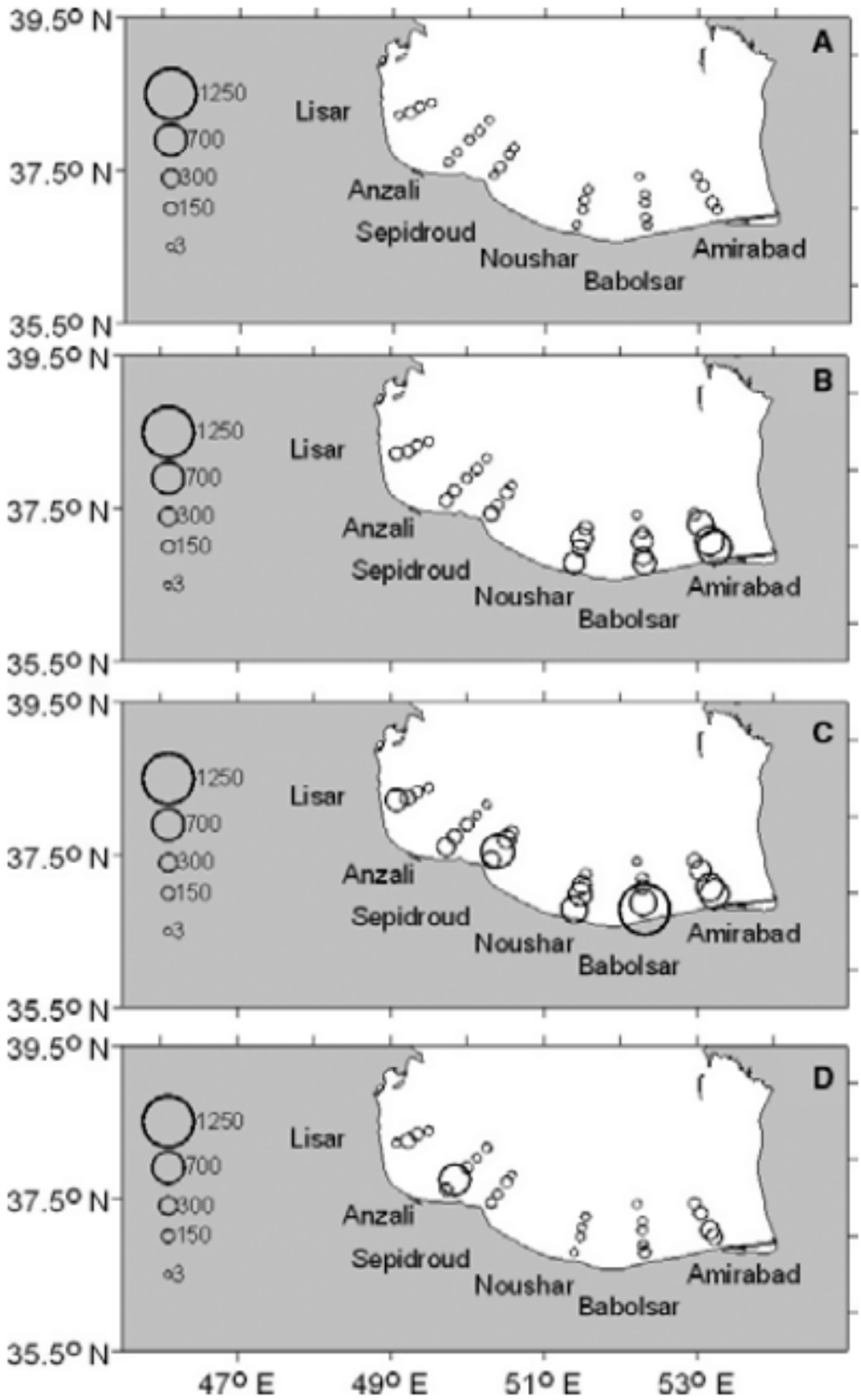
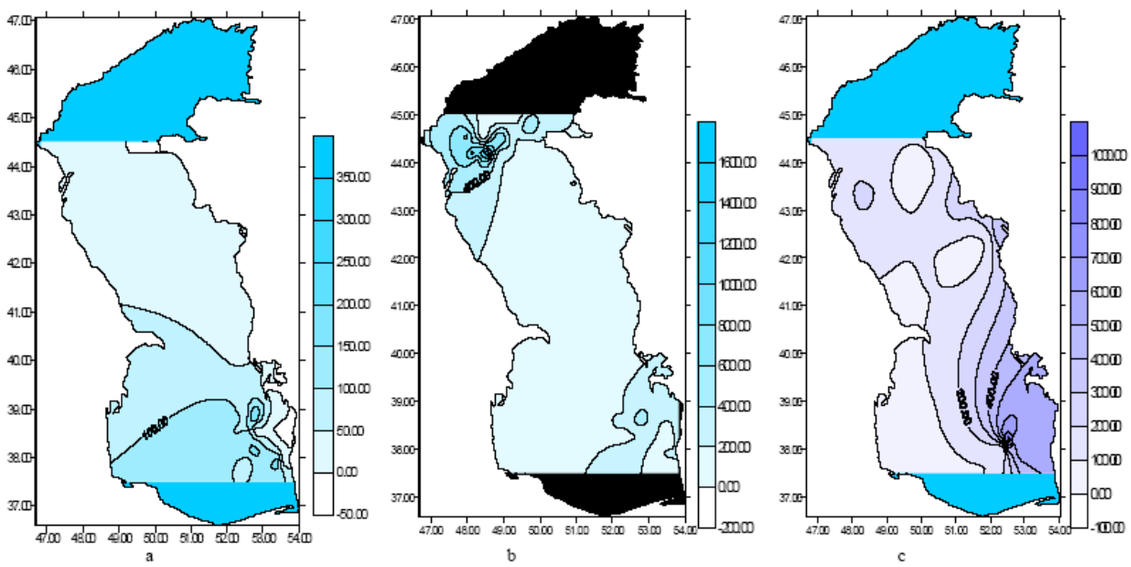


