CHAPTER 6 THE STATE OF ZOOPLANKTON (T. Shiganova et al.)

T. Shiganova, E. Musaeva, E. Arashkevich

P.P.Shirshov Institute of oceanology Russian Academy of Sciences

L. Kamburska(1), K. Stefanova(1), V. Mihneva(2)

(1)Institute of Oceanology, Bulgarian Academy of Sciences, Varna, Bulgaria
(2)Institute of Fishing Resources, Varna, Bulgaria

L. Polishchuk

Odessa Branch, Institute of Biology of the Southern Seas, NASU, Odessa, Ukraine

F. Timofte

National Institute for Marine Research and Development "Grigore Antipa" (NIMRD), Constanta, Romania

F. Ustun(1), T. Oguz(2)

(1) Sinop University, Fisheries Faculty, Sinop, Turkey
(2) Middle East Technical University, Institute of Marine Sciences, Erdemli, Turkey

M. Khalvashi

Georgian Marine Ecology and Fisheries Research Institute, Batumi, Georgia

Ahmet Nuri Tarkan

Mugla University, Faculty of Fisheries Mugla, Turkey

6.1. Introduction

Zooplankton community structure serves as a critical trophic link between the autotrophic and higher trophic levels. On the one hand, zooplankton as consumer of phytoplankton and microzooplankton controls their abundance; on the other hand, it serves as food resource to small pelagic fishes and all pelagic fish larvae and thus controls fish stocks. The Black Sea zooplankton community structure is more productive but has lower species diversity as compared to the adjacent Mediterranean Sea. Many taxonomic groups that are wide-spread in the Mediterranean Sea are absent or rarely present in the Black Sea such as Doliolids, Salps, Pteropods, Siphonophors, and Euphausiids (Mordukhai-Boltovskoi, 1969). It consists of about 150 zooplankton species, of which 70 are mainly Ponto-Caspian brackish-water types and about 50 constitute meroplankton (Koval, 1984). They are euryhaline and thermophilic species of the Mediterranean origin as well as cold-water species of the North Atlantic boreal origin. The wide temperature range in the Black Sea (2-25°C) permits development of psychrophilic, eurythermic and thermophilic species. Therefore, their vertical distribution, seasonal and interannual dynamics are defined by their thermophilic properties.

Mass development of mixotrophic algae and changes in phytoplankton species composition provided a base for the development of zooplankters, both phytophagous and detritophagous (Zaitzev and Aleksandrov, 1997). The most important feature of zooplankton community after the 1970s was the change in species composition between various zooplankton groups. Some species almost disappeared, whereas some other species increased their abundance such as outbursts of gelatinous planktonic species *Aurelia aurita* and *Noctiluca scintillans*./ Opportunistic zooplankton species such as *Acartia clausi* greatly increased their abundance and share of trophic zooplankton. These events were most profound in the northwestern part of the sea, where the regional hydrochemical characteristics are primarily governed by the nutrient enrichment supplied from Danube, Dniester, and Dnieper runoffs.

The zooplankton community has been dramatically affected by the population outburst of alien ctenophore species *Mnemiopsis* leidyi after 1988 due to their intensive preying on edible zooplankton (Vinogradov et al., 1989; Shiganova, 1998). The ctenophore *M.leidyi* affected the physical properties by reducing the water transparency, and more significantly the biological properties by causing a cascade effect up on all trophic levels. Their strong grazing on zooplankton populations reduced food resources for planktivorous and predatory fishes, and favored phytoplankton growth. It also supported microplankton growth through mucous excretion, which then led to more abundant bacteria population and thus its predator ciliates and zooflagellates (Shiganova et al., 2004). The introduction of its predator *Beroe ovata* which came from either the Mediterranean Sea or eastern coast of North Atlantic through ballasts waters during 1997 helped later recovery of the ecosystem (Konsulov and Kamburska, 1998; Shiganova, 2000). *B. ovata* was first encountered in the western shelf (Konsulov and Kamburska, 1998 a) and the northeastern basin in the summer 1997 (Shiganova et al., 2004). In addition, the entire planktonic system has been affected by the severe climatic cooling regime in the 1980s followed by similarly strong warming regime of the 1990s and the early 2000s (Oguz et al., 2006). The present chapter provides a detailed account of these modifications of the zooplankton community structure in terms diversity, abundance and biomass in different regions of the Black Sea and outlines the present state (after 2000) with respect to the previous decades.

6.2. Ukrainian shelf area

Significant changes in total abundance, biomass, and community structure of zooplankton in the northwestern shelf are depicted in Table 6.1. Most noticeable change in the early phase of eutrophication was the increase of *Noctiluca scintillans* and medusa *Aurelia aurita* abundances, the main indicators of eutrophic waters. *Aurelia* biomass started increasing from negligibly low values (<50 g m^{-2}) in the 1960s to around 500 g m^{-2} in the early-1980s (Fig. 6.1a). Similarly, Noctiluca share in the total zooplankton abundance changed from 35-42% prior to the early- 1970s to more than 90% after the mid-1970s and in the 1980s (Fig. 6.1b). Therefore, eutrophication increased total non-trophic zooplankton share in biomass and abundance, and reduced those of trophic zooplankton from 200-500 mg m^{-3} range and > 30000 ind.m^{-3} in the 1960s to < 100 mg m^{-3} and 10000 ind.m^{-3} within a decade (Fig. 6.1a, 6.1c). The declining biomass of *Aurelia* during the mid-1980s coincided with the period of more predominant control of *Noctiluca* on trophic zooplankton population due to its reproduction, growth, and food competition advantages with respect to *Aurelia* (Fig. 6.1d).

The edible zooplankton community structure also experienced a significant reduction in species diversity during the 1970s-1980s. *Pontellidae, Paracartia latisetosa, Podon* *intermedius, Bryozoa* larvae, *Centropages ponticus, Penilia avirostris, Evadne spinifera, Pleopis tergestina, O. minuta, P. tergestina, E. spinifera* disappeared due to high predation pressures and food competition by *A. aurita* and *N. scintillans* during the intense eutrophication (Table 6.1, Fig. 6.1b). *A. clausi* abundance was reduced; *C. ponticus* and *Paracalanus parvus* abundances were seriously endangered. Population explosion of the comb jelly M. leidyi aggravated the situation in the subsequent years.

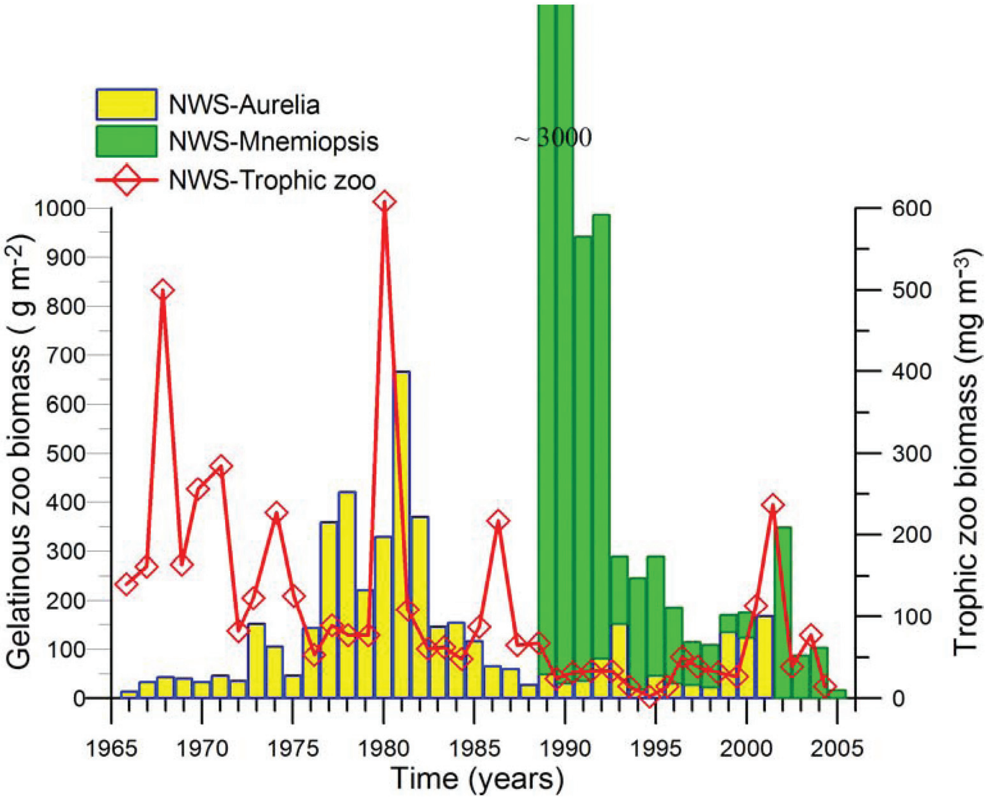

Fig. 6.1a. Long-term biomass changes of *Aurelia, Mnemiopsis* (left axis) and edible zooplankton (right axis) in the northwestern sector of Ukranian shelf waters. No *Aurelia* biomass data were reported after 2001. Data source: YugNIRO, Kerch, Ukraine, sorted out by Dr. A. Grishin, see Velikova V. and Chipev N. 2005.

Even though the changes in the average multi-year total zooplankton biomass in offshore areas along the southern cost of Crimea was not as high as in the northwestern part from the early 1960s to the mid-1990, edible zooplankton biomass also steadily decreased at the expense of higher share (>75%) of non-edible species Noctiluca scintillans and Pleurobrachia pileus (Table 6.2).

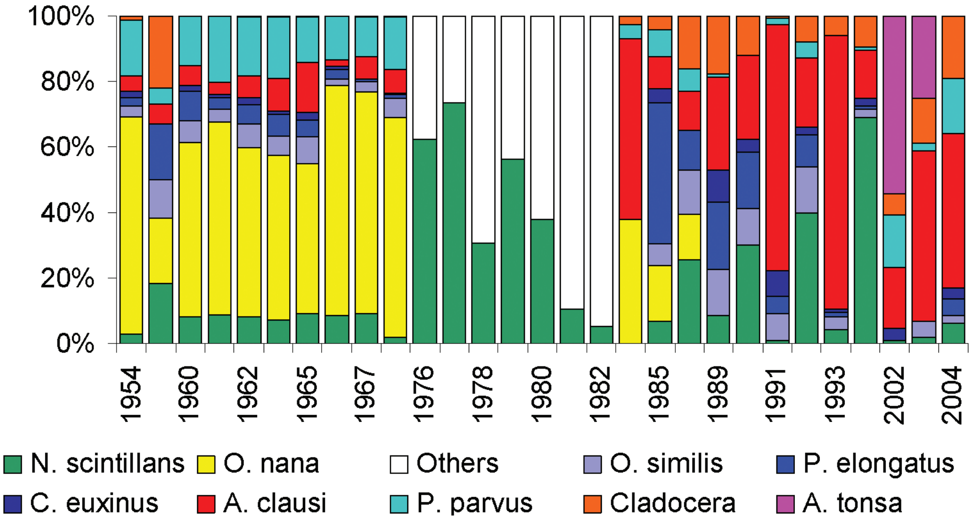

Fig. 6.1b. Long-term changes in abundance (%) of mesozooplankton species in the Northwest part of the Black Sea (after Temnykh et al. 2006).

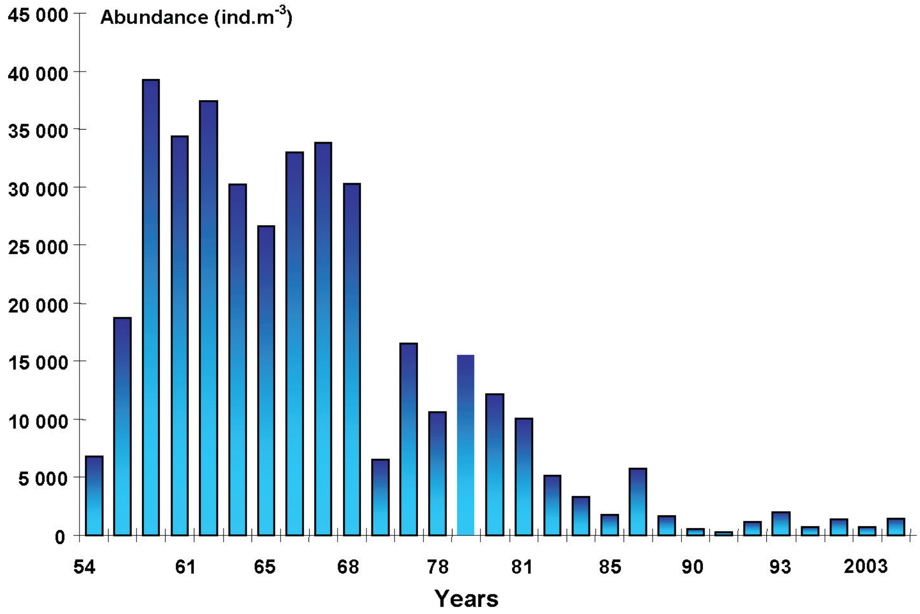

Fig. 6.1c. Long-term changes of mesozooplankton abundance (ind. m^{-3}) in the Northwest part of the Black Sea (after Temnykh et al. 2006).

Table 6.1. Long-term dynamics of biomass (mg.m-3) of the main species of zooplankton of the northwestern Black Sea (provided by Polischuk and Nastenko (1998) and Polyshchuk (2005) up to 1999, modified by L. Polishchuk afterwards).

Taxa	1951-60	1959-74	1975-80	1981-85	1986-89	1990-95	1996-99	2000-05	2006-007
N. scintillans	163.00	133.20	3366.00	3331.00	5262.00	733.10	2100.3	393.6	1736.1
A. clausi	36.00	40.20	46.40	32.10	64.00	16.10	14.2	82.7**	62.2**
P. parvus	8.00	8.20	2.40	0.90	1.70	0.08	0	0.5	0.03
P. elongatus	24.00	21.10	2.10	3.40	17.30	8.50	5.4	11.7	2.8
C. euxinus	3.00	17.00	0.09	1.40	2.10	0.40	0.1	0	0.4
C. ponticus	5.00	--	0.06	0.90	0.40	0.01	0	0.02	0.1
O. minuta	8.00	4.80	10.70	13.50	6.30	0.00	0	0	0
O. similis	--	3.30	0.40	0.20	0.70	0.06	0.05	0.1	0.03
P. avirostris	26.00	--	7.80	3.30	6.00	0.07	0.55	3.3	33.6
P. polyphemoides	6.00	--	20.90	18.40	21.60	9.10	6.1	6.2	3.7
P. tergestina	4.00	--	0.08	0.00	1.00	0.00	0	0	0.7
E. spinifera		--	0.07	0.02	1.00	0.00	0.01	0.002	0
P. pileus	49.00	87.60	43.30	30.50	25.20	36.50	0.6	140.1	84.0
P. setosa	24.00	7.30	6.80	5.50	3.30	0.40	0.5	11.8	6.2
Meroplankton	14.00	--	29.20	33.50	6.70	20.20	72.1	31.9	23.0
Varia	14.00	54.00	59.90	36.20	45.60	68.90	39.7	113.7	12.4
M. leidyi						--	--	--	--
B. ovata							58.7	295.8	77.8
Total zooplankton	384.00	376.70	3596.20	3510.80	5464.90	893.40	2298.3	1091.5	2043.1
Trophic zooplankton	148.00	148.60	180.10	143.80	174.40	123.40	138.2	250.2	138.4
Non-trophic zooplankton	236.00	228.10	3416.10	3367.00	5290.50	770.00	2160.1	841.3	1904.8
% *N. scintillans*	42.40	35.30	93.50	94.80	96.20	82.00	91.4	36.0	84.9

-- lack of data; ** together with A.tonsa.

Table 6.2. Average multiyear biomass (mg.m^{-3}) of total zooplankton and its main components in the 0-100 m layer in offshore areas near the southern Crimean coast.

Group of organisms	Years				
	1960-70	**1971-80**	**1981-88**	**1989-94**	**1994-95**
Total zooplankton	346	328	287	--	438
Trophic zooplankton	87	78	64	58	45
Noctiluca scintillans	199	150	141	--	45
Pleurobrachia pileus	60	100	82	--	348
% N. scintillans+P. pileus	75	76	78	--	90
Mnemiopsis leidyi				12545	8383
Aurelia aurita				1795	2122

-- lack of data

Following the development of *M. leidyi* in the Black Sea up to 3000 g m^{-2} by 1989, *N. scintillans* and *Aurelia* biomass decreased abruptly and total abundance and biomass of trophic zooplankton continued to remain at low levels (Fig. 6.1a, 6.1c). This situation persisted until 1998, although Mnemiopsis biomass was reduced by half with respect to its early 1990s outburst period. Following the development of *Beroe* in 1998, the *Mnemiopsis* biomass reduced further at the expense of some recovery of *Aurelia* and *Noctiluca*. Trophic zooplankton biomass was affected positively by the *Mnemiopsis* decline. Its biomass increased 3-4 folds for two years (2000, 2001), but then dropped abruptly in 2002 and remained below 10% of total zooplankton biomass due to overwhelming domination of zooplankton community by *N. scintillans* (Table 6.1, Fig. 6.1a, 6.1d).

Near the Zmeiny Island located in the Danube delta region and in Zhebriansky Bay (Fig. 6.2), observations in spring-summer 2005-2007 showed exceptionally high abundance of gelatinous zooplankton (comb jellies *M. leidyi* and *B. ovata*) contributing to 75% of the total zooplankton in August. In autumn, they were rarely encountered (*M. leidyi* - 11%, *B. ovata* - 8%) and the *B. ovata* population that was formed by small young specimens and larvae did not have a significant influence on the development of *M. leidyi*. The zooplankton biomass was lower in the Odessa region than near the Zmeiny Island (Fig. 6.3).

Table 6.3. Biomass (mg.m $^{-3}$) of main groups of dominating zooplankton species in the Danube estuary area in May and November 2004-2005.