Fig. 3. Seasonal distribution of Mnemiopsis leidyi abundance (depth averages of available months) in the Southern Caspian Sea during 2001–2006. (A) Spring. (B) Summer. (C) Autumn. (D) Winter.

very small: up to 3.6 mm in the Southern Caspian and 4.2 mm in the Middle Caspian. It is well known that *Mnemiopsis* shrinks in unfavorable conditions; here, salinity, food, or a combination of both may have been strongly suboptimal.

In May, a few eggs and larvae were found in the Southern and Middle Caspian, but mass reproduction did not start yet because of scarcity of reproducing adults and probably, low spring temperatures (16°C in the Southern and 15°C in the Middle Caspian) (Fig.4).

In June 2001, *Mnemiopsis leidyi* began to reproduce and continued its expansion towards the north: in the Southern and south Middle Caspian (Fig. 4), its average abundance was 680 ± 16.8 ind. m^{-2} (34 ± 2 ind. m^{-3}), and biomass 88.3 ± 7.78 g m^{-2} (4.3 ± 1 g m^{-3}) (Fig. 4). The highest abundance and biomass, found in the Southern Caspian, represented values of 2005 ± 1248 ind. m-2 (100 ± 62 ind. m-3) and 230 ± 197.66 g m^{-2} (10.2 ± 9 g m^{-3}), respectively (Shiganova et al., 2004).



a) February- March b) August- September c) October- November

Fig. 4. Seasonal distribution of the Caspian population of *Mnemiopsis leidyi* (ind.m^3) in 2003 (shiganova et al., 2004)

7. A review of zooplankton investigations of the Caspian

Investigations performed in the last decade indicate that there have been important changes in the zooplankton composition and structure in the Caspian Sea. However, contrasting events taking place in different regions of the Caspian Sea indicate a non-uniform structure of its ecosystem. Several fodder zooplankton species have either disappeared from or substantially decreased in number at different sampling sites of the Caspian Sea over the last decade. Some other species adapted to thrive in eutrophic conditions have either appeared or increased in quantity especially meroplankton. Meanwhile the biomass of the fodder zooplankton has also fluctuated considerably through the years. However, there seems to be a reverse trend in the long-term variation of fodder zooplankton between the shallow western and deep eastern areas. Over the last decade the abundance of fish larvae has decreased significantly when compared either to past records or with larval abundances

of other seas. This was shown to be due mainly to malnutrition of larvae. One of the most striking changes in the Ichtyoplankton has been the shift in the spawning areas of the main fish species in Caspian Sea. Even the invading ctenophore *Mnemiopsis* were found to be starving. The condition of other species (*Calanipeda aquae dulcis* and *Limnocalanus grimaldii*) disclosed the fact that cyclonic regions where chlorophyll and nutrient concentrations are high provide better nutrition than anticyclonic regions.

8. Species composition of zooplankton

A total of 18 zooplankton species (mero- and holozooplankton) were found. Among them there were 13 species of merozooplankton and only five species of holozooplankton. The latter belonged to Copepoda (four species) and Cladocera (one species) (Table 2). The only Cladocera species was *Podon polyphemoides*. Four copepod species were found, with the predominant calanoid *Acartia tonsa* present in all stations and every season. In 2006, a slightly higher diversity of Copepoda was seen; *Eurytemora grimmi*, absent in 2001–2005, was then observed for the first time at 50 m depth of the 100-m-deep station off Anzali (49˚N and 37˚E) in 2006.

Zooplankton group	Before *Mnemiopsis*	After *Mnemiopsis leidyi* invasion					
Year	Hossieni *et al.* (1996)	2001	2002	2003	2004	2005	2006
Copepoda	7	3	3	3	3	2	4
Cladocera	24	0	1	1	1	1	1
Merozooplankton	5	5	11	9	7	7	8
Total	36	8	15	13	11	10	13

Table 2. Species number of zooplankton before and after *Mnemiopsis leidyi* invasion in the Southern Caspian Sea.

9. Zooplankton frequency

In general, low zooplankton abundance and biomass (wet weight) were observed in summer months from 2001 to 2006. The highest abundance and biomass of zooplankton along the whole water column were not regularly found in the same season each year (Fig. 5). The maximum abundance recorded was 22,088 ± 24,840 ind.m^3 (average of stations and depths) in December 2001, whereas the highest biomass was 64.1 ± 56.8 mg.m^3 (average of stations and depths) in August 2004. Monthly variations of zooplankton biomass were similar to the fluctuations in abundance except in some summer–autumn periods when large-sized specimens dominated. The minimum zooplankton abundance and biomass were 397 ± 567 ind.m^3 and 1.8 ± 2.6 mg.m^3, respectively, in September 2002. The annual mean zooplankton abundance varied between 3361 and 8940 ind.m^3 during 2001–2006. The

average zooplankton abundance and biomass for all months and years were calculated as 7015 ± 11.959 ind.m^3 and 32.8 ± 57.6 mg. m^3, respectively.

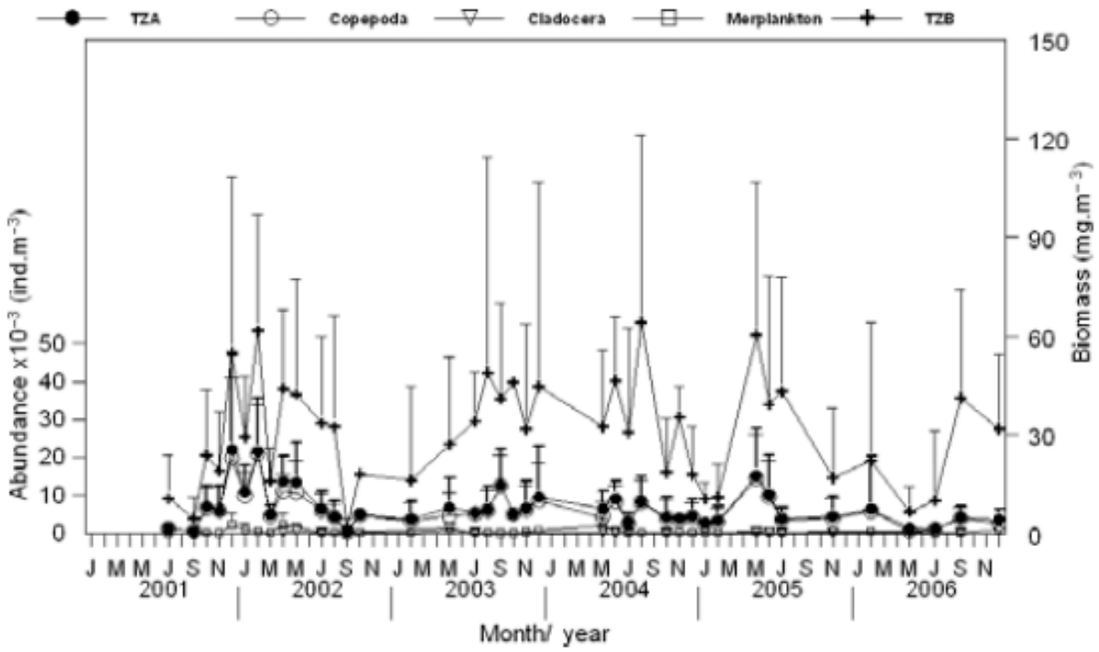


Fig. 5. Monthly variations in spatial and depth averages of Copepoda. Cladocera merozooplankton and total zooplankton abundance and biomass in the Southern Caspian Sea during 2001–2006. TZA, total zooplankton abundance; TZB, total zooplankton biomass

The maximum seasonal mean of zooplankton abundance was recorded in spring and the minimum in summer (Table 3, Fig. 6A–D). In spring, the greatest zooplankton abundance was observed at the Sephidroud River inlet (9×10^4 ind.m^3) (Fig. 6A). In summer, the abundance of zooplankton decreased compared with the values reported in spring, and an almost even distribution was found along the coastal regions (max. 8– 11 · 103 ind.m^3) decreasing towards the open sea (Fig. 6B). In autumn, zooplankton concentration was slightly greater than in summer; again the highest abundance (2×10^4 ind.m×10^4) was reported at the Sephidroud River inlet of 5 m depth (Fig. 6C). In winter, abundance was greater than in autumn and the maximum was observed at the Babolsar stations (3 ×10^4 ind.m^3, Fig. 7D).

Comparison among different groups of zooplankton showed that Copepoda accounted for the maximum abundance and biomass every year from 2001 to 2006 (Fig. 6). Among Copepoda, different developmental stages of the calanoid species A. tonsa dominated during the study period. Copepoda, Cladocera and merozooplankton constituted 88%, 4% and 8% of total zooplankton abundance, respectively.

Hossieni et al. (1996) reported 36 zooplankton species (86% holoplankton and 14% meroplankton) in the southern Caspian Sea, consisting of 24 species of Cladocera, seven species of Copepoda and meroplankton such as larvae of Bivalvia and Balanidae (Table 3).