	2004		**2005**	
	May	November	May	November
Protozoa	29.979	10.523	359.798	1915.077
Noctiluca scintillans	29.877	10.523	359.555	1915.077
Rotifera	12.642	0.012	149.191	0.086
Synchaeta	5.653	0	128.174	0
Cladocera	4.690	0.080	30.544	76.908
Pleopsis polyphemoides	1.242	0.045	29.043	5.463
Penilia avirostris	0	0	0	67.515
Podonevadne trigona	0	0	0	3.700
Copepoda	21.502	118.658	61.575	644.237
*Acartia clausi+ tonsa**	9.184	105.260*	41.997*	641.509*
Paracalanus parvus	0.039	2.608	0	0
Pseudocalanus elongates	4.740	3.459	1.887	0
Ctenophora				
Beroe ovata	0	753.279	0	3316.438
Mnemiopsis leidyi	0	+	0	0
Pleurobrachia pileus	0	0	214.610	0
Chaetognatha	0	3.933	0	82.863
Appendicularia	1.872	0.258	0.024	0.018
Meroplankton	22.317	18.780	99.810	38.128
Total zooplankton	93.002	905.523	927.465	6074.452
- without *B.ovata*		152.244		2758.014
Non-trophic zooplankton (%)	32.100	84.800	61.900	87.500
- without *B.ovata*		9.500		72.400

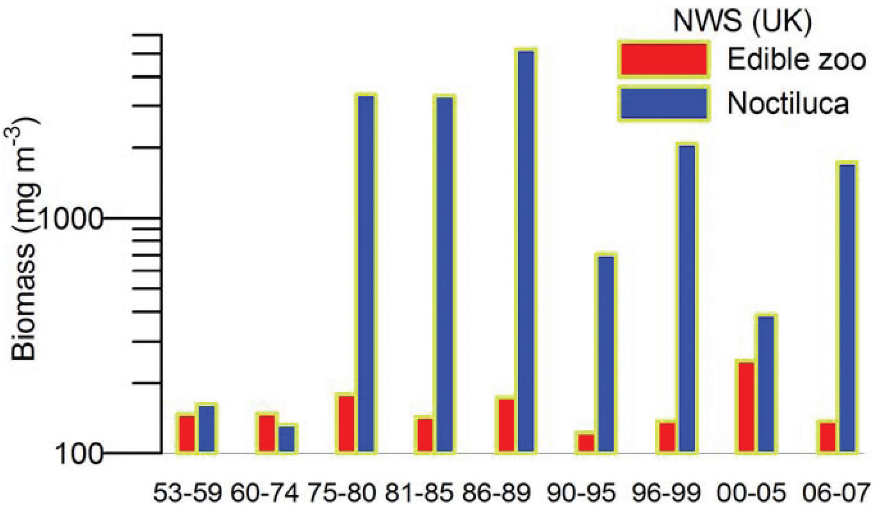

Fig. 6.1d. Biomass (mg·m^{-3}) of edible zooplankton and Noctiluca scintillans in the Ukrainian (UK) coastal waters of the northwestern Black Sea (NWS) during 1953-2007.

In the absence of *M. leidyi* after the *B. ovata* settlement into the Black Sea, the role of Cladocera and Copepoda in the zooplankton community structure increased (Fig. 6.1b). The Cladocera species *P. avirostris* and the endemic Ponto-Aral *Podonevadne trigona*, earlier quoted as rare species, became widespread in recent years whereas the density of Cladocera *Pleopsis polyphemoides* decreased. Among Copepoda, *Acartia clausi* and *A. tonsa* were observed at higher abundances for the first time since their disappearance. *Pleurobrachia* and *Sagitta* were also observed abundantly in some years. In the summer 2005, *A. tonsa* almost replaced *A. clausi* in terms of abundance and biomass in the Dnieper-Bug area (8456 ind·m^{-3} and 85.7 mg·m^{-3}), the Tendrovsky Bay (10242 ind·m^{-3} and 117.5 mg ·m^{-3}) and the Egorlitsky Bay (29075 ind· m^{-3} and 488.8 mg·m^{-3}). *N. scintillans* still dominated the total zooplankton biomass albeit the declining tendency by 56% in the Dnieper-Bug area, 43% in the Tendrovsky Bay and 15.6% in the Egorlitsky Bay. The frequency and abundance of Bryozoa larvae was also found in large quantities during the summer 2005 with respect to 1980s-1990s in these regions.

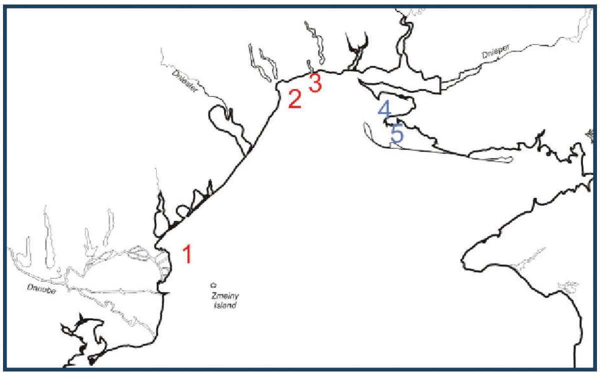

Fig. 6.2. The regions studied most extensively in the NWS coastal waters during 2000-2007: 1 - Danube river mouth (Ukrainian part of the Danube Delta), 2 - Odessa Bay area, 3 - Grygorivsky Liman, 4 - Yagorlytska Bay, 5 - Tendrivska Bay.

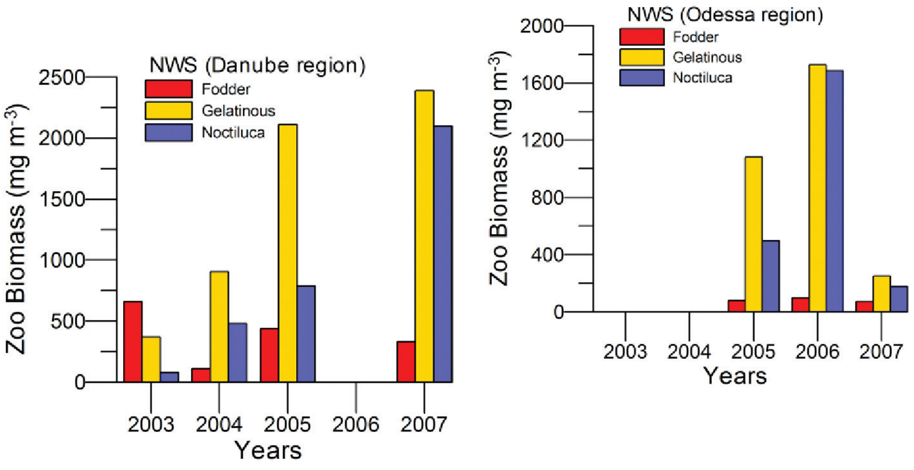

Fig. 6.3. Edible, gelatinous, and Noctiluca biomass changes during 2003-2007 in the Danube discharge and Odessa regions.

Similar changes were also monitored in the qualitative and quantitative characteristics of zooplankton along the Crimean coast as they can be noted by the data collected in the Sevastopol Bay during 1976-2002 (Table 6.4). Abundance of *M. leidyi* and *B. ovata* in the Sevastopol Bay during 1999-2005 varied between 500-1000 ind.m^{-3} and 50-100 ind.m^{-3}, respectively, whereas the corresponding abundances within the adjacent shelf were twice lower (Finenko et al., 2007). The timing of *M. leidyi* mass appearance changed ± 1 month around August depending on the mixed layer temperature. This period coincided with the initiation of *B. ovata* bloom that typically lasted for 3 months (September -November).

Table 6.4. Long-term changes in annual and/or multi-annual average abundance (ind.m^{-3}) of main zooplankton species in the Sevastopol Bay.

	1976	1976-80	1989-90	2002
Cladocera				
Evadne spinifera	<1	0	0	<1
Penilia avirostris	8	128	<1	219
Pleopis polyphemoides	445	1206	370	141
Pseudoevadne tergestina	0	0	0	4
Copepoda				
Acartia clausi+ tonsa	540	1121	443	857
A. margallifi (Acartia clause, small form)	1225	3923	0	0
A.latisetosa	2	19	0	0
Anomaloara patersoni	<1	0	0	0
Calanipeda aquae-dulcis	<1	0	0	0
Calanus euxinus	1	2	4	2
Centropages ponticus	16	315	1	52
Labidocera brunescens	0	<1	0	0
Oitona minuta (O.nana)	3464	2942	0	<1
O.similis	197	74	29	15
Paracalanus parvus	513	472	4	173
Pontella mediterranea	0	0	0	<1
Pseudocalanus elongates	273	63	58	30
Harpacticoida	43	55	19	7
Meroplankton	1759	3287	828	2280
Varia				
Hydromedusae	<1	<1	<1	19
Oikopleura dioica	59	124	3	11
Parasagitta setosa	12	14	<1	34
Noctiluca scintillans	1065	5067	1703	115
Total zooplankton	**10116**	**19454**	**3545**	**4113**

From July to September, during the peak *Mnemiopsis* development, their daily mesoplankton biomass consumption decreased from 30-40% of the mesozooplankton biomass in 1995 (prior to the *Beroe* settlement) to 2-13% during 2000-2005. The daily ration of of *Mnemiopsis* larvae on microzooplankton was close or even higher than those on mesoplankton, and found around 23-25% of microzooplankton biomass in August 2003.

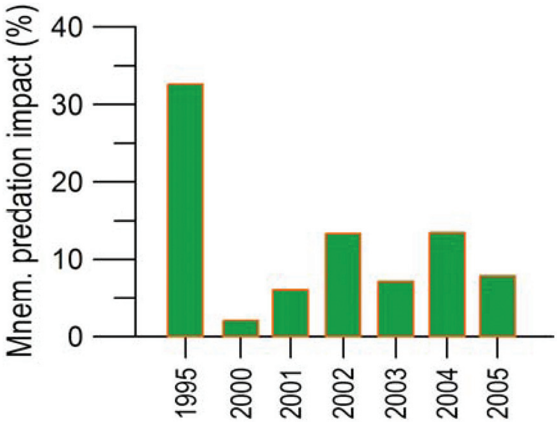

Fig. 6.4a. Mnemiopsis predation impact on mesozooplankton during July in Sevastopol Bay. Data source: Finenko et al. (2007).

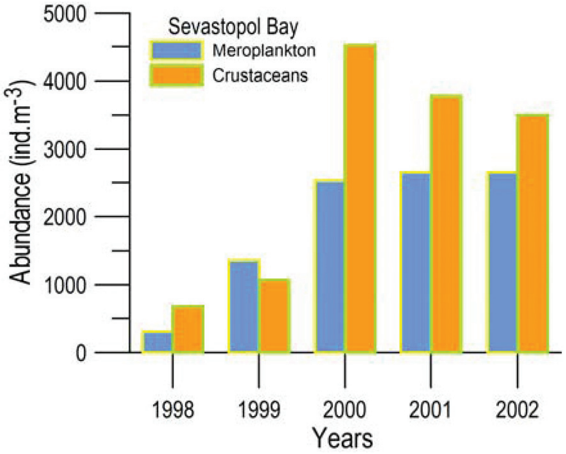

Fig. 6.4b. Meroplankton and Crustacean abundances during spring-autumn 1999-2002 in the Sevastopol Bay. Data source: Finenko et al. (2007).

Weaker and shorter predation pressure of *M. leidyi* on mesozooplankton after the arrival and establishment of *Beroe*, as shown in Fig. 6.4a by the reduction of its daily predation impact, resulted in higher mesozooplankton biodiversity and abundance. In spring-autumn 2000-2005, species composition in the Sevastopol Bay resembled that of 1990-1996. *Evadne spinifera, Pseudoevadne tergestina, Pontella mediterranea* and *Oithona nana* were found for the first time. The trophic zooplankton biomass increased two-folds and the abundance and biomass of *N. scintillians* significantly reduced, while those of meroplankton (Hydromedusae and *Parasagitta setosa*) increased from 310 ind.m^{-3} in 1998 to 2650 ind.m^{-3} in 2000-2002 (Fig. 6.4b) and decreased in the subsequent three years (Finenko et al. 2007). The mean abundance of Crustaceans increased 8 times during the same period (Fig. 6.4b). In the Cladocera group, as in the NWS, *P. avirostris* prevailed over the former dominant species *Pleopis polyphemoides.* These changes were evidently linked to the decrease in *M. leidyi* abundance due to the *B. ovata* predation.

6.3. Romanian shelf area

Long term changes of zooplankton community structure in the Romanian coastal waters possessed large fluctuations not only in terms of biomass and density but also in species diversity. The research conducted at 5-30 nautical miles coastal zone (20-50 m) between 1960 and 1966 showed a well-defined seasonal community structure. Copepods *Pseudocalanus elongatus* and *Calanus euxinus* and, in some years, *Oithona nana* and *O. similis* were the predominant members of winter zooplankton community representing 98% of the total biomass every year. The summer zooplankton population was dominated by the Cladoceran *Penilia avirostris* and the Copepod *Centropages ponticus*. In some years, the non-trophic organism *Noctiluca scintillans* has been recorded as a part of the community structure although its population density was limited to several thousands species per cubic meter. Very high abundance of minute copepods *Paracalanus parvus* and *Oithona nana* dominated the autumnal zooplankton population with the total biomass comparable to the spring (Porumb, 1972). This structure has prevailed until 1975. Meroplankters were a predominant group of the zooplankton community in shallow waters above the sandy, rocky seabed.

After 1977, the total zooplankton abundance decreased and zooplankton population was mainly represented by the pollution-resistant Copepod species *Acartia clausi* and *Oithona similis*. The increase in total biomass of the zooplankton was mostly for the case of the biotope inhabited in the surface layer that was most exposed to pollution. The Cladoceran *Penilia avirostris* was also present in small numbers as compared to 1975 (Porumb, 1980). Species from the family *Pontellidae* (*Anomalocera patersoni, Pontella mediterranea* and *Labidocera brunescens*) diminished their populations. Some species were totally disappeared as in the case of the family *Monstrillidae* (*Monstrilla grandis, M. helgolandica* and *M. longiremis*).

Another eutrophication-induced structural modification in the zooplanktonic biocoenose was the reduction in abundance of some sensitive holoplanktonic species, such as the copepod *Centropages ponticus* and the cladoceran *Penilia avirostris*. In summers between 1960 and 1967, these two species attained their highest densities and biomasses and, together with copepod *Anomalocera pattersoni*, had produced the richest biomass (225.28 mg.m^{-3}) in 1967. They achieved last high biomass development in summer 1975 and then gradually reduced towards extinction and were substituted by other opportunistic zooplankton species. After 1994, the populations of these two species became more abundant again although they were sporadically appeared.

The copepod species belonging to the family *Pontellidae* (*Anomalocera patersoni, Pontella mediterranea* and *Labidocera brunescens*), which had once formed large concentrations particularly in the contact zone between the marine and fresh waters, suffered a considerable decline. Other zooplanktonic organisms which have been present in large numbers in the plankton of the Romanian littoral in 1960s (*Monstrilla grandis, M. helgolandica* and *M. longiremis*) have not been observed any more after the 1980s.

Table 6.5. Mean density (ind.m^{-3}) and biomass (mg.m^{-3}) of Noctiluca scintillans along the Romanian continental shelf during the 1970s and 1980s.

Year	Density	Biomass	Year	Density	Biomass
1970/1971	4787	381.61	1978/1979	5937	474.94
1971/1972	14694	1119.03	1979/1980	15995	1276.38
1972/1973	1084	86.78	1980/1981	62676	5045.80
1973/1974	275	21.98	1982/1983	47241	3833.07
1974/1975	8097	639.89	1984/1985	17074	1365.89
1975/1976	1534	122.75	1985/1986	47999	3838.01
1977/1978	3945	312.35			

During 1980-1986, Copepods dominated zooplankton population with their annual-mean density exceeding 7100 ind.m^{-3}. The mean annual zooplankton biomass continuously increased due mainly to high summer abundance of the Copepod *Acartia clausi* and the Cladoceran *Pleopis polyphemoides* in response to the increase in primary production and the organic matter content. Copepods formed a peak in warm seasons (spring, summer and early-autumn) and provided a valuable food resource for planktivorous fish such as sprat *Sprattus sprattus phalericus* and anchovy *Engraulis encrasicolus ponticus* whose production also increased during this period.

One of the most important ecological modifications produced by the eutrophication in the pelagic ecosystem was the explosive development of the Cystoflagellate *Noctiluca scintillans* in the 1970s and 1980s, which has a negligible trophic value in the pelagic ecosystem. The biomass share of *Noctiluca* in the overall biomass of zooplankton increased eight-folds in 1980-1986 as compared to the 1970s with the mean annual density higher than 15900 ind.m^{-3} and occasionally reaching up to 62600 ind.m^{-3} (Table 6.5). This period was also characterized by population explosion of the scyphozoan jellyfish *Aurelia aurita*.

After 1988, there has been a significant decline in the quantity of major zooplankters which had a high trophic value for planktivorous fish both in shallow and offshore waters. These changes could be attributed to the pressure exerted by the zooplanktivorous comb jelly *M. leidyi* which was the most important exotic species introduced into the Black Sea in terms of its impact on the local fauna. The *Mnemiopsis* invasion had a significant impact upon the Romanian small pelagic fishery, whose stocks have declined dramatically since 1988. *M. leidyi* typically reached at its maximum abundance and biomass during summer and modified seasonal zooplankton dynamics. Instead of two zooplankton biomass and/or abundance peaks in spring (the lower one) and summer (the higher one), only the spring peak remained to exist (Petran and Moldoveanu, 1994; Petran et al., 1999).

Surveys conducted after 1993 revealed that *Mnemiopsis leidyi*, together with *Aurelia aurita*, accounted for 90% of the total zooplankton biomass until the settlement of the ctenophore *Beroe ovata*. Nevertheless, the first signs of ecosystem rehabilitation appeared at edible zooplankton community after 1994 due to the reduction of pollution and eutrophication as well as the shift of the Black sea hydro-climatic regime into the warm climatic cycle. *Centropages ponticus* and *Penilia avirostris* became more abundant after 1994 (Fig. 6.5).

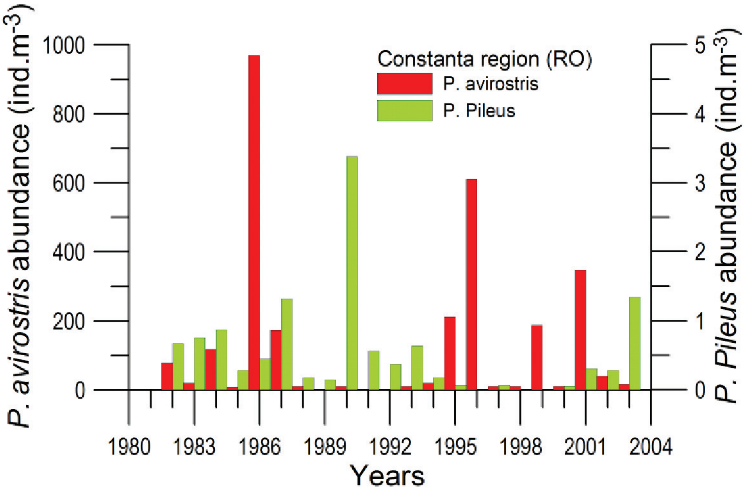

Fig. 6.5. Changes in Penilia avirostris and Pleurobrachia pileus abundances in Constantza region during 1982-2003.

After the invasion of ctenophore *Beroe ovata* and its active consumption of *Mnemiopsis,* the mean *Mnemiopsis* density 123 ind.m^{-3} in the summer 1999 reduced to very low values after 2002. In the present decade, as the pollution and eutrophication continued to reduce and *Mnemiopsis* population was controlled by *Beroe*, the zooplankton biodiversity started to flourish as evident by growing populations of *Anomalocera patersoni, Pontella mediterranea* and *Labidocera brunescens.* The ctenophore *Pleurobrachia pileus individuals*, that were present in significant densities between 1982 and 1995, but they became almost extinct in the period of Mnemiopsis dominance, started regaining their ecological niche after 2001 once occupied by Mnemiopsis leidyi (Fig. 6.5).