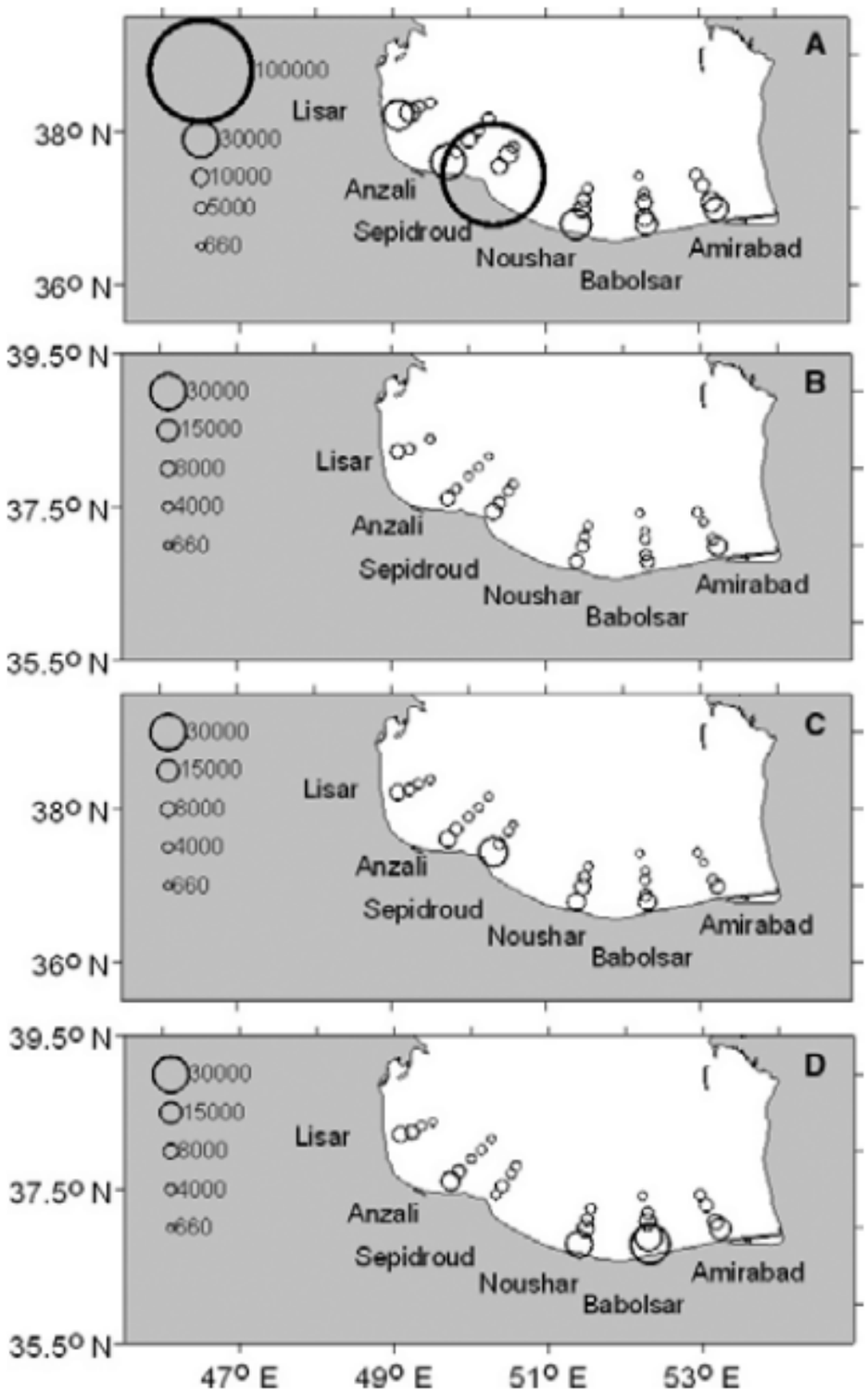


Fig. 6. Spatial distribution of zooplankton abundance in different seasons (depth averages of available months) in the Southern Caspian Sea during 2001–2006. (A) Spring. (B) Summer. (C) Autumn. (D) Winter.

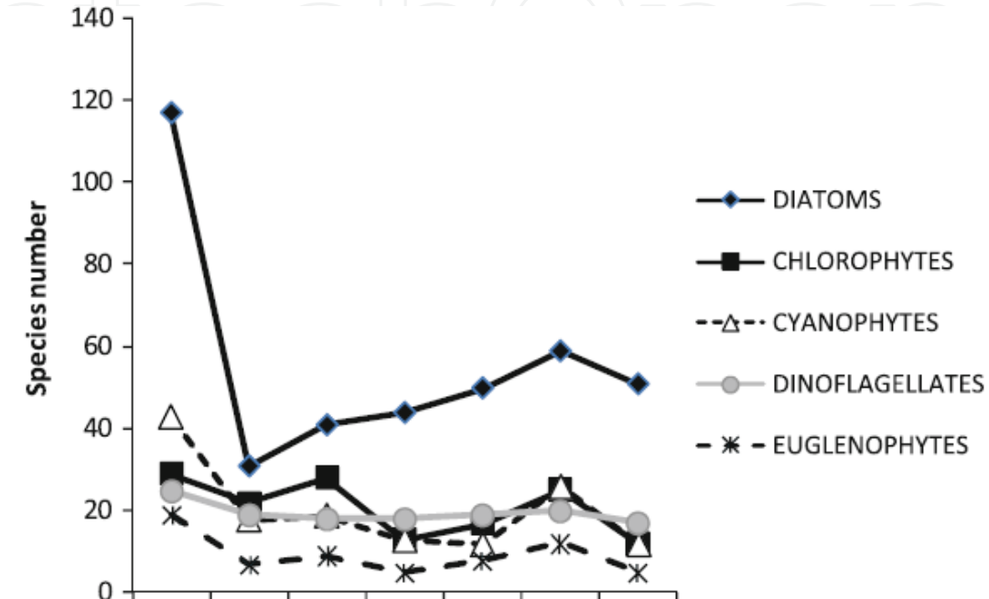
	Hossieni	After *Mnemiopsis leidyi* invasion												
	et al. (1996)	2001		2002		2003		2004		2005		2006		
Zooplankton	A	SD	A	SD	A	SD	A	SD	A	SD	A	SD	A	SD
A)														
Acartia tonsa	5766	4935	6999	12,544	10,360	8831	6176	6758	5370	4676	8144	8793	3975	8944
Limnocalanus grimaldii	5	11	0	0	0	0	0	0	0	0	0	0	0	0
Calanipeda aquae dulcis	85	115	1	0	0	0	1	0	0	0	0	0	0	0
Eurytemora grimmi and *Eurytemora minor*	2172	1774	0	0	0	0	0	0	0	0	0	0	5	0
Nauplii Calanoida	2763	3296	0	0	0	0	0	0	0	0	0	0	0	0
Halicyclops sarsi (Cyclopoida)	170	168	5	0	2	0	120	2	5	1	22	3	1	0
Ectinosoma consimum (Harpacticoida)	0	0	0	0	3	3	0	0	1	0	11	19	0.4	0
Total Copepoda	10,961	10,300	7005	12,544	10,364	8834	6296	6760	5375	4678	8177	8814	3981	8944
Podon polyphemoides	237	442	0	0	450	672	1205	822	228	342	328	398	367	415
Polyphemus exicus	83	129	0	0	0	0	0	0	0	0	0	0	0	0
Total Cladocera	320	571	0	0	450	672	1205	822	228	342	328	398	367	415
Lamellibranchia larvae	5459	13,156	0	0	282	642	33	23	365	777	55	75	430	934
Cirripedia larvae (*Balanus* spp.)	439	648	86	378	661	1446	387	708	723	1359	328	617	277	430
Arachnida larvae	0	0	14	25	170	488	3	1	8	11	0	0	0.3	0
Mysidaceae larvae	NQD	0	0	0	0	0	0	0	0	0	0	0	2	0
Nematidae	NQD	0	0	0	214	361	163	137	0	0	2	2	0.5	0
Nereididae larvae	0	0	573	1838	435	877	12	18	13	23	38	52	9	0
Ostracoda larvae	NQD	0	5	8	32	106	2	2	58	117	0	0	0	0
Chironomidae larvae	0	0	0	0	0	0	5	8	0	0	0	0	4	0
Oligochaeta larvae	0	0	0	0	13	1	133	284	208	241	150	281	75	244
Total Meroplankton	5898	13,804	677	2248	1806	3920	738	1181	1374	2527	572	1027	799	1608
Total Zooplankton	17,180	24,675	7682	14,792	12,620	13,426	8239	8763	6977	7547	9077	10,239	5147	10967

	Hossieni	After *Mnemiopsis leidyi* invasion												
	et al. (1996)	2001		2002		2003		2004		2005		2006		
Zooplankton	B	SD	B	SD	B	SD	B	SD	B	SD	B	SD	B	SD
B)														
Acartia tonsa	37.2	36.5	23.0	32.0	35.4	26.6	30.1	33.6	36.9	34.2	42.0	38.6	22.9	33.4
Limnocalanus grimaldii	0.4	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Calanipeda aquae dulcis	0.8	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Eurytemora grimmi and *Eurytemora minor*	20.7	20.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
Nauplii Calanoida	7.6	7.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Halicyclops sarsi (Cyclopoida)	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.004	0.0
Ectinosoma consimum (Harpacticoida)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.003	0.0
Total Copepoda	68	67	23	32	35.4	26.6	30.1	33.6	37.0	34.2	42.2	38.8	23.0	33.4
Podon polyphemoides	1.6	2.7	0.0	0.0	1.8	2.7	4.8	3.3	0.8	1.3	0.9	1.3	1.5	1.7
Polyphemus exicus	0.5	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Cladocera	2.1	3.4	0.0	0.0	1.8	2.7	4.8	3.3	0.8	1.3	0.9	1.3	1.5	1.7
Lamellibranchia larvae	26.9	65.0	0.0	0.0	1.4	3.2	0.2	0.1	1.8	3.9	0.3	0.4	2.152	4.6704
Cirripedia larvae (*Balanus* spp.)	1.0	1.5	0.2	0.8	1.4	2.9	1.4	3.7	4.2	8.5	1.4	1.8	1.114	2.0674

Table 3. Annual variations (A) in abundance (ind.m^3) and (B) in biomass (wet weight, g.m^3) of total zooplankton, Copepoda, Cladocera and merozooplankton species in the Southern Caspian Sea (before and after Mnemiopsis invasion). (C) Seasonal variations in abundance and biomass of zooplankton species in 1996 from Hossieni et al. (1996). (D) Full list of Cladocera species reported by Hossieni et al. (1996).

10. Phytoplankton population

In the present study, a total of 226 phytoplankton species were identified. While diatoms constituted 45% of the total species number, chlorophytes, cyanophytes, dinoflagellates and euglenophytes formed 20, 17, 11 and 8% of phytoplankton species, respectively (Fig. 7). Number of species in spring (91 species) and summer (101 species) were higher than in autumn (86 species) and winter (77 species).