The long-term edible zooplankton biomass changes within the upper 10 m of Romanian coastal and shelf waters during 1994-2007 has a declining trend from 350 mg m^{-3} to 50 mg m^{-3} in 1999-2007 irrespective of large interannual variations (Fig. 6.6). The edible zooplankton biomass possessed four distinct peaks at 1995, 1999, 2001 and 2003, of which the first two arise due to high summer abundance and the latter two due to high autumn abundance. The relatively high biomass measured within the uppermost 10 m layer of the water column in 1995 was initiated in February (10.5 mg.m^{-3} in Mangalia station), increased gradually in spring and summer and reached its maximum value of 598.1 mg.m^{-3} (in Mila station) in July. The spring and summer mean values of the edible zooplankton biomass attained about 120 mg m^{-3} and 210 mg m^{-3}, respectively. Likewise, the biomass in summer 1999 varied between 23.769 mg.m^{-3} at Sf. Gheorghe and 364.776 mg.m^{-3} at Portitza.

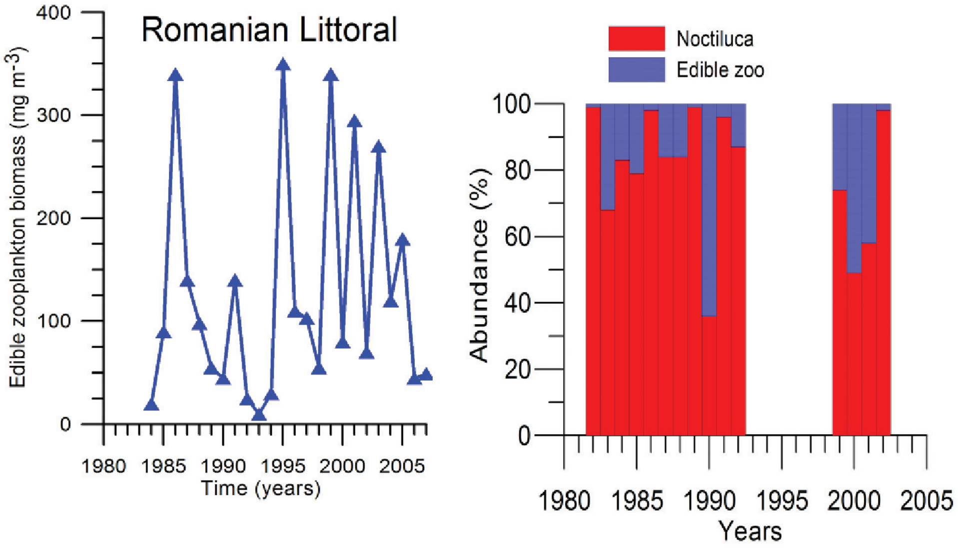

Fig. 6.6. Annual variations of edible zooplankton biomass (left) and relative abundances of edible zooplankton and Noctiluca (right) in the Romanian littoral zone 0-10 m layer.

The maximum edible zooplankton biomass in 2001 and 2003 was 1.2 and 1.3 times higher than in 1995, respectively. They were realized in autumn following very low summer values (Fig. 6.7). Although low trophic zooplankton biomass in summer 2001 was comparable to the 1970s and 1980s, it consisted of a more diverse structure comprising 13 and 17 species in near-shore waters of Mangalia and Portitza, respectively, that corresponded to the highest diversity index (3.70) for the summer season. Compared with the earlier years of mono-specific zooplankton populations that were mostly dominated by the opportunist copepod *Acartia*, the observed situation in the summer 2001 suggested a tendency toward normalization in the fodder zooplankton community structure. Following the unstable status of zooplankton structure during the eutrophication period and outburst of *Mnemiopsis* population, the cladoceran *Penilia avirostris* became more abundant in the recent decade and was measured up to a maximum value of 340 ind.m^{-3} in 2001 (Fig. 6.5).

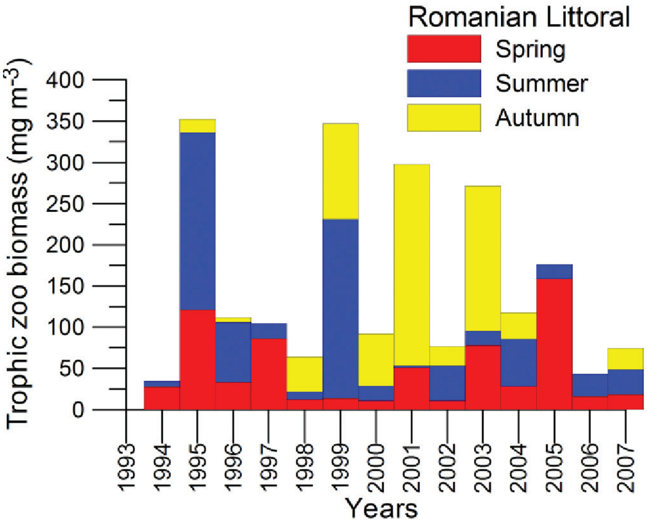

Fig. 6.7. Seasonal changes of trophic zooplankton along the Romanian littoral zone in the upper 10 m layer during 1994-2007.

Low edible zooplankton biomass in 2002 was due to dramatic population outburst of non-trophic species *Noctiluca scintillans* that constituted 98% of the total zooplankton biomass (Fig. 6.6, right). Its population outburst resembled the 1970s when the eutrophication syndrome first started due to proliferation of planktonic algae. The highest edible zooplankton biomass was only 11.18 mg.m^{-3} in Portitza and remained below 1 mg.m^{-3} within the rest of the region studied.

In 2003, the highest biomasses of edible zooplankton were registered in autumn (139.9 mg.m^{-3}), that was 12.8 times higher than in the summer and 1.8 than in the spring. As for the spatial distribution, the richest quantities were found off the northern littoral (Sulina - 277.63 mg.m^{-3}, Portita - 185.536 mg.m^{-3}). On the other hand, the mean trophic biomass was very low (16.7 mg.m^{-3}) due to high *Mnemiopsis* predation impact but zooplankton community was richer in diversity in the summer 2003. The gelatinous and non-trophic species *Noctiluca scintillans* (449.29 mg.m^{-3}) and *Mnemiopsis leidyi* 1939.549 mg.m^{-3}) abundantly developed and suppressed the development of fodder species.

2004 and 2007 were also unproductive years in terms of edible zooplankton. 2005 and 2006 did not include autumn surveys and therefore it is unclear whether the edible zooplankton community experienced high production. But the summer biomass was again low due to dominance of the gelatinous and non-trophic species. In 2007, trophic zooplanktonic biocoenosis was represented by 26 taxa pertaining to 16 taxonomical groups in spring, summer and autumn. Maximum values of total trophic zooplankton density (12211 ind. m^{-3}) and biomass (993.6 mg m^{-3}) were registered along southern littoral off Costinesti in summer. But, on the average, the trophic zooplankton biomass was one of the lowest (50 mg m^{-3}) since the beginning of 1990s. Among the exotic species, dominant forms were the ctenophores *Mnemiopsis leidyi* and *Beroe ovata*.

Thus, during 2000-2007, the non-trophic species *Noctiluca scintillans* and *Mnemiopsis leidyi* abundantly developed during the summers, even though they were lower than in the eutrophication period. They exerted great deal of interannual variability in the development of fodder species over a marked declining trend.

6.4. Bulgarian shelf area

Investigations on zooplankton community along the Bulgarian Black Sea coast started at the beginning of the 20th century (Chichkoff, 1912, Valkanov, 1935, 1936). The taxonomic structure, diversity, distribution and ecology were the main target of scientific interests, especially after the 1960s. More recent investigations after the intense eutrophication in the 1970s-1980s were focused on trends in the zooplankton fauna. Below, the changes in zooplankton assemblages in the Bulgarian coastal waters is presented using data derived from samples collected in various cruises in the shelf (< 200m depth; 30 sampling stations) and offshore (> 200 m depth; 10 sampling stations) as well as the time-series station located at 3 miles offshore of the Cape Galata (43°10' N , 28°10' E) and the monitoring network in Varna Bay-Varna-Beloslav Lakes during 1990-2005.

In the pre-eutrophication period, the zooplankton community structure along the Bulgarian coast included phylum Protozoa, Cnidaria, Nemathelminthes, Annelida, Mollusca, Arthropoda, Chaetognatha, Chordata and Ctenophora. Copepods of genus

Acartia, Paracalanus, Oithona mostly occurred inshore, while *Pseudocalanus* and *Calanus* were regularly observed in offshore waters. Cladocerans, such as *Evadne spinifera*, *E. tergestina, Penilia avirostris, Pleopis polyphemoides,* co-dominated the summer and fall community structure. *Parasagitta setosa* (Chaetognatha) and *Oikopleura dioica* (Appendicularia) were also co-dominant species. Benthic larvae (mainly Cirripedia, Polychaeta, Decapoda, Mollusca) contributed substantially to the inshore abundance structure. Usually, the estuaries and lagoons were enriched by brackish and fresh water species. Coastal areas (Varna and Beloslav lakes) were regularly abundant in rotifers (Kamburska, Stefanova, 2002).

This taxonomic composition, however, significantly changed during the intense eutrophication period (i.e. the 1990s) and afterwards (Table 6.6). While *A. clausi, P. parvus, O. similis* became a permanent component of the plankton fauna, other copepods such as *Pontella mediterranea and Anomalocera patersoni* were almost lost. The former species groups were occasionally recorded during the 2000s (Table 6.6). Similar trend was evident for warm-water copepods *O. nana* and *C. ponticus* (=*C. kröyeri pontica*). The non-indigenous *A. tonsa* that was first recorded in the Black Sea during the 1970s (Gubanova et al., 2001) has been reported again in the Bulgarian coastal waters after 2000 (Kamburska, 2004). Regarding cladocerans, small-sized *Pl. polyphemoides* occurred frequently whereas *E. spinifera, E. tergestina, E. nordmani, P. avirostris, Podon leuckarti* were scarcely distributed (Table 6.6).

From biodiversity perspective, the indices of species richness and evenness of zooplankton assemblages fluctuated considerably during the last ten years between 17 and 25. The evenness index of summer-autumn community became temporarily as high as 0.78 for a year and then became comparable to the early 1990s in the subsequent years. The Shannon diversity index similarly exhibited large fluctuations (Table 6.7). They all indicated species disproportion in the abundance structure and can be considered as a symptom of community instability, not ignoring also the natural (seasonal, annual) variability of the zooplankton associations.

Table 6.6 Taxonomic composition of dominant groups in sprign-summer at 3 miles station at Cape Galata (st. 301) including Varna Bay)
(🟨 recorded; 🟥 not recorded).

Species	Years										
	1954-1967	1984-1987	1991-1995	1996-1997	1998	1999	2000	2001	2002	2004	2005
Copepoda											
Acartia clausi	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
Acartia tonsa	🟥	🟥	🟥	🟥	🟥	🟥	🟨	🟨	🟨	🟨	🟨
Paracalanus parvus	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
Oithona similis	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
Pseudocalanus elongatus	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
Calanus euxinus	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
Anomalocera patersoni	🟨	🟥	🟥	🟥	🟥	🟨	🟨	🟨	🟥	🟥	🟥
Pontella mediterranea	🟨	🟥	🟥	🟥	🟥	🟨	🟨	🟥	🟨	🟥	🟥
Oithona nana	🟨	🟨	🟨	🟥	🟨	🟨	🟥	🟨	🟥	🟥	🟥
Centropages ponticus	🟨	🟨	🟥	🟨	🟥	🟨	🟨	🟨	🟨	🟨	🟨
Calanipeda aquae dulcis	🟨	🟨	🟨	🟥	🟥	🟥	🟥	🟨	🟨	🟥	🟥
Cladocera											
Pleopis polyphemoides	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
Podon leuckarti	🟨	🟨	🟨	🟥	🟥	🟥	🟥	🟥	🟨	🟥	🟥
Penilia avirostris	🟨	🟥	🟨	🟥	🟨	🟨	🟨	🟨	🟨	🟨	🟨
Evadne nordmani	🟨	🟨	🟥	🟥	🟥	🟨	🟥	🟨	🟥	🟥	🟥
Evadne tergestina	🟨	🟨	🟨	🟥	🟥	🟨	🟨	🟨	🟨	🟥	🟨
Evadne spinifera	🟨	🟨	🟥	🟨	🟥	🟨	🟥	🟨	🟨	🟥	🟥

Table 6.7. Number of zooplankton species (S), the Shannon-Wiener index (H) and the Pielou's evenness index (J) by years in summer-autumn in the Varna Bay.

Sampling area	Years						
Varna Bay	**1990-91**	**1996**	**1997**	**1998**	**1999**	**2001-02**	**2004-05**
S	17	21	23	24	21	25	22
J	0.60	0.69	0.80	0.78	0.57	0.64	0.66
H	2.44	3.02	3.30	3.01	2.50	3.14	2.93

Long - term changes: Varna Bay is one of the hot spots due to its highly disturbed ecosystem from direct and indirect human impacts. High nutrient and particulate and suspended organic matter, pesticides and other pollutant loads together with limited vertical water exchange give rise to frequent oxygen deficiency near the bottom (Stefanova et al., 2006a; 2007). Its total zooplankton abundance increased from 3660 ind. m^{-3} in 1996 to 38756 ind.m^{-3} in 2001-2002 followed by a reduction to ~11876 ind.m^{-3} in 2004-2005 (Fig. 6.8a). Both the percentage share and abundance of *N. scintillans* decreased continuously after 1990 contrary to increasing role of first Meroplankton and then Copepoda up to 2000-2001 (Fig. 6.8a, 6.8b). This trend however changed during 2004-2005 due to reduction in Meroplankton abundance and increase in Copepoda abundance, although meroplankton still constitutes the highest biomass share in total zooplankton biomass.

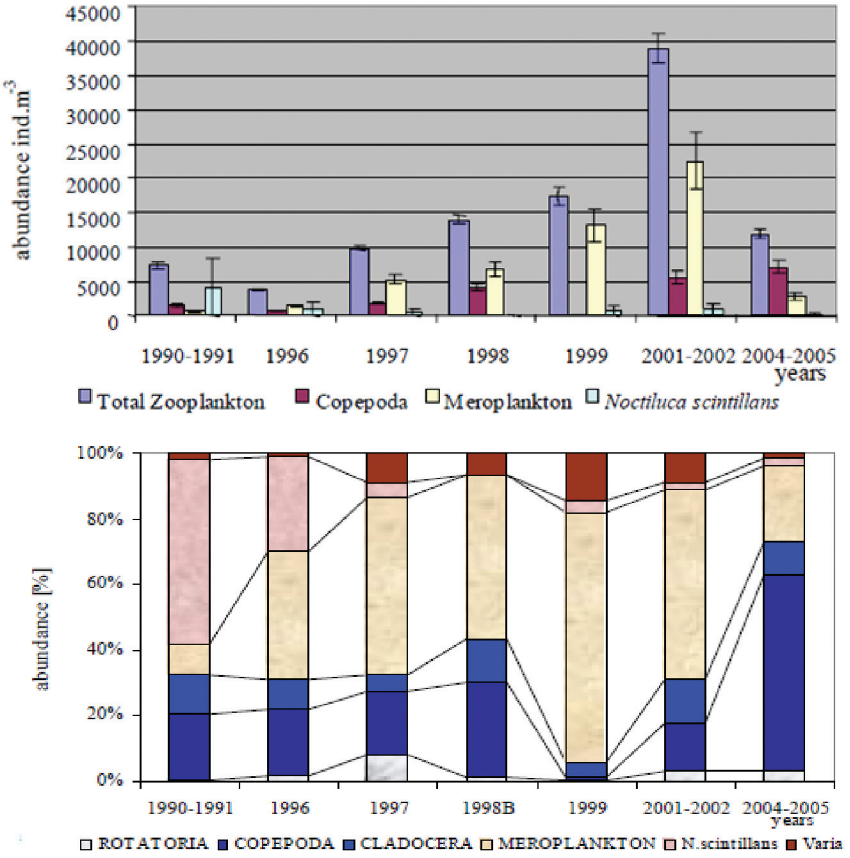

Fig. 6.8. Interannual variations of total zooplankton abundance (ind. m^{-3}) and percent share of key taxonomic groups in Varna Bay.

The community structure shifted over the decades also in front of the Cape Galata especially in summer. Cladocera and Copepod populations which were abundant in the late 1960s-early 1970s decreased during the 1990s and the early 2000s with the exception of summer 2005 (Table 6.9). Four sampling campaigns performed during summer periods in 1998-2001 disclosed that Copepods, Cladocerans and benthic larvae dominated the abundance structure in the surface homogeneous layer (SHL) (Fig. 6.9). Copepods and Cladocerans constituted 80 % of the total biomass in the layer above the thermocline. Besides, the amount of *Oicopleura dioica* was also high together with benthic larvae which varied from 28 % to 51 % of the total abundance. The contribution of Cladoceran biomass was much higher in 2000-2001 varying in the range of 40 % to 56 %.

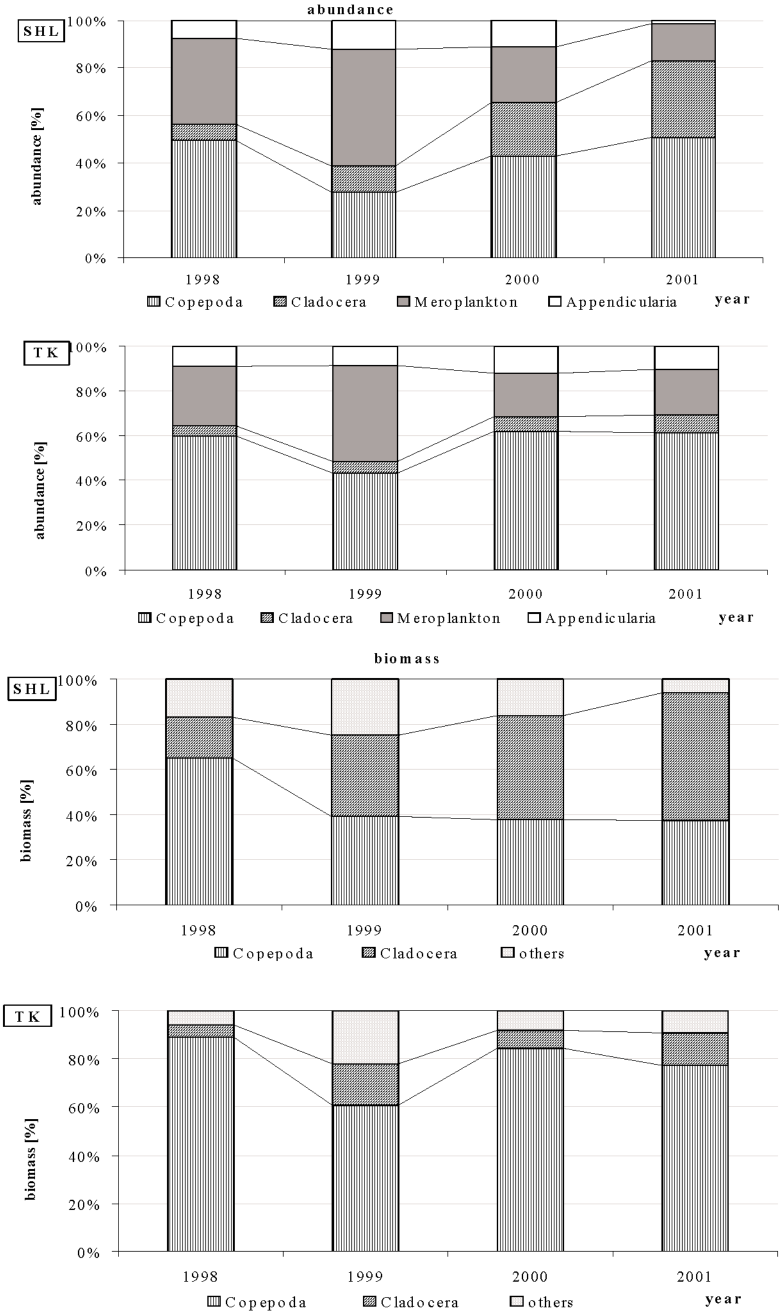

Fig. 6.9. Vertical distribution of total edible zooplankton abundance and biomass by taxonomic groups [in %] in surface homogeneous layer (SHL) and the sub-thermocline layer (TK) off the Bulgarian Black Sea coast during summer period 1998-2001.