Years	1986-1994	2001	2002	2003	2004	2005	2006	2001-2006
DIATOMS	117	31	41	44	50	59	51	101
CHLOROPHYTES	29	22	28	13	17	25	12	45
CYANOPHYTES	43	18	19	13	12	26	12	38
DINOFLAGELLATES	25	19	18	18	19	20	17	25
EUGLENOPHYTES	19	7	9	5	8	12	5	17

Fig. 7. Variations in species number of different phytoplankton groups in the southern Caspian Sea during 2001–2006 and 1986–1994

The highest monthly mean phytoplankton abundance and biomass were 396 × 10^6 ± 299 × 10^6 cells m-3 in January 2002 and 1,789 ± 1,761mg m-3 in May 2002 (Fig. 8). Minimum abundance and biomass values were observed in August 2003 (1 × 10^6 ± 1 × 10^6 cells m-3 and 7 ± 5 mg m^{-3}) (Fig. 8).The overall average cell abundance and biomass of phytoplankton during 2001–2006 were 64 × 10^6 ± 76 × 10^6 cells m-3 and 250 ± 360 $mg.m^{-3}$, respectively. While diatoms were the most abundant phytoplankton group during 1996, after the introduction of *M. leidyi* the abundances of cyanophytes (in autumn) and dinoflagellates (in winter) exceeded diatom abundance in 2001 and 2002 (Fig. 8 and 9). Excluding 2005, diatom abundance was again high during 2003–2006. An unprecedented bloom of the toxic cyanophyte *Nodularia* sp. was observed between the second half of August and the end of

September in 2005. The bloom area covered ˜20,000 km2 (CEP 2006, Fig. 9). According to the sampling on 20 September 2005, in addition to *Nodularia* sp., another cyanophyte Oscillatoria sp. was also high in abundance. Abundance of Nodularia sp. was 18 ×10^6 cells m^{-3} at 7 m depth and 1,006 × 10^6cells m^{-3} at 20 m depth. Average cyanophyte abundance and biomass at 7 and 20 m depths were 582 9 106 cells m-3 (of which 512 cells m^{-3} was Nodularia sp.) and 1,655 mg m^{-3}. The highest seasonal means of phytoplankton abundance and biomass were 179 × 106 cells m^{-3} and 880 mg m-3 in winter during 2001– 2006.

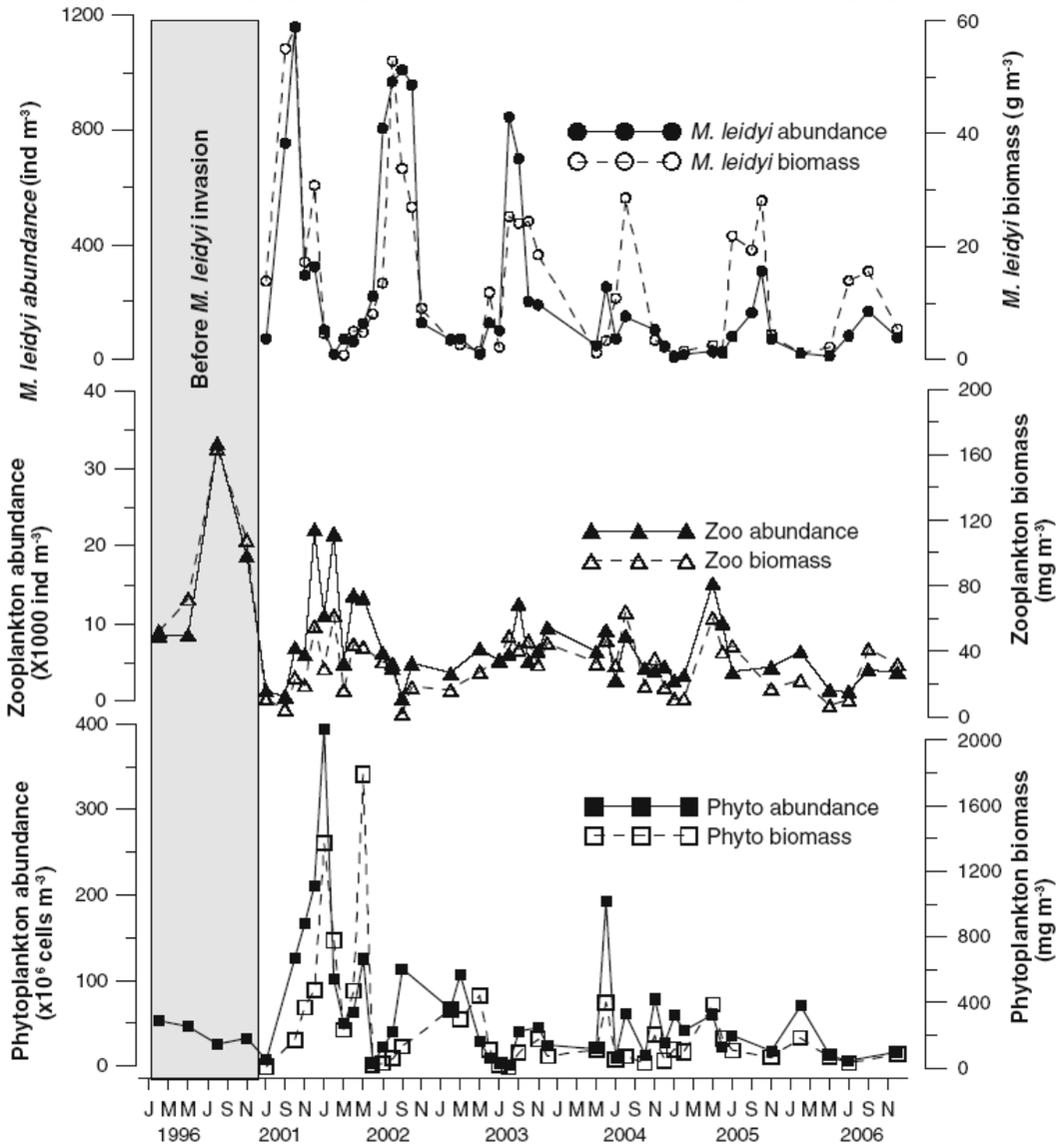


Fig. 8. Annual variations in the abundance and biomass of phytoplankton, zooplankton and Mnemiopsis leidyi in the southern Caspian Sea during 2001–2006 (values are depth and station averages). 1996 values are from Hossieni et al. (1996), spring 2001 values are from Kideys et al. (2001)

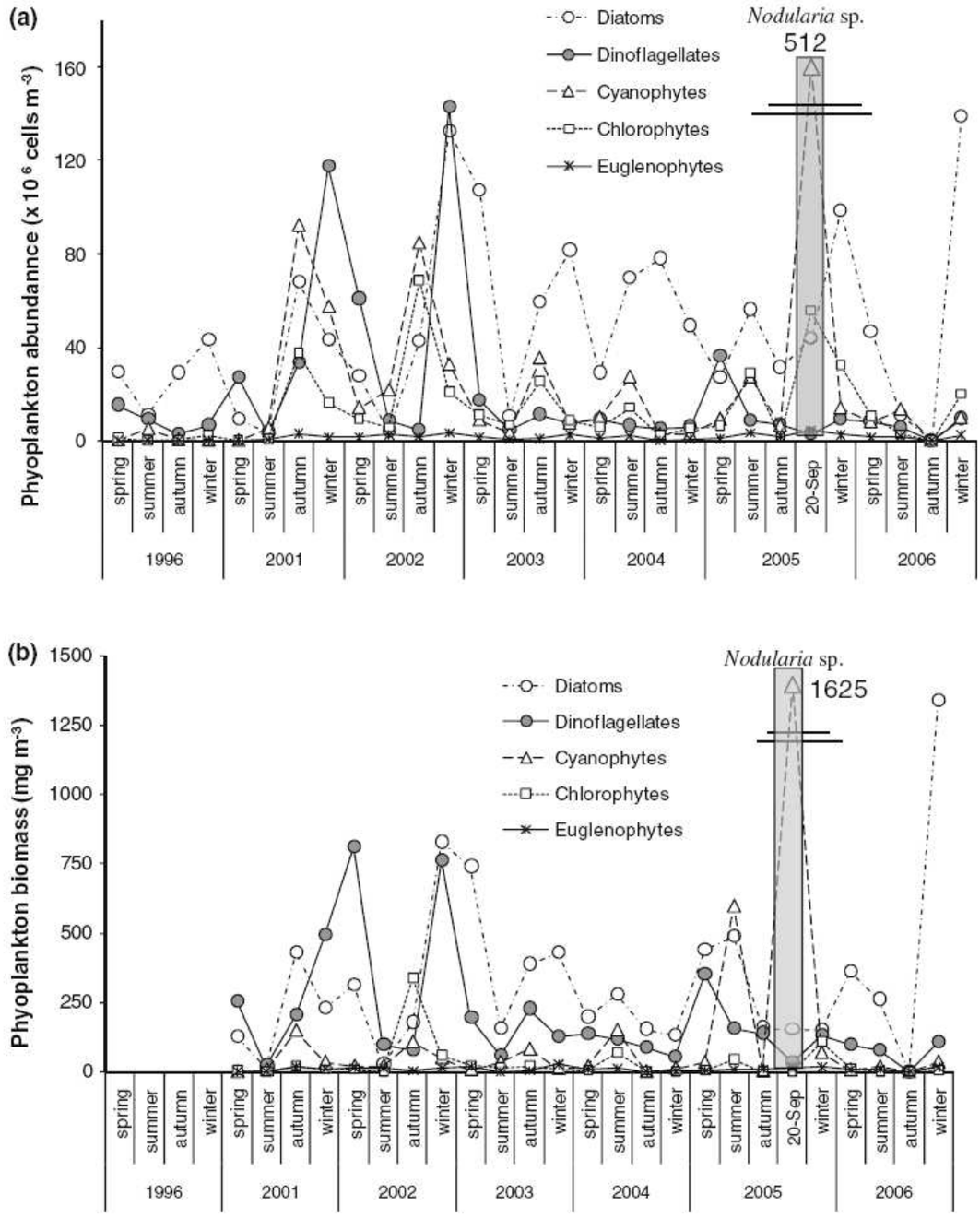


Fig. 9. Seasonal changes a in abundance and b in biomass of different phytoplankton groups before (Hossieni et al. 1996) and after Mnemiopsis leidyi invasion in the southern Caspian Sea (values are depth and station averages)