In regards to the sub-thermocline layer (TK), the Copepoda group dominated the abundance and biomass structure (Fig. 6.9). The zooplankton biomass was higher at shelf stations along with steady decrease from north to the south and towards the open sea with some exceptions (Table 6.9). For instance, the lowest biomass (5 mg m^{-3}) was recorded in the shelf during summer 1998. The increase afterwards was due to enhanced amount of Cladocerans biomass. In addition, large aggregates of C. euxinus were noted along the coast of Cape Kaliakra and at an offshore station during summer 2000.

Table 6.8. Summer mean abundance of dominant taxonomic groups [ind.m^{-3}] at 3 miles offshore of the Cape Galata.

Periods/ Groups	1967-69	1970-79	1980-89	1990-99	2000-04	2005
Copepoda	9986	10368	8805	3388	1319	3612
Cladocera	12865	4816	2946	1222	471	7673

The period 1990-2005 involved significant inter-annual variations such as the decline of M. leidyi in 1991 1993, the introduction of B. ovata in 1997, and climatic changes. The period 1990-1997 was characterized by large amount of M. leidyi and subsequent strong decrease in mesozooplankton abundance (Fig. 6.10) and biomass (Fig. 6.11). Later, once Mnemiopsis was controlled by its predator Beroe and reduced to moderate concentrations depending on environmental conditions (Kamburska, Stefanova, 2005).

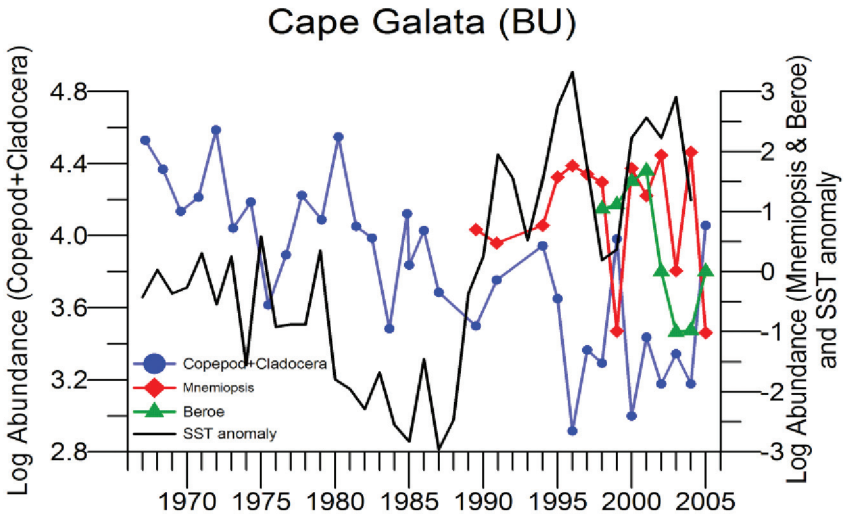

Fig. 6.10. Long-term changes of Copepoda+Cladocera, *M. leidyi* and *B. ovata* abundances (log transformed) and SST anomaly at 3 miles off the Cape Galata during summer 1967-2005 (from Kamburska et al., 2006b).

The distribution of *M. leidyi* manifested considerable time-space variability after 1997; its abundance was confined into the warm surface mixed layer above the thermocline and much higher in the shelf compared to offshore area (Fig. 6.12). *M. leidyi* was more abundant in summer 2000-2002 and 2004, but it was rare in 1999, 2003 and 2005. Due to such strong year-to-year fluctuations, individual years may be identified as "poor", "normal" or "rich" if 40 ind.m^{-3} gelatinous plankton is accepted as the threshold bloom concentration. Accordingly, 1999, 2001, 2003 and 2005 are classified as "poor" years with rare and/or almost absent populations of trophic zooplankton. The changes in mesozooplankton structure therefore can not be attributed alone to the impact of *B. ovata* and should likely be affected by anthropogenic and climatic factors (Oguz, 2005). The Black Sea maintained warm SSTs after the mid-1990s similar to those observed prior to 1980 (Oguz, 2005, Oguz and Gilbert, 2007). Winters became gradually warmer, springs colder, and the summers were short and hot during 1995-2000. On the other hand, anthropogenic nutrient and pollutant loads diminished due to the limited use of fertilizers in agriculture after the beginning of 1990s (Moncheva et al., 2002). Furthermore, long-term data revealed a decreasing trend of salinity in front of the Cape Galata to 10 miles offshore (Dineva, 2005). Both the augmented temperature and decreased salinity of surface waters contributed to enrichment of Cladocerans (Kamburska et al., 2006a).

Table 6.9. Mesozooplankton biomass statistics by areas (shelf, open sea) during summer period 1998-2001 (number of observations, n=250).

Year, Region	1998	1999	2000	2001
	Mg.m^{-3}	mg.m^{-3}	mg.m^{-3}	mg.m^{-3}
		Shelf		
Total	577.31	2503.76	1394.8	620.9
Mean ± stdev	30.4 ± 18.4	119.2 ± 153.9	51.7 ± 28.9	62.1 ± 42.2
Minimum	5.2	7.64	14.5	12.3
Maximum	71.7	636.72	121.8	168.1
		Open sea		
Total	479.2	106.9	408.7	-
Mean stdev	95.9 34.5	26.8 11.0	58.4 45.9	-
Minimum	49.8	12.4	14.9	-
Maximum	131.3	38.4	147.8	-

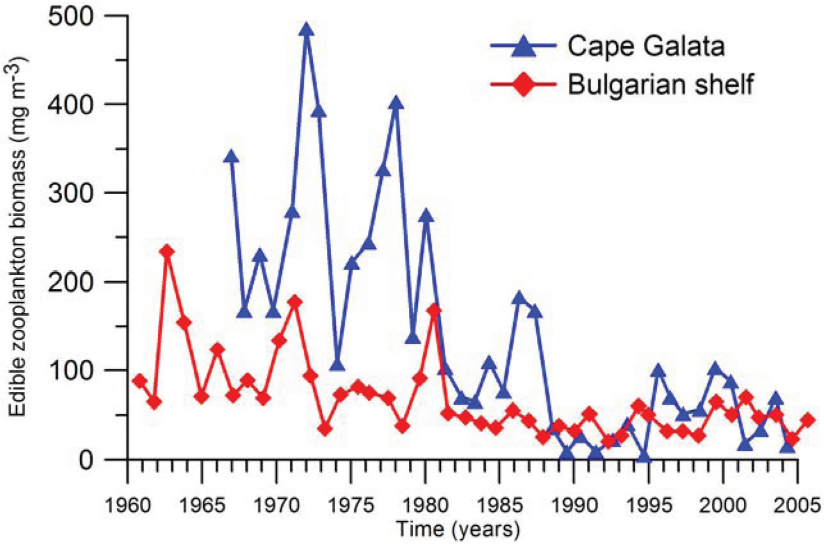

Fig. 6.11. Long-term changes of annual-mean edible zooplankton biomass at 3 miles off the Cape Galata and its average over the Bulgarian coastal waters.

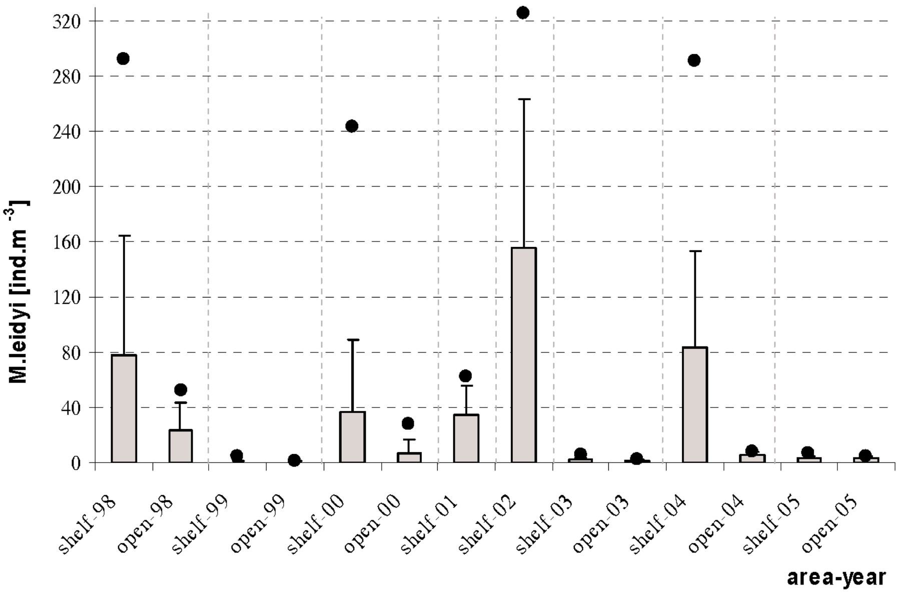

Fig. 6.12. Mean and maximum abundances of Mnemiopsis leidyi [ind.m^{-3}] in the Bulgarian shelf and open sea areas during summer 1998-2005 (number of observations n=172).

The heterotrophic dinoflagellate *N. scintillans* was a dominant component of the zooplankton community structure with frequent and massive blooms during the early and intensive eutrophication phases (Fig. 6.13). It was regularly found at inshore waters, but large aggregates also occurred in offshore waters (Konsulov, Kamburska, 1998b). The decreasing trend of its abundance in the post eutrophication phase (Fig. 6.13) was partly due to a reduction in eutrophication as well as its competitive disadvantage of food consumption against *Mnemiopsis*. Mucus excretions by *Mnemiopsis* may also likely limit its growth and distribution. The summer-autumn mean *Noctiluca* abundance displayed some increase during 2003-2005 even though it was lower than the eutrophication period. Their large blooms were still frequent in the early summer and/or autumn seasons, but their duration was relatively short with respect to the eutrophication period. Assuming the biomass abundance ratio as 0.08, their biomass during 2004-2005 is around 1000 mg m^{-3}.

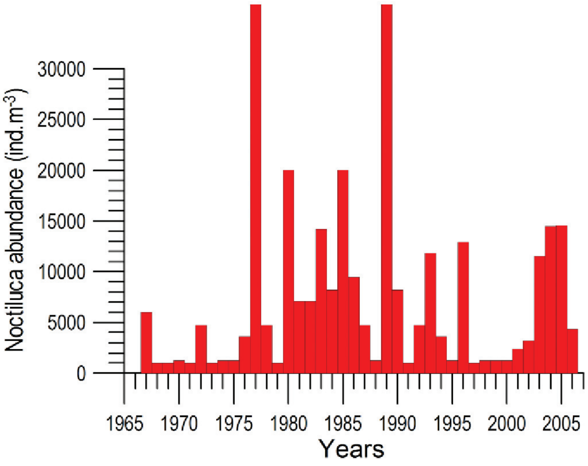

Fig. 6.13. N. scintillans spring-autumn mean abundance (ind.m^{-3}) along the Bulgarian coastal waters.

Seasonal Changes: Trophic zooplankton abundance along the Bulgarian shelf during 2002-2006 revealed a linear trend of increase from low winter abundance (< 5000 ind. m^{-3}) to highest abundance (>18000 ind. m^{-3}) in July (Fig. 6.14a). *N. scintillans* follows trophic zooplankton and its population started building up in April and reached more than 10000 ind. m^{-3} in June-July (Fig. 6.14b) and therefore limited to some extent trophic zooplankton abundance. This period (spring-early summer) also involved weak development of *A. aurita* with a typical biomass of 50 g m^{-2} possibly due to its competitive disadvantage of consuming zooplankton against *Noctiluca* (Fig. 6.14c). Its high biomass (~200 g m^{-2}) in September 2004 coincided with the low *M. leidyi* and *Noctiluca* biomass. Starting by August, trophic zooplankton abundance decreased abruptly and remained below 5000 ind. m^{-3} when *M. leidyi* biomass elevated up to 250 g m^{-2} in August-September (Fig. 6.14d). This peak biomass season of *M. leidyi* lasted only 2 months and dropped significantly by October due to the grazing impact of *B. ovata*.

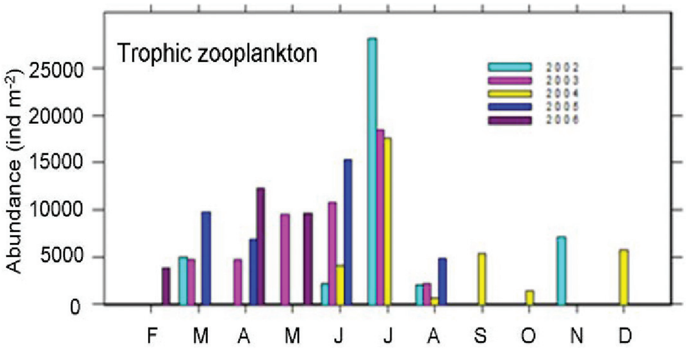

Fig. 6.14a. Seasonal changes of trophic zooplankton abundance along the Bulgarian shelf waters in 2002-2006.

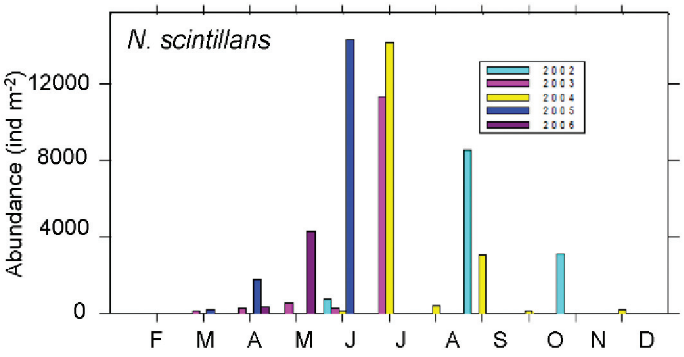

Fig. 6.14b. Seasonal changes of Noctiluca scintillans abundance along the Bulgarian shelf waters in 2002-2006.

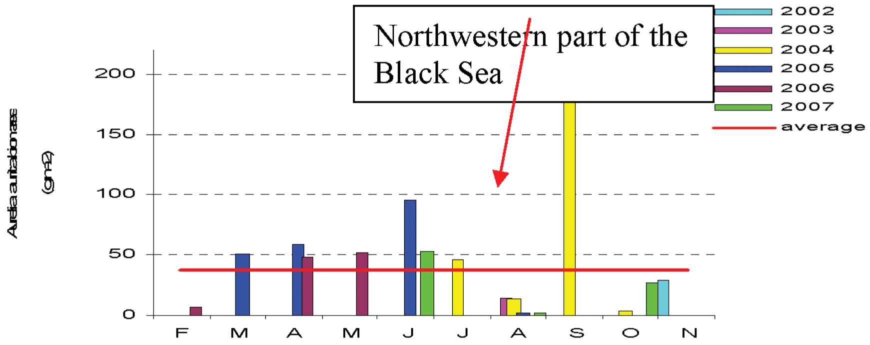

Fig. 6.14c. Monthly changes of *Aurelia aurita* biomass (g m^{-2}) along the Bulgarian shelf waters in 2002-2007 (with data from the north-western region in 09.2004). The red line depicts the average of all monthly data in Bulgarian waters.

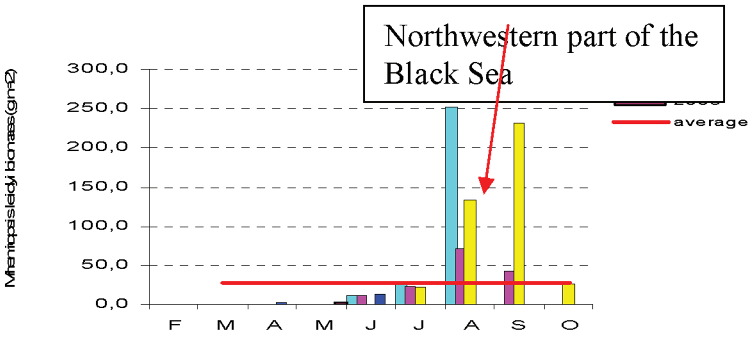

Fig. 6.14d. Monthly changes of *Mnemiopsis leidyi* biomass (g m^{-2}) along the Bulgarian shelf waters in 2002-2006 (with data from the north-western region in 09.2004). The red line depicts the average of all monthly data in Bulgarian waters.

6.5. Turkish shelf area

The time series measurements performed in front of the Cape Sinop situated at the central sector of the southern coast suggested relatively low annual-mean zooplankton biomass with respect to western coastal waters during 1999-2005 (Fig. 6. 15). The sum of edible and non-edible (*Noctiluca*) biomass was maintained around 100 mg m^{-3} in 1999, 2004, 2005 whereas it was at least twice lower in relatively cold years 2002-2003. In all cases, more than 70% of the total biomass was formed by the non-edible zooplankton group which was mainly composed by *Noctiluca scintillans*, the main indicator species of eutrophic waters. *Noctiluca* biomass was particularly dominant in the winter and early-spring during the cold year 2003 and in the spring and summer (up to a maximum of 20 g m^{-2}) during the subsequent relatively warm year, 2004 (Fig. 6.16). In terms of abundance, both edible zooplankton and *Noctiluca* varied in the range 0-4000 ind. m^{-3} during 1999-2005 that was two-to-three times smaller than in the Bulgarian shelf (Fig. 6.17) and therefore can not be considered as the bloom level.

Edible zooplankton was mostly dominated by Copepoda throughout the observation period (Fig. 6.18). Highest edible zooplankton abundance and biomass was recorded in February-March during 1999, 2000, and 2003, but shifted to the late summer-early autumn in 2004, 2005 (Fig. 6.16, 6.17). *N. scintillans* generally dominated zooplankton community in late-spring and summer months. Edible zooplankton abundance reduced substantially during the months of high *N. scintillans* abundance (Fig. 6.16, 6.17) as well as of high *Mnemiopsis* abundance (Fig. 6.19) that was generally lower than 50 ind.m^{-2} except twice higher abundance during the summer 2003. Copepoda and *Noctiluca* contributed almost equally to the total zooplankton population during 2004 and 2005, but Copepoda was more dominant in other years (Fig. 6.15).

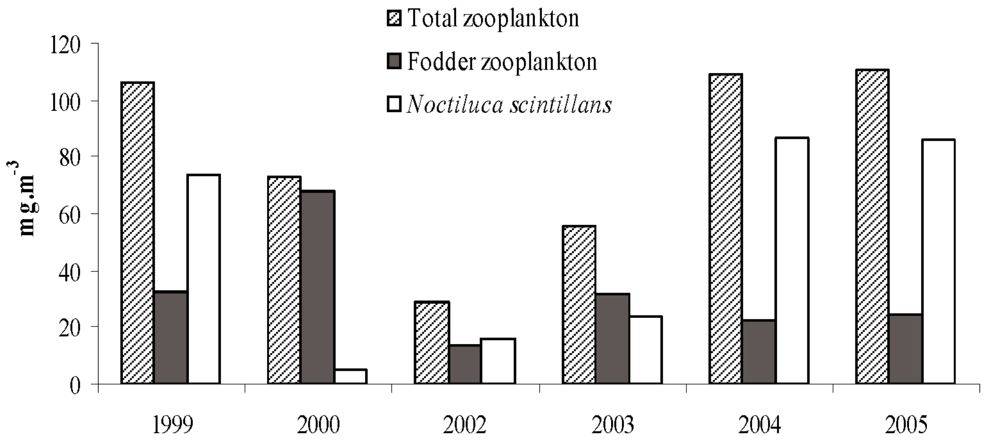

Fig. 6.15. Annual mean biomass (mg.m^{-3}) of the total zooplankton, fodder zooplankton and Noctiluca scintillans off the Cape Sinop (in the central sector of the southern coast) during 1999-2005. Data sources: Unal, (2002), Ustun (2005), Bat et. al. (2007), Ustun et. al. (2007).

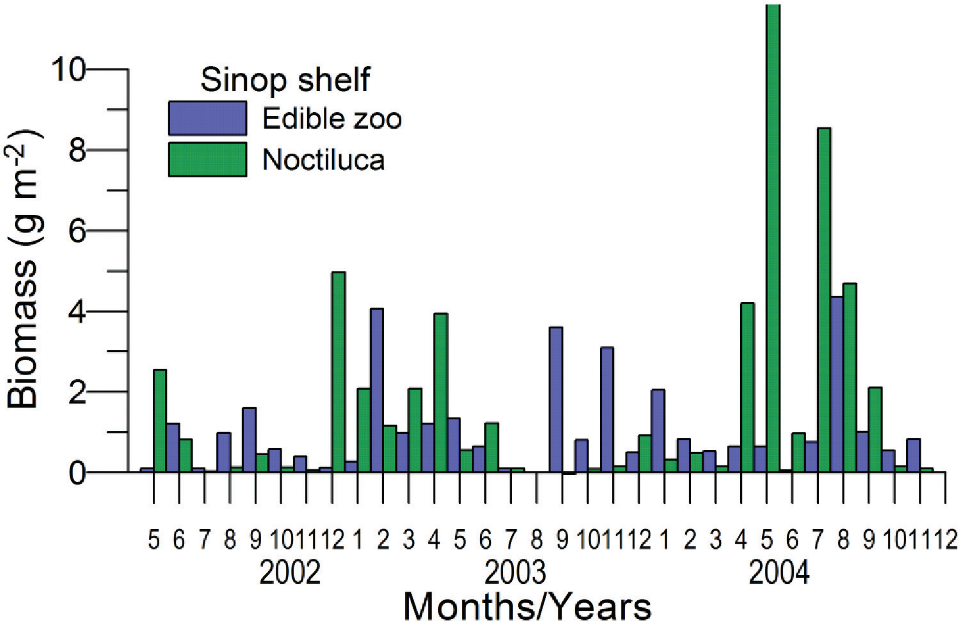

Fig. 6.16. Monthly biomass (g.m^{-2}) changes of edible zooplankton and Noctiluca scintillans off the Cape Sinop (in the central sector of the southern coast) during 2002-2004. Data source: Ustun (2005).

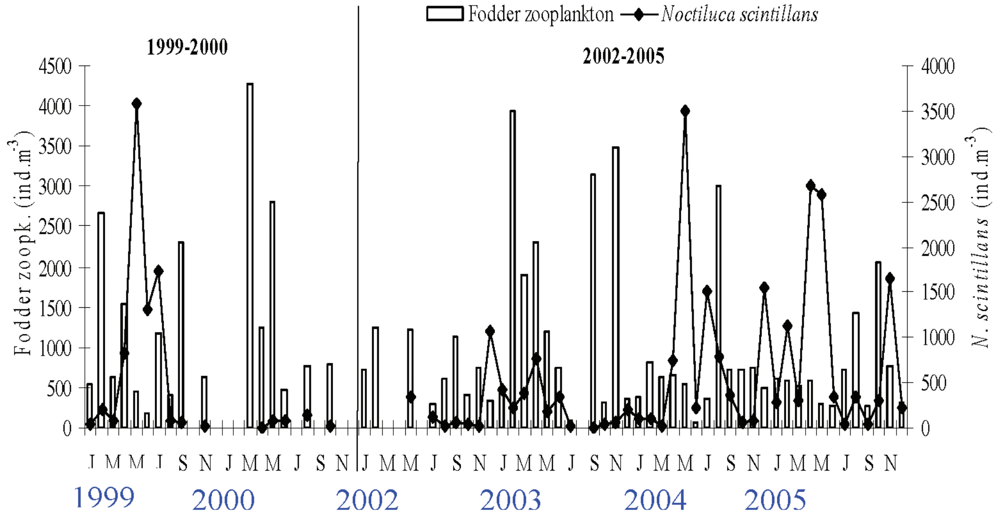

Fig. 6.17. Abundance (ind.m^{-3}) variations of trophic zooplankton and N. scintillans off the Cape Sinop (in the central sector of the southern coast) during 1999-2005.

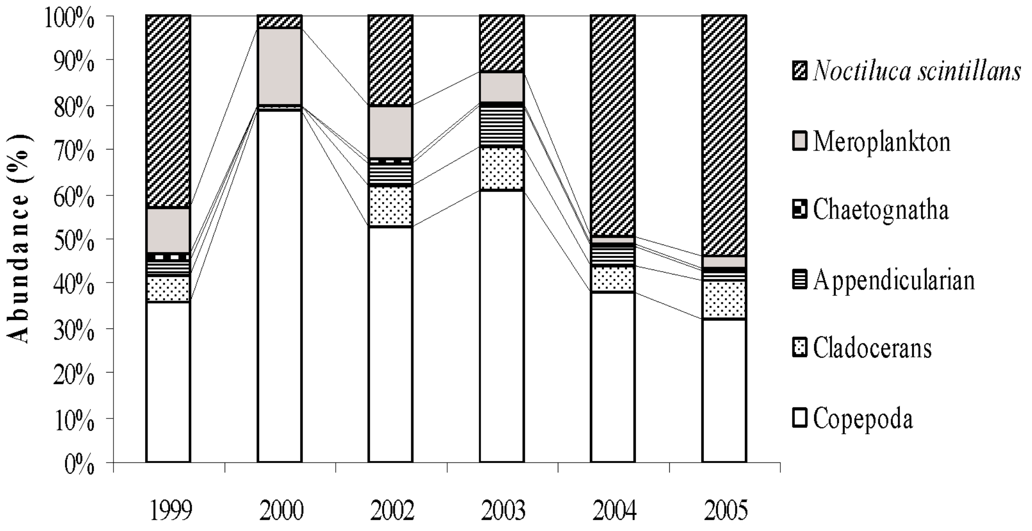

Fig. 6.18. Annual variation of zooplankton community structure abundance (%) in in the sea off Sinop.

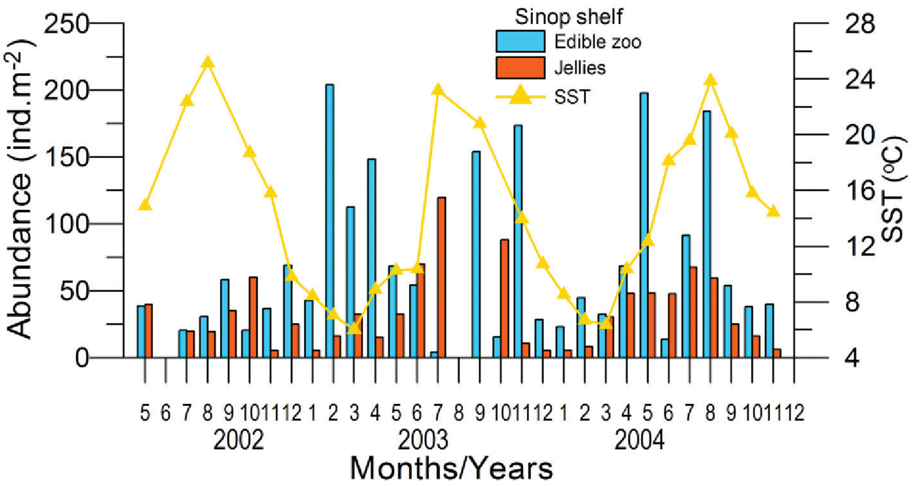

Fig. 6.19. Variations of edible zooplankton and jelly abundance (ind.m^{-3}) and sea surface temperature off the Cape Sinop (in the central sector of the southern coast) during 2002-2004.

6.6. Georgian shelf area

Research on zooplankton biodiversity of the south-eastern Black Sea was limited. The data from pristine phase 1955-1957 (Table 6.10) indicated edible zooplankton biomass around 100±50 mg m^{-3} within the upper 25 m layer, of which 70-80% was produced during the spring-summer months. Owing to more enhanced production, abundance and biomass of trophic zooplankton formed mainly by Protozoa, Copepoda, and Cladocera increased two-folds during the 1990s but they were subject to high year-to-year variations (Fig. 6.20). The *N. scintillans* contribution to the total zooplankton biomass reduced from 50% in 1995 to 5% in 2002. The data further showed reappearance of Pontellidae *Pontella mediteranea* after 2002 that indicated recovery of the regional ecosystem.

The comparison of annual-mean biomass of the upper 100 m layer from 1950s with the recent data from the 1990s and early 2000s suggested an increase from less than 75 mg m^{-3} up to a minimum of ~150 mg m^{-3} during 1996 and 2002 and a maximum of around 500 mg m^{-3} during 1998-1999 corresponding to the strong *Beroe* impact on *Mnemiopsis* population. The edible zooplankton biomass reduced gradually in the following years up to ~130 mg m^{-3} at 2002. However, even this minimum biomass registered in 2002 was higher than the maximum biomass measured at Galata site of the Bulgarian coastline during the same period.

Table 6.10. Annual changes of the trophic zooplankton biomass (mg.m^{-3}) in the south-eastern part of the Black Sea.

Months	1955		1956		1957	
	(25-0 m)	**(100-0 m)**	**(25-0 m)**	**(100-0 m)**	**(25-0 m)**	**(100-0 m)**
January	44.5	34.7	23.4	48.5	-	-
March	76.6	66.6	11.4	18.0	95.0	65.0
May	69.7	95.1	-	-	145.0	89.3
Jun	38.8	33.8	191.5	121.0	100.4	62.2
July	41.4	22.7	56.0	43.3	99.6	53.8
August	-	-	69.8	31.3	305.4	98.1
Total	271	252.9	352.1	262.1	745.4	368.4
Average	54.2	50.6	70.4	52.4	149.1	73.7

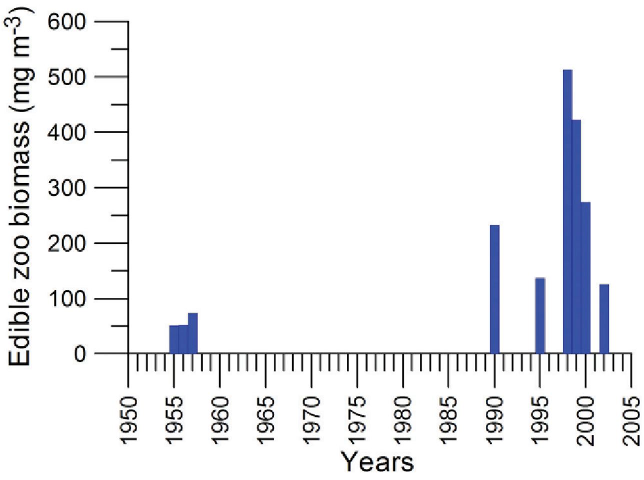

Fig 6.20. Annual-mean trophic zooplankton (Protozoa, Copepoda, Cladocera) biomass (mg m^{-3}) variations in the Georgian waters during 1955-1957 and 1990-2002 within the upper 100 m layer.

6.7. Northeastern shelf area

The north-eastern part of the Black Sea has been monitored regularly by P.P.Shirshov Institute of Oceanology, Russian Academy of Sciences. The most important feature of zooplankton community structure after the early- 1970s was the change in species composition and quantitative proportions between various groups of zooplankton species. The species of Copepoda and Pontelidae (e.g. *Anomalocera patersoni, Pontella mediterranea, Labidocera brunescens*) were the first victims of heavy pollution in the surface layer and their abundance declined to a negligible level in 1983 even though *Pontella mediterranea* was rather common in the open waters until the end of 1980s. Abundances of *Oithona nana* and *Centropages ponticus* were also reduced considerably in the early 1970s. Thus, the degradation of the zooplankton community started well-before the *Mnemiopsis* invasion. As the proportion of trophic zooplankton decreased, its species composition changed the proportion of non-trophic zooplankton, first *Noctiluca scintillans* then jellyfish *Aurelia aurita* increased. The significant increase of non-trophic zooplankton population and its grazing on large and small zooplankton and phyto- and microplankton led to worsening of the zooplankton community structure. The conditions also favored establishment of the new gelatinous warm-water ctenophore species *M. leidyi*. Within the warm surface layer, it found optimal conditions of temperature, salinity, and productivity, and hence reached extremely high abundances by the end of the 1980s.

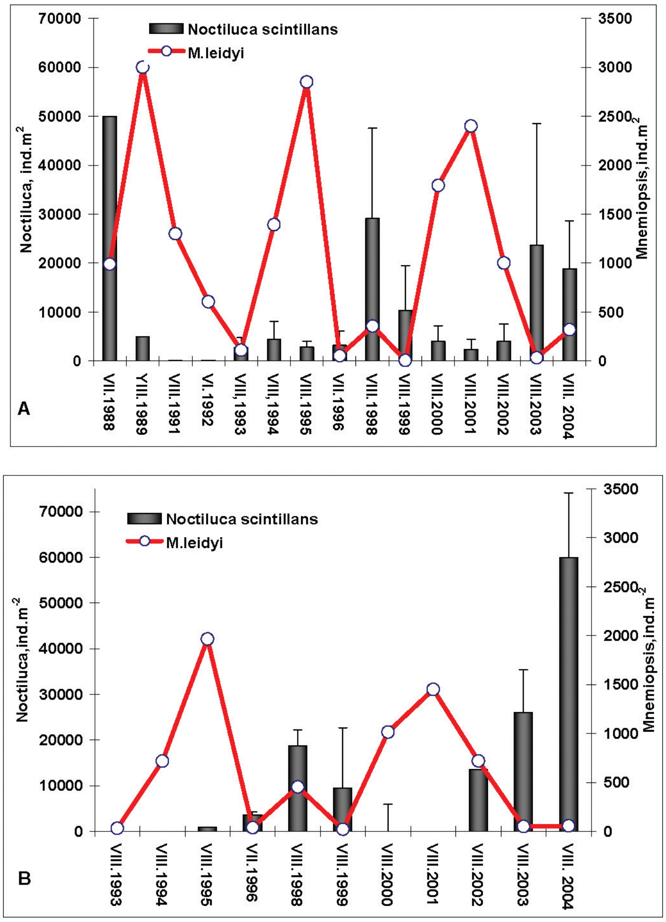

Fig. 6.21. Interannual variations of summer *M. leidyi* and *N. scintillans* abundances indicating their negative correlation for (a) inshore waters ($r = -0.3$) and (b) offshore waters ($r = -0.4$ $p < 0.02$) of the north-eastern basin.

Heterotrophic dinoflagellates *Noctiluca scintillans* was the first gelatinous organism that reached at an enormously high biomass in response to intense eutrophication during the 1980s. Later, its abundance decreased by strong food competition pressure exerted by *Mnemiopsis* (Fig. 6.21). During the first years of intense *M. leidyi* development (1989-1991), the *Noctiluca scintillans* abundance dropped due to food competition advantage of *M. leidyi* as both of them feed on similar food resources (Greze, 1979). This is supported by the negative correlation between their summer abundances shown in Fig. 6.21. This correlation was partly controlled by the severity of climatic regime.

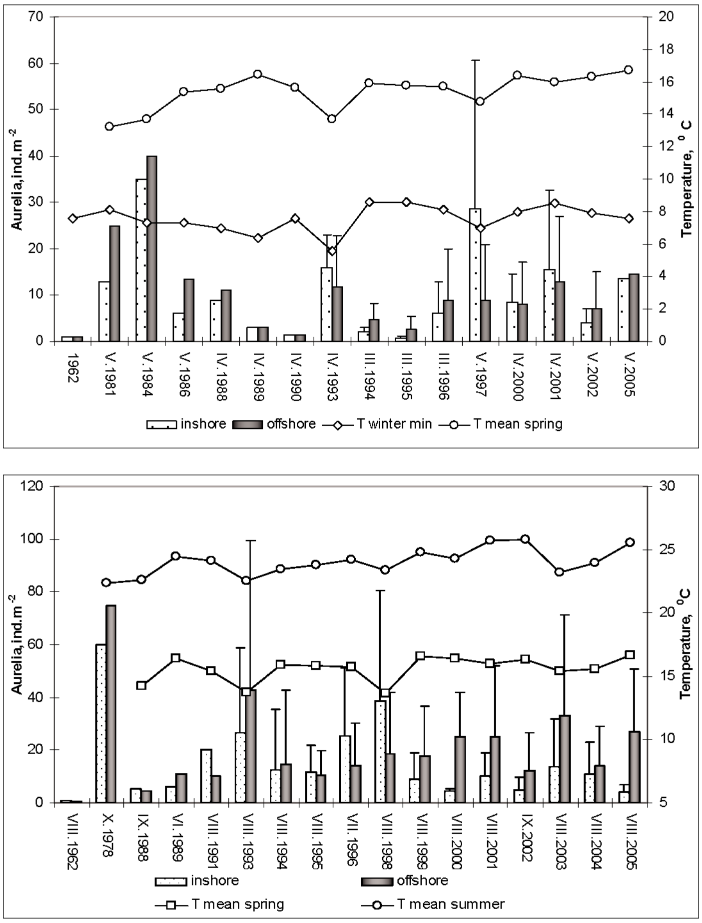

Fig. 6.22. Interannual variations of *Aurelia aurita* abundance in near-shore and offshore waters during (a) spring and (b) summer months, as well as of the mean spring and summer temperatures. The data are complied from various sources: Shushkina and Musaeva (1983); Shushkina and Arnautov (1987); Flint, Arnautov, and Shushkina (1989); Shiganova et al. (2003, 2006).