11. Other factors that have to be considered

11.1 Increased chlorophyll levels in the southern Caspian Sea after ML invasion

A significant correlation was observed between satellite derived chlorophyll *a* (Chl *a*) concentrations and the biomass of the invasive comb jellyfish *Mnemiopsis leidyi* in the

southern Caspian Sea. By consuming the herbivorous zooplankton, the predatory ctenophore *M. leidyi* may have caused levels of Chl *a* to rise to very high values (~9mg m^{-3}) in the southern Caspian Sea. There might also be several other factors concurrent with predation effects of *M. leidyi* influencing Chl *a* levels in this region, such as eutrophication and climatic changes which play major roles in nutrient, phytoplankton, and zooplankton variations (kideys et al., 2008). The decrease in pelagic fishes due to overfishing, natural, and anthropogenic impacts might have provided a suitable environment for *M. leidyi* to spread throughout this enclosed basin (Fig. 10).

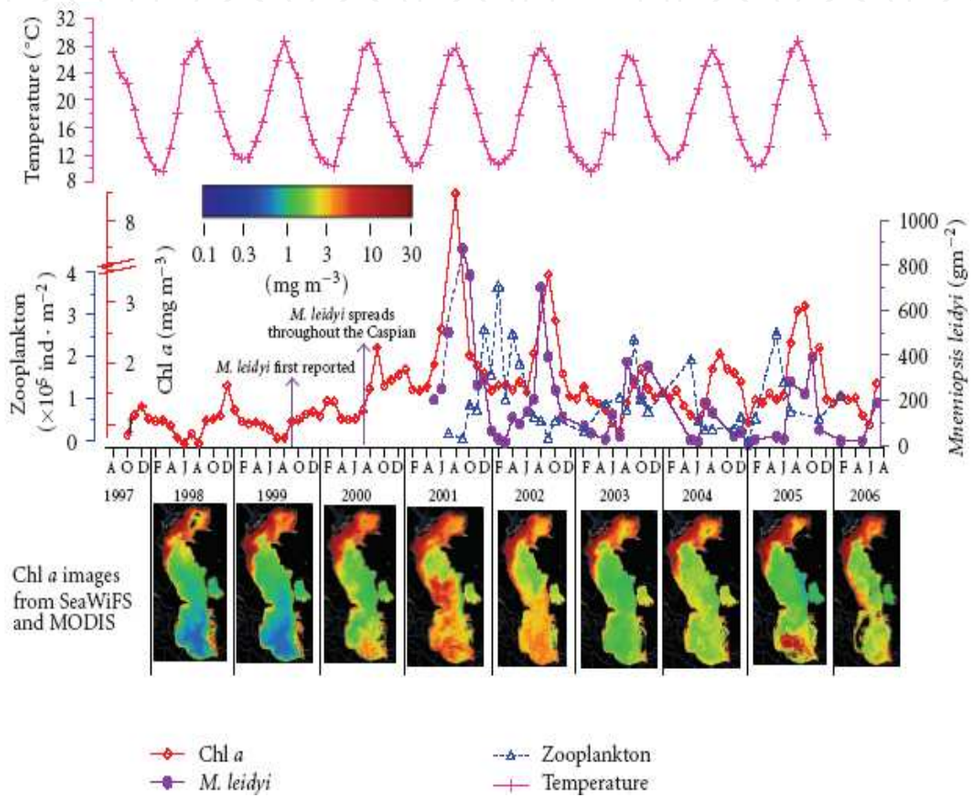


Fig. 10. Spatiotemporal distribution of Chl *a* concentration (mgm−3, note the broken scale here), zooplankton abundance (ind ·m−2), *Mnemiopsis leidyi* biomass (g m−2 values for June and August 2001 are from Shiganova et al. 2004), and sea surface temperature (◦C) obtained from NOAA in the Caspian Sea. Note the strong difference in Chl *a* distributions (as seen from satellite during a warm period, September) before (1998 and 1999) and after *Mnemiopsis leidyi* impact (2001 and 2006) in the lower section of the figure.

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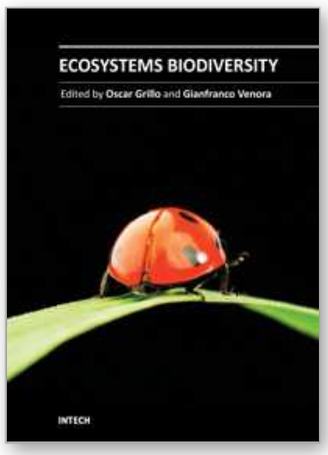
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Ecosystems can be considered as dynamic and interactive clusters made up of plants, animals and micro-organism communities. Inevitably, mankind is an integral part of each ecosystem and as such enjoys all its provided benefits. Driven by the increasing necessity to preserve the ecosystem productivity, several ecological studies have been conducted in the last few years, highlighting the current state in which our planet is, and focusing on future perspectives. This book contains comprehensive overviews and original studies focused on hazard analysis and evaluation of ecological variables affecting species diversity, richness and distribution, in order to identify the best management strategies to face and solve the conservation problems.

How to reference

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