As *M.leidyi* tended to have lower abundance after cold winters, *N. scintillans* attained higher abundance due to lack of its competitor. Conversely, being a boreal cold-water organism, *N. scintillans* had more favorable reproduction capability in the years with cooler late-spring (May-June) temperatures after more severe winters. In contrast, being a thermophilic species *M. leidyi* lived in the warm surface layer and reproduced better in warm climatic years. In the years with low *M. leidyi* control, *N. scintillans* abundance generally exceeded 20000 ind. m^{-2} and reached occasionally at 50000 ind. m^{-2}, that was much higher than in the Bulgarian shelf and comparable to the NWS.

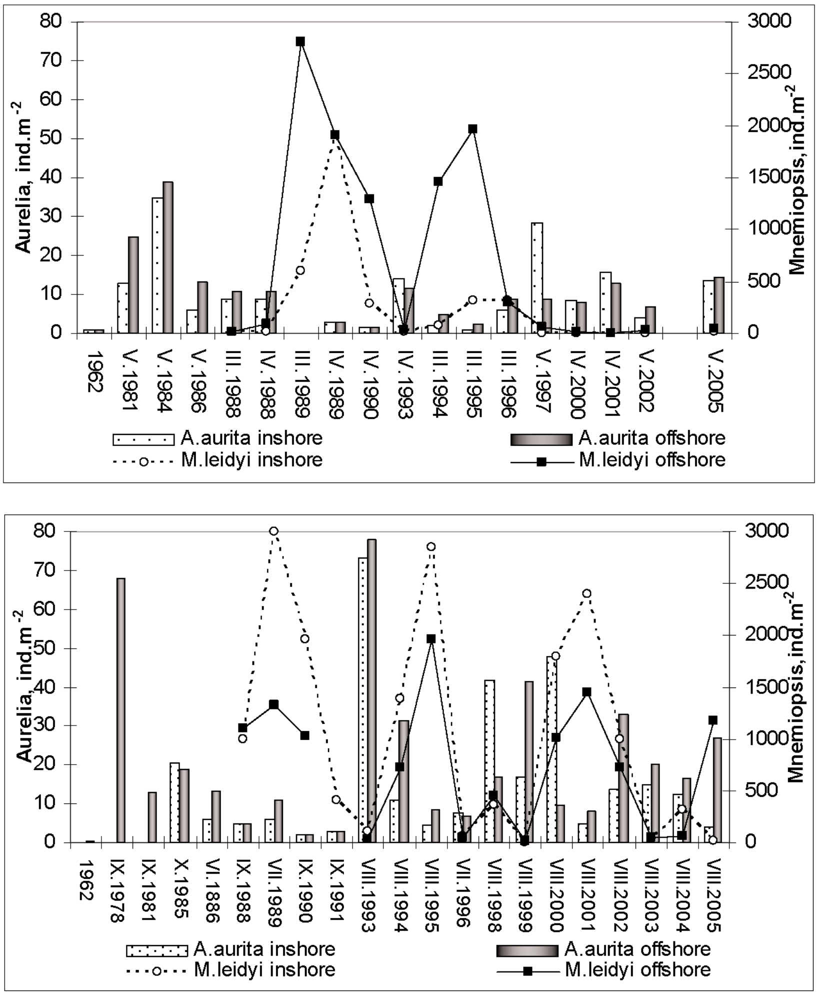

Fig. 6.23. Interannual variations of Aurelia aurita and Mnemiopsis leidyi abundances in coastal and offshore waters of the northestern basin during (a) spring, (b) summer months.

Aurelia aurita is also a cold-water species and more commonly distributed in boreal waters despite its presence in different climatic zones. Therefore, its abundance also likely followed the interannual climatic variations. During cooler spring phases, its abundance was higher due to more favorable winter generation at minimal winter temperatures of 7-8°C (Fig. 6.22a). Its correlation with spring temperatures is $r = -0.38$ for coastal waters and $r = 0.7$ for cooler offshore waters ($p < 0.01$). A similar trend was also noted for the case of lower summer temperatures with the correlation of $r = -0.28$ and $r = -0.5$ ($p<0.02$) for coastal and offshore regions (Fig. 6.22b). Up to 90% of its individuals were aggregated in the thermocline layer where the temperature is precisely 8-11°C and the subsequent Cold Intermediate Layer at depths of 30-50 m (Fig. 6.22b). But their accumulation was observed to extend up to 70-80 m depths, and small individuals were present in the mixed layer at the temperature range of 19-20°C as well (Shushkina and Arnautov, 1987). In the near-shore zones, they settled relatively cold waters near the bottom during warm periods (Gomoiu and Kupriyanov, 1980; Zaitsev, 1998; Shiganova, 2000).

Medusas physiological food demand amounts to 9-13% of the total primary production which may be realized at a level of 95-100% throughout the year. This implies that they can consume 34-67% of the total mesozooplankton production or 47-90% of the Copepod production. Increasing *Aurelia aurita* population therefore impose a strong negative influence on trophic zooplankton. Their detritus consumption, on the other hand, is relatively insignificant and roughly corresponds to the non-assimilated part of their ration.

A.aurita is not an obligate zooplanktivorous predator such as *M. leidyi,* and its ration may contain detritus, alga cells, and aggregates of bacteria. Moreover, their populations were disconnected from *M. leidyi* population that was largely confined into the surface mixed layer. Nevertheless, its abundance sharply dropped with the appearance of *M. leidyi.* In the years with high *M.leidyi* abundances, its both spring and summer populations decreased drastically (Fig. 6.23). Their correlation was respectively $r= -0.38$ and $r= -0.7$ ($p < 0.01$) for coastal and offshore waters in the spring and $r= -0.28$ and $r= -0.5$ ($p<0.02$) in the summer.

The absence of its predator and being a better competitor with respect to *A. aurita* and *N. scintillans* allowed *M. leidyi* to reach high abundance and biomass and to introduce enormous influence on the ecosystem. Edible zooplankton, meroplankton, and eggs and larvae of fishes were the main food resources for juvenile and adult individuals of *M.leidyi*. Therefore, it directly and most strongly affected their abundance, biomass, and species composition. The correlation between edible zooplankton and *M.leidyi* biomass in August prior to the settlement of *Beroe* is $r = -1$ ($p < 0.01$) (Fig. 6.24).

M. leidyi was capable of consuming unlimited trophic zooplankton without any satiety as long as the zooplankton concentration higher than 3000 ind.m^{-3} (Tsikhon-Lukanina et al., 1992). Although it had no food selectivity, it preferred small-sized preys in the range 0.75-1 mm. In the near-shore waters, its food was more diverse than in the open sea and its gastrovascular cavinity most often contained larvae of bivalves (Sergeeva et al., 1990; Tsikhon-Lukanina et al., 1991). Food objects might however change depending on the region, season, and even time of the day, varying also with the changes in species composition of zooplankton available. The most intensive feeding of M. leidyi was noted in the evening and about midnight (Sergeeva et al., 1990, Shiganova, 2000).

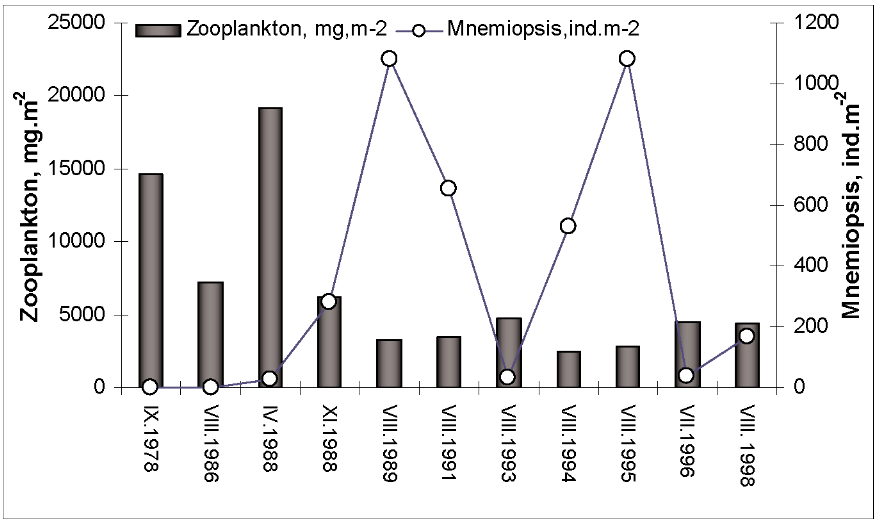

Fig. 6.24. Interannual variations of zooplankton biomass (mg m^{-2}) and M. leidyi abundance (ind. m^{-2}) before the B. ovata appearance.

M.leidyi appeared in selected regions of the Black Sea in spring 1988, but spread over the entire basin in summer 1988. The studies performed as early as in August-November 1988 showed large drop in zooplankton biomass (Fig. 6.24). In summer 1989, when *M.leidyi* reached its maximal development with respect to its abundance and biomass, the zooplankton community deteriorated even stronger (Fig. 6.24). This first affected small-sized zooplankton species; biomass of nanophages less than 1 mm in size decreased from 3 g m^{-2} in spring 1988 to 0.2 g m^{-2} in September. The abundance of *Acartia clausi, Oithona nana, O. similis,* adult *Paracalanus parvus,* and *Parasagitta setosa* experienced a decreasing trend (Fig. 6.25, 6.26). While their abundance was as high as 1000 ind. m^{-2} during the years prior to the *M.leidyi* appearance (Pasternak, 1983), only three *Parasagitta setosa* individuals were sampled at all stations in September 1988 (Vinogradov et al., 1989). In addition, the Copepods *Centropages ponticus* and *Paracalanus parvus* were represented by single individuals. *Oithona nana* and representatives of the Pontellidae family and *Parasagitta setosa* disappeared by 1990. Starting from 1990, a decrease in the abundance of other planktonic species was observed such as *Oithona similis, Acartia clausi,* all the Cladocera species, and *Oikopleura dioica,* as well as *Calanus euxinus* that dwelled in deeper layers (Fig. 6.25, 6.26). *Calanus euxinus* executed vertical migration to subsurface layers in the night-time, where it became available for *M.leidyi*.

In 1991 and 1992, the total abundance and biomass of zooplankton decreased drastically (Fig. 6.24). During the first years of its development, *M. leidyi* therefore strongly affected the abundance, biomass, and species composition of the Black Sea zooplankton in coastal regions. As *M.leidyi* dwelled in the upper mixed layer and reached at its highest abundances in the summer, its first victims were the near-surface species of zooplankton that developed in the warm period of the year as well as the species that migrated to the surface layers for feeding.

In the exceptionally cold year 1993, the abundance and biomass of *M.leidyi* decreased (Fig. 6.24). The species diversity and abundance of selected zooplankton species, such as *Pseudocalanus elongates, Calanus euxinus,* and *Oithona similis,* increased in summer in the open waters owing to the low abundance of *M.leidyi* (Fig. 6.26). An increase in the abundance of the eurithermal *Acartia clausi* was observed in the near-shore waters (Fig. 6.25). The total abundance of edible zooplankton, however, remained very low (Fig. 6.24). *Parasagita setosa* was also noticed (Fig. 6.25). Among thermophilic species, significant amounts of *Penilia avirostris* were recorded. The species diversity and abundance were higher in the near-shore waters (Fig. 6.25) although even *Centropages ponticus,* which was absent in the previous years, was encountered in open waters (Fig. 6.26). However, the decrease in the abundance of eurithermal species all-year-round by 1993 was very high both in the open and near-shore waters with respect to the previous years.

The edible zooplankton diversity index was changing in the range 1.35-1.8 in the spring prior to the *Mnemiopsis* era depending on the region and temperature (Zaika and Andryushchenko, 1996). But, it reduced to 0.5-0.7 range after the introduction of *Mnemiopsis* and attained its lowest value during its second population outburst at 1995, then it increased to 1.0-1.1 during 1996-1998 when *Mnemiopsis* abundance became lower (Fig. 6.27).

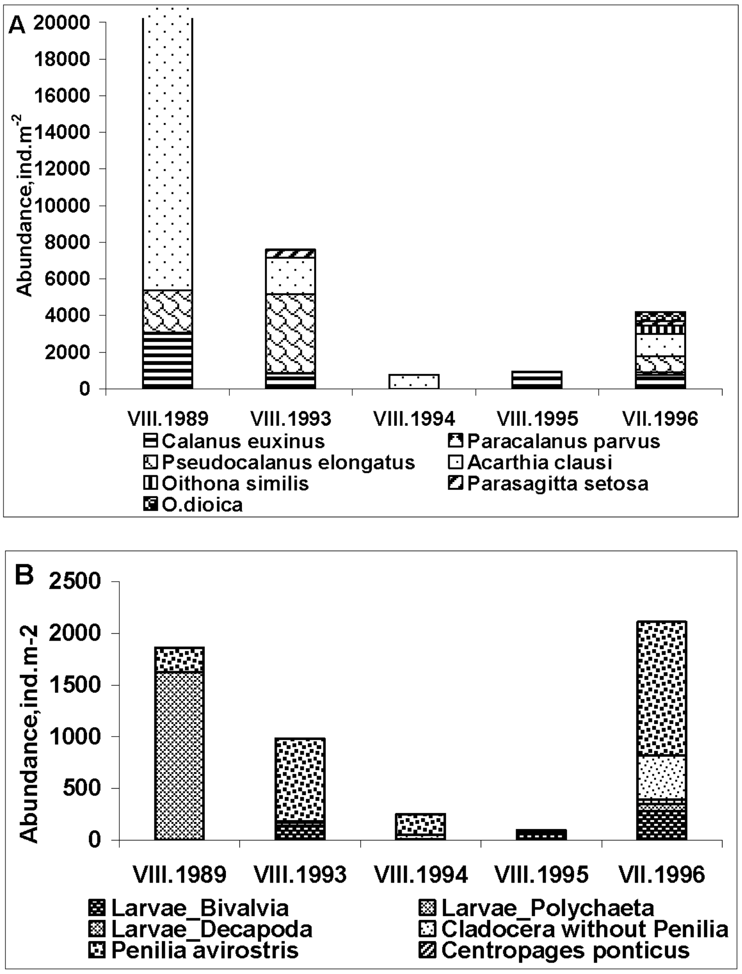

Fig. 6.25. Interannual variations of species composition and abundance of edible zooplankton in the inshore waters in August after the introduction of M.leidyi: (A) coldwater and eurythermal species, and (B) thermophilic species.

More noticeable increase in edible zooplankton abundance and biomass was observed after 1998 following the population outburst of *Beroe ovata*. During the first *B. ovata* outburst in August-September 1999 (Fig. 6.28), the quantitative parameters of the edible zooplankton increased notably as compared to the last 10-year period of the *M.leidyi* invasion (Fig. 6.29, 6.30). The abundances of Cladocera species and *Penilia avirostris* were especially high. *Pontella mediterranea* appeared for the first time after its long-term absence. Among eurithermal species, *Acartia clausi* significantly increased its abundance, *Paracalanus parvus* and *Centropages ponticus* appeared, and *Oikopleura dioica* became abundant. A great number of nauplii and early copepodite stages (I-IV) of *A. clausi* and *C. ponticus* were encountered, which suggested their high reproduction ability during this period. Among the cold water species, even in the near-shore zone, *Pseudocalanus elongates* became abundant, and the abundance of *Parasagitta setosa* reach 6-15 ind. m^{-2}.

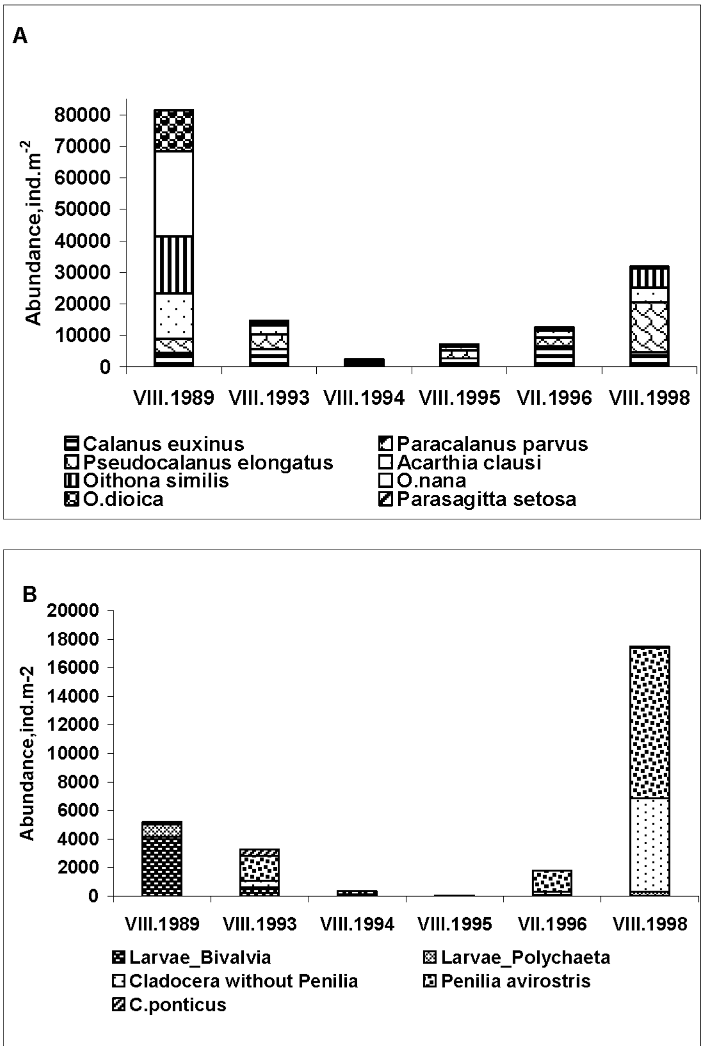

Fig. 6.26. Interannual variations in the species composition and abundance of edible zooplankton in the open sea waters in August after the introduction of M.leidyi: (A) coldwater and eurythermal species and (B) thermophilic species.

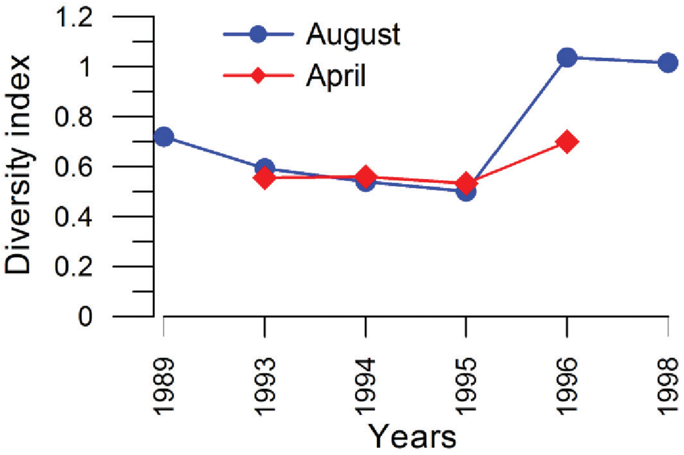

Fig. 6.27. Interannual variations in zooplankton biodiversity index of edible zooplankton (as an average of the inshore and offshore data) in the spring and August after the introduction of *M. leidyi*.

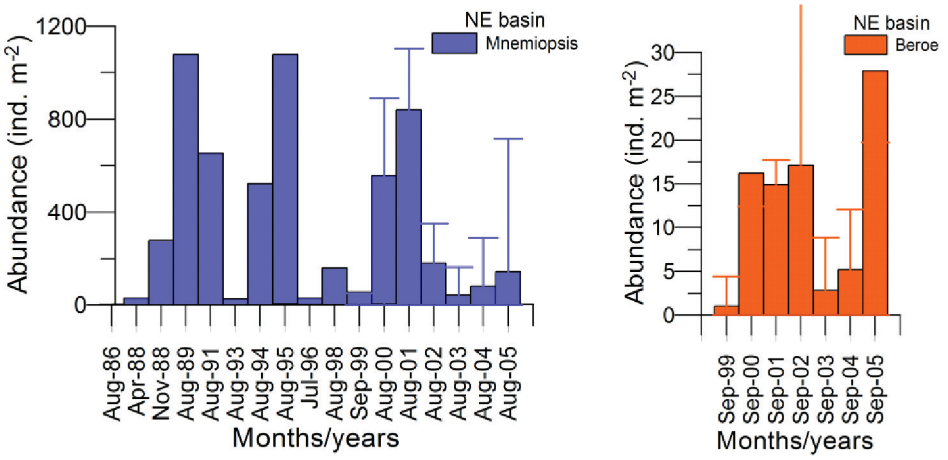

Fig. 6.28. Interannual variations of Mnemiopsis and Beroe abundances (ind.m^{-2}) in August and September, respectively.

The edible zooplankton biomass and abundance underwent to large oscillations in the subsequent years (Fig. 6.31). In the warmest years (2000-2002), before the seasonal development of *B. ovata* in August, *M.leidyi* reached high abundances comparable to pre-*B.ovata* period (Fig. 6.28) and reduced trophic zooplankton biomass. Nevertheless, it was higher than in the years before the *B. ovata* appearance. In the cold year of 2003, against the background low *M.leidyi* abundance in the near-shore zone (Fig. 6.28), a significant increase was observed in abundances of *Acartia clausi, Oikopleura dioica, Calanus euxinus, Pseudocalanus elongates,* and *Parasagitta setosa* (Figs. 6.29, 6.30). In the open sea, zooplankton abundance increased even more significantly; this refers both to thermophilic subsurface species and eurythermal and cold water ones. Their interannual variations were not so great (Fig. 6.30), though an increasing trend in zooplankton species diversity was evident after the appearance of *B. ovata*. Despite this increase, their abundance was well below prior to the *M. leidyi* invasion (Zaika and Andryushchenko, 1969).

By the beginning of spring 2000, a noticeable increase in the abundance and biomass of edible zooplankton was observed as compared to the previous years due to the absence of *M.leidyi* (Fig. 6.32). The abundance of *P. parvus, P. elongatus,* and *C. euxinus,* which were represented in the spring mainly by nauplii and copepodites, increased. Also, the biomass of S. *setosa* became significantly higher. As a matter of fact, *C. euxinus* and *P. setosa* made a significant contribution to the biomass growth of forage zooplankton as early as April 2000, and this contribution reached 25.37 g m^{-2} in the open waters where the abundance and biomass of total zooplankton were higher than in the near-shore zone (Fig. 6.32).

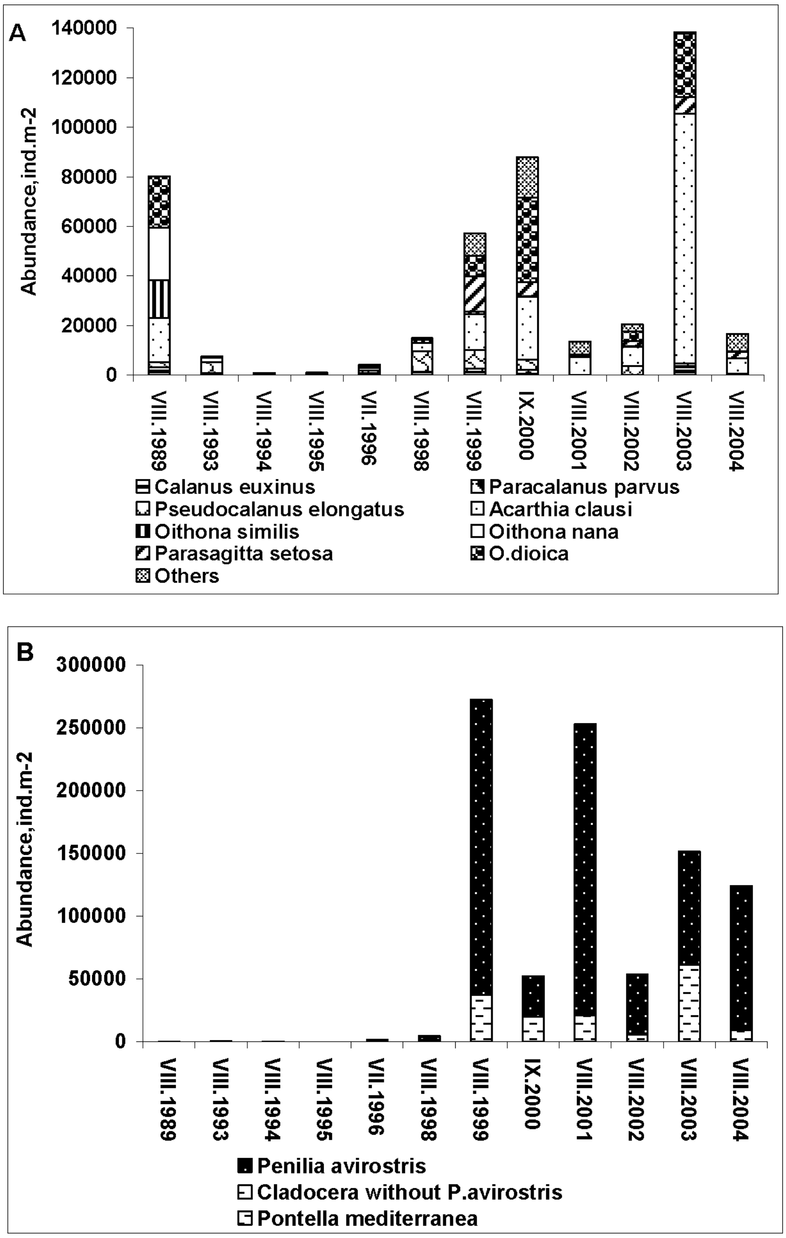

Fig. 6.29. Interannual variations in the species composition and abundance of edible zooplankton in the inshore waters in August: (A) coldwater and eurythermal species and (B) thermophilic species.

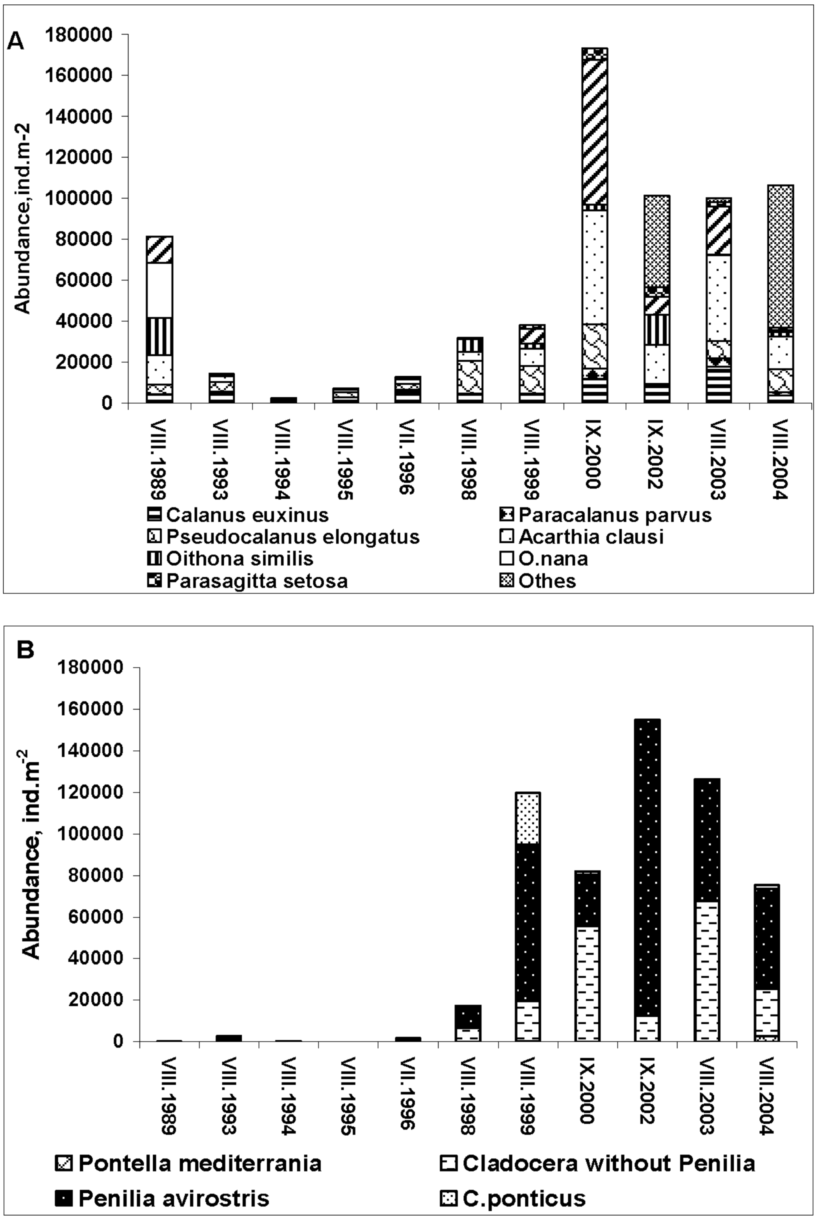

Fig. 6.30. Interannual variations in the species composition and abundance of zooplankton in the open sea waters in August: (A) coldwater and eurithermal species and (B) thermophilic species.

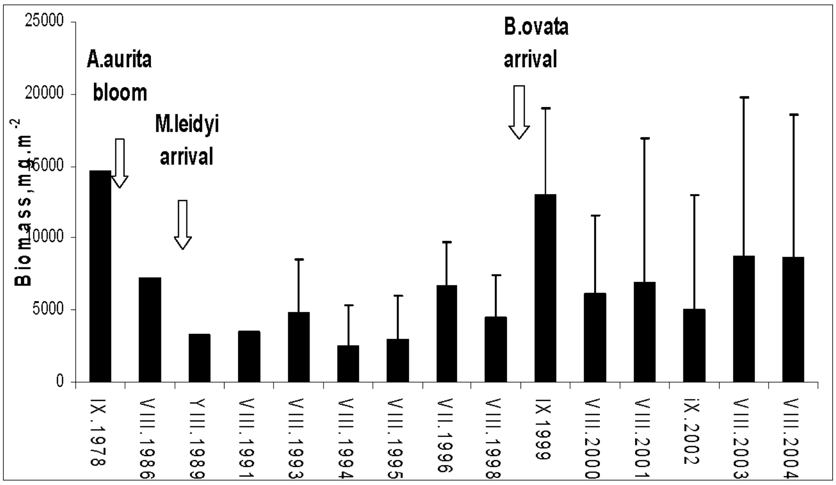

Fig. 6.31. Long-term changes of edible zooplankton biomass in the northeastern Black Sea during August-September, 1978-2004. The data for 1978-1991 were taken by Vinogradov et al. (1992) and for 1993-2004 by Shiganova et al. (2004).

Fig. 6.33 shows the change in edible zooplankton biomass within the deep basin following its lowest values during the early 1990s. In response to the weakening of *Mnemiopsis* grazing pressure after the introduction of *Beroe*, it increased from less than 3 g m^{-2} in the early 1990s to 12 g m^{-2} in 1999 and then exceeded 20 g m^{-2} by 2001. The edible zooplankton biomass was strongly dominated by *Calanus euxinus* in 1993, but its 80-90% abundance comprised *Parasagitta setosa, Calanus euxinus* and *Acartia clausi* in 1999-2008 (Fig. 6.34). *Calanus euxinus* increased steadily whereas *Parasagitta setosa* and *Acartia clausi* oscillated within the ranges 4-12 g m^{-2} and 1-4 g m^{-2}, respectively. *Noctiluca scintillans* decreased to low quantities (< 1 g m^{-2}) except 2000 and 2005 (Fig. 6.34) when its annual-mean biomass was elevated to about 5 g m^{-2} implying appreciably strong bloom episodes during either late-spring or autumn.

Fig. 6.35 depicts the influence of local circulation system on the zooplankton biomass distribution. When the Rim Current jet is confined over the narrow continental slope (November 2000 case in Fig. 6.35), relatively high edible zooplankton biomass is confined into the inshore part of the Rim Current zone and decreases offshore. In the presence of an anticyclonic coastal eddy and thus shift of the Rim Current jet axis further offshore, the region of higher zooplankton biomass expands offshore (July 2005 case in Fig. 6.35). Weakening of the Rim Current and its more pronounced offshore meandering homogenize the zooplankton biomass along the offshore transect and result in a patchy distribution (October 2001 case in Fig. 6.35). Alternatively, formation of a recurrent mesoscale eddy in the open sea causes a significant increase in zooplankton biomass within the eddy, as in the case of September 1999 in Fig. 6.35.

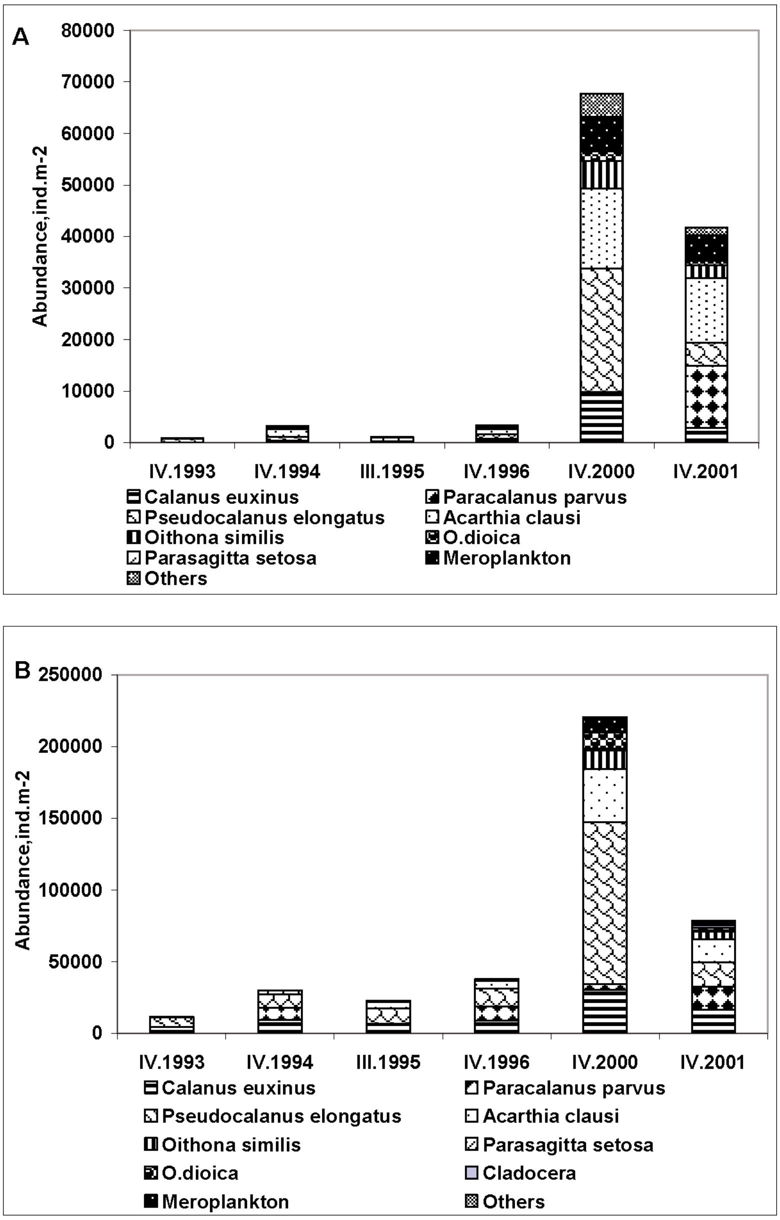

Fig. 6.32. Interannual variations in the species composition and abundance of edible zooplankton in the spring: (A) in the inshore zone and (B) in the open sea waters.

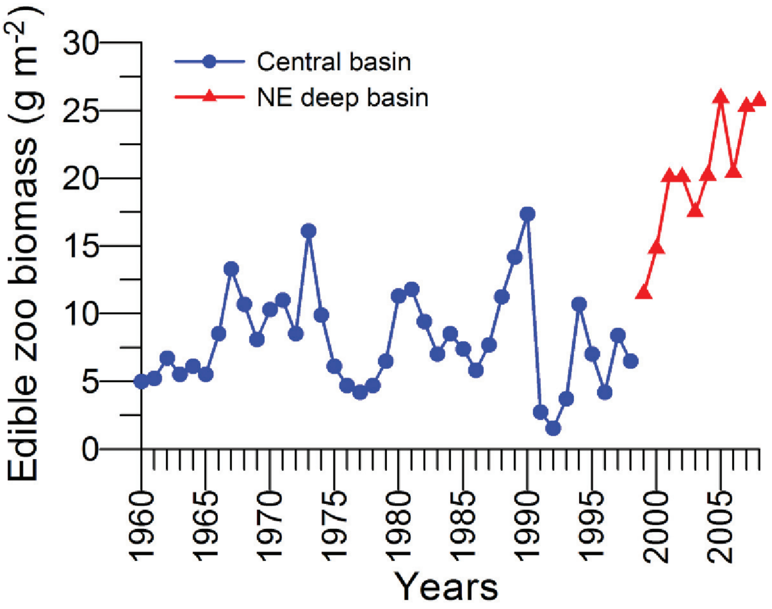

Fig. 6.33. long-term changes of edible zooplankton biomass within the deep interior basin of the Black Sea. The data shown by dots and triangles are provided by Kovalev et al. (1998) and Arashkevich et al. (2008a) for the northeastern basin.

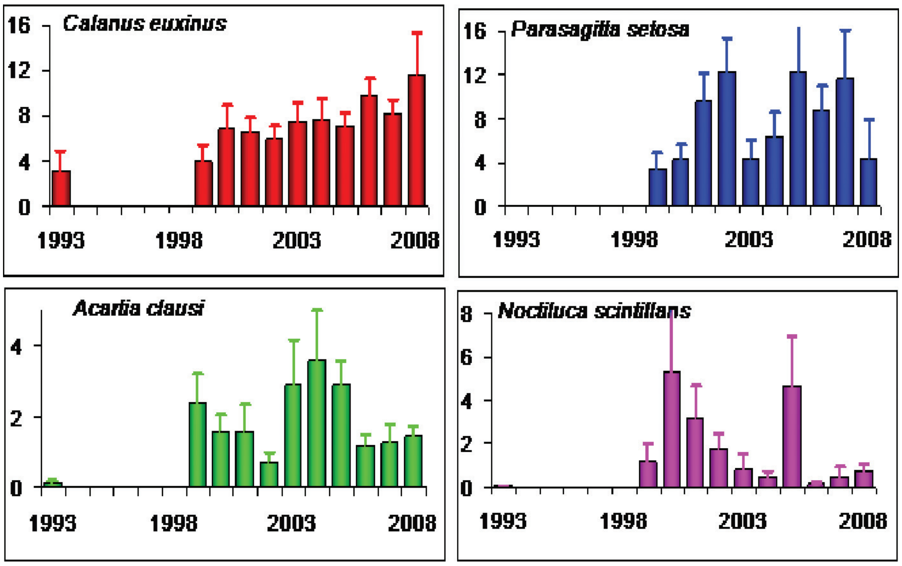

Fig. 6.34. Inter-annual biomass (g m^{-2}) variations of dominant zooplankton groups during 1998-2008 (after Arashkevich et al., 2008a).

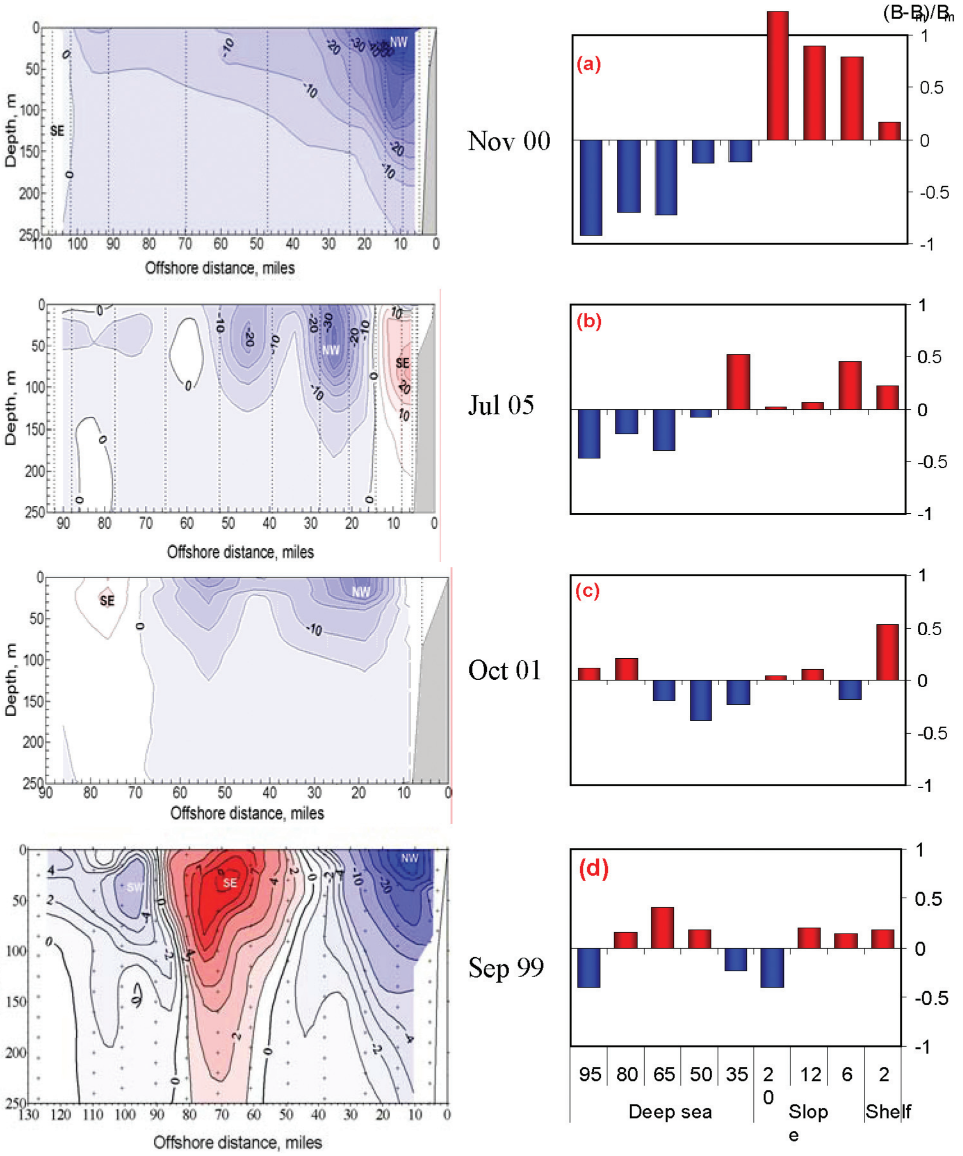

Fig. 6.35. The relation between mesoscale variability of the circulation system (left) and zooplankton biomass distribution (right) along an offshore-onshore transect in the NE basin. Zooplankton biomass was expressed by its normalized difference with respect to the mean biomass of each set of measurements (after Arashkevich et al., 2008a).

Most recent monthly measurements conducted along the northeastern coast of the Black Sea (Fig. 6.36) confirmed the negligible role of *Mnemiopsis* with respect to *Aurelia* during 2005-2007. *Aurelia* biomass typically constituted 80% of the total gelatinous biomass during all the measurement period except the autumn 2005 and the summer-autumn 2007 in which *Pleurobrachia* and *Mnemiopsis* dominated the gelatinous group, respectively. *Aurelia* attained its highest biomass of 400-600 g m^{-2} during its spring outburst period and persisted during rest of the year at the level of ~200 g m^{-2}. On the other hand, *Mnemiopsis* reached at the biomass of ~800 g m^{-2} during the autumn 2008 that prevailed through the winter 2008, but it was still at least twice lower than its biomass measured during the 1990s.

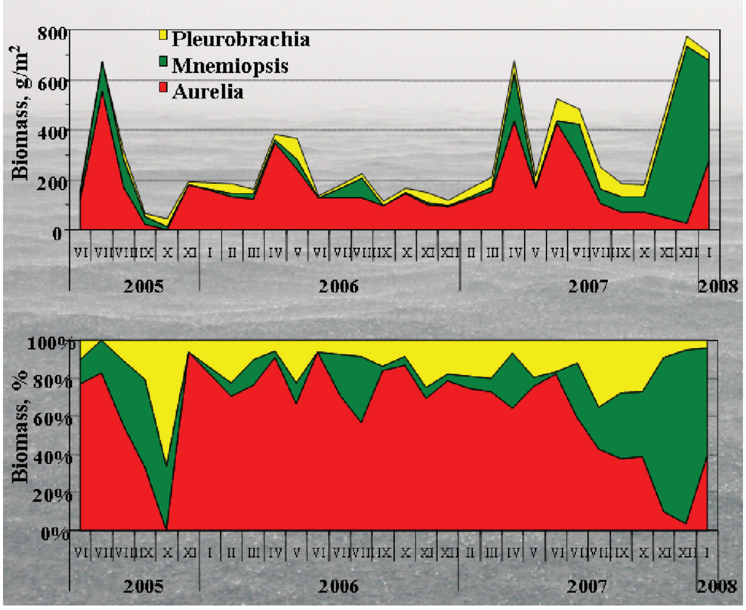

Fig. 6.36. Monthly changes of gelatinous predators Aurelia, Mnemiopsis, and Pleurobrachia as the mean of measurements at three stations within the northeastern coastal waters during 2005-2007 (after Araskevich et al., 2008b).

6.8. Conclusions

The zooplankton fauna experienced strong interannual variability in abundance, biomass and composition over the entire basin starting by the early 1970s. During the 1980s of intense eutrophication phase prior to the *Mnemiopsis* population outbreak, its species composition changed in favour of non-trophic zooplankton species, first *Noctiluca scintillans* then jellyfish *Aurelia aurita*. During 1990-2005, two particular phases were evident; strong *M.leidyi* domination prior to *B. ovata* settlement (1990-1997) and weak *M.leidyi* domination after *B. ovata* (1998-2005). During the former phase, biomass and abundance of edible zooplankton community decreased and species community was simplified considerably.

With the appearance of ctenophore *Beroe ovata* after 1997, edible zooplankton community began to recover both in species composition and abundance. The *Mnemiopsis leidyi* impact on trophic zooplankton structure was reduced to two months of the year instead of 6-8months before *B.ovata* arrival. But indigenous gelatinous species *Noctiluca scintillans* and *Aurelia aurita* also increased their population in some parts of the Black Sea due to low *Mnemiopsis leidyi* and *Beroe ovata* (the predator) abundances in cold years. *Mnemiopsis leidyi* was able to attain relatively high abundance and affected more adversely zooplankton community in warm years. Nevertheless, Copepod and Cladoceran biomass and abundance increased in some areas, *P. mediterranea, C. ponticus* and *A. patersoni* which were almost absent during 1980s-1990s were recorded during the 2000s at higher abundances. Other three holoplanktonic species (Copepod *Centropages ponticus,* Cladocer *Penilia avirostris* and Chetognata *Parasagitta setosa*) suffered from the eutrophication impact begun to recover their populations; their abundance exceeded opportunistic Copepod species *Acartia clausi* and Cladoceran species *Pleopis polyphemoides*. Non-indigenous *A. tonsa* was also observed in limited numbers after 2000. The almost extinct species *P. mediterranea,* being an indicator of high quality waters, re-appeared after 2000 as a sign of positive ecosystem changes. The ctenophore *Pleurobrachia pileus* also started occupying its ecological niche, which was totally replaced by *Mnemiopsis* after 1989.

From the diversity viewpoint, there are inevitable signs of improvement and rehabilitation of the coastal zooplankton biocoenose and an overall trend of recovery with respect to the 1980s. But the quantitative trophic zooplankton structure is still unstable and undergoes large interannual fluctuations at almost all regions of the Black Sea. The entire zooplankton community was particularly sensitiv e to the year-to-year climatic changes during the present decade. *Aurelia aurita, Pleurobrachia pileus* controlled trophic zooplankton population in cold years whereas *Mnemiopsis leidyi* served as the main predator in warm years. The trophic zooplankton biomass has a clear declining trend along the entire western coast whereas inclining trend along the northeastern coast. It has lowest values at the coastal site near the Cape Sinop, a relatively unpolluted and poorly productive region representing background conditions, along the central part of southern coast.

References

Arashkevich, E., Timonin, A., Nikishina, A., Louppova, N. (2008a) Impact of climate variations on zooplankton community in the NE Black Sea. In: 2nd biannual and Black Sea Scene EC project joint conference on climate change in the Black Sea - hypothesis, observations, trends, scenarios and mitigation strategy for the ecosystem. 6-9 October 2008, Sofia, Bulgaria.

Arashkevich, E., Chasovnikov, V., Kremenetskiy, V., Louppova, N., Mosharov, S., Nikishina, A., Pautova, L., Romanova, N., Sazhin, A., Soloviov, K., Timonin, A., Zatsepin, A. (2008b) Seasonal dynamics of the NE Black Sea shelf ecosystem. In: Sesame Project 1st Scientific Workshop. 18-20 November 2008, Palma de Mallorca, Spain.

Bat, L., Şahin, F., Satılmış, H.H., Üstün, F., Birinci Özdemir, Z., Kıdeys A.E., ve Shulman, G.E. (2007). Karadeniz'in değişen ekosistemi ve hamsi balıkçılığına etkisi. Journal of FisheriesSciences. DOI: 10.3153/jfscom.2007024, 1 (4):191-227.

Chichkoff G., 1912. Contribution á l'étitude de la faune de la Mer Noire. Animaux écoltés sur les côtes bulgares. - Arch. Zool. exp. gen., 10 (2): 29-39.

Dineva S., 2005. Long-term evolution and trends of the hydrological and hydrochemical parameters in Bulgarian Black Sea waters during the period 1992-2000. Water Sci Technol., 51(11):19-26.

Finenko, G.A., Romanova, Z.A., I.Abolmasova, G.I., E.Anninsky, B.E., Pavlovskaya, T.V., Bat, L., Kideys, A. (2007) Ctenophores -- invaders and their role in the trophic dynamics of the planktonic community in the Crimean coastal regions of the Black Sea (Sevastopol Bay). In: 4th international zooplankton production symposium, May28 - June1, 2007, Hiroshima, Japan.

Flint, M.V., Arnautov, G.N., Shushkina, E.A. (1989) Quantitative distribution of jellyfish Aurita. In: Structure and productional characteristics of plankton communities in the Black Sea. Nauka, Moskow, 315-322.

Gomoiu M.-T. and Kupriyanov, S. S. (1980) Estimation of the Abundance and Distribution of the Medusas Aurelia aurita in the Eastern Part of the Black Sea. In: Ecosystems of the Pelagic Zone of the Black Sea, Ed. by M. E. Vinogradov (Nauka, Moscow,), 191-198 (in Russian)

Greze,V.N., Boguslavsky, S.G., Belyakov, Yu.M. (1979) Principles of Biological productivity of the Black Sea (eds.Greze V.N.). Kiev, Naukova dumka, 391,1979 (in Russian).

Gubanova A., Yu. Prusova, U. Niermann, N. Shadrin, I. Polikarpov, 2001. Dramatic Change in the Copepod Community in Sevastopol Bay (Black Sea) during two Decades (1976-1996)., Seckenbergiana marit., 31 (1): 17-27.

Kamburska L., 2004. The role of nonindigenous ctenophores Mnemiopsis leidyi and Beroe ovata for the zooplankton alterations along the Bulgarian Black Sea coast, PhD Thesis, IO-BAS, 171 pp. (in Bulgarian).

Kamburska L., Stefanova K., 2002. Ecological state of zooplankton community in the system Beloslav Lake-Varna Lake-Varna Bay. Sixth International Conference on Marine Science and Technology "Black Sea'2002", Proceedings vol. 1, 336-341.

Kamburska L., K. Stefanova, 2005. Distribution and size structure of nonindigenous ctenophore Mnemiopsis leidyi (Agassiz, 1874) in the Western Black Sea, 1998-2001. Acta Zool. Bulg., 57 (1), 2005: 83-94.

Kamburska L., Schrimpf W., Djavidnia S., Shiganova T., Stefanova K., 2006a. Addressing the ecological issue of the invasive species, Special focus on the ctenophore Mnemiopsis leidyi (Agassiz, 1865) in the Black Sea. EUR 22310 EN, JRC-EC Publication office, 59 pp.

Kamburska L., Shiganova T., Stefanova K., Moncheva S., Dowell M., 2006b. Interannual variations in the summer distribution of the invasive ctenophore Mnemiopsis leidyi A. Agassiz in the Black Sea. In: A. K. Stips, W. Schrimpf (eds.) Proceedings of the Workshop on "Understanding and modelling the Black Sea ecosystem in support of marine conventions and environmental policies", EUR 22176 EN, JRC-EC Publication office, 8-14.

Konsulov A, L. Kamburska, 1998 a. Ecological determination of the new ctenophora Beroe ovata invasion in the Black Sea. Океанологиˇ, ИО-БАН, Варна, т. 2, 195-198

Konsulov A., L. Kamburska, 1998b. Black Sea zooplankton structural dynamic and variability off the Bulgarian Black Sea coast during 1991 1995. NATO ASI Series, "NATO TU BLACK SEA PROJECT Ecosystem Modeling as a Management Tool for the Black Sea, Symposium on Scientific Results", L. Ivanov & T. Oguz [eds.], Kluwer Academic Publishers, v. 1, 281 293.

Koval, L.G. (1984) Zoo- and necro-zooplankton of the Black Sea. Kiev, Nauka Dumka, 127pp (in Russian).

Kovalev, A., Besiktepe, S., Zagorodnyaya, Yu.A. and Kideys, A.E., 1998. Mediterranization of the Black Sea zooplankton is continuing. In: NATO TU-Black Sea Project: Ecosystem Modeling as a Management Tool for the Black Sea, Symposium on Scientific Results, L. Ivanov&T. Oguz (eds.), Kluwer Academiz Publishers, pp.221-234.

Moncheva S., Doncheva V., Shtereva G., Kamburska L., Malej A., Gorinstein S., 2002. Application of eutrophication indices for assessment of the Bulgarian Black Sea coastal ecosystem ecological quality, Water Sci. Technol., v. 46, No. 8, 19-28.

Mordukhay-Boltovskoy F.D. (1969) Crustacea. In: Guide of fanua of Black and Azov Seas.V.1. Invertabrates, 8-151 (in Russian).

Oguz, T., 2005. Long-term impacts of anthropogenic forcing on the Black Sea ecosystem. Oceanography, Special issue features: Black Sea Oceanography, vol. 18, 2, 112-121.

Oguz, T. and D. Gilbert. 2007. Abrupt transitions of the top-down controlled Black Sea pelagic ecosystem during 1960-2000: Evidence for regime-shifts under strong fishery exploitation and nutrient enrichment modulated by climate-induced variations. Deep-Sea Res. I (54), 220-242.

Pasternak, A. F. (1983) Seasonal Dynamics of the Abundance and Biomass of Zooplankton off the Coast of the Northern Caucasus. In: Seasonal Changes in the Black Sea Plankton, Ed. by Yu. I. Sorokin and V. I. Vedernikov, Nauka, Moscow, 139-177 (in Russian).

Petran A., Moldoveanu M. (1994) Characteristics of the structure and quantitative development of zooplankton from the Black Sea shallow water during 1990-1994. Cercetari marine - Recherches marines.

Petran A., Apas M., Bodeanu N., Bologa A.S., Dumitrache C., Moldoveanu M., Radu, G., Tiganus V. (1999) Status and evolution of the Romanian Black Sea coastal ecosystem. In: Environmnetal degradation of the Black Sea: Challenges and Remedies, 175-195. Kluwer Academic Publishers, Printed in Netherlands.

Polischuk L.N. Nastenko E.V. (1998) Some features of development of zooplankton of the northwestern Black Sea and its composition of the Danube estuarine area. Ecosystem of the marine part of the Danube. Odessa: Astroprint, 188-224 (in Russian).

Polischuk L.N. (2005) The state of zooplankton near Zmeiny Island and Danube estuarine areas in 2003. Visnik Odeskogo natsionalnogo universiteta, 10(4), in Russian.

Porumb F. (1972) Contributions a la coonoissance de la dynamique des populations et a la productions des Copepodes dans les eaux roumaines de la mer Noire, Cercetari Marine IRCM Constanta, 4, 57-94.

Porumb F. (1980) Developpement du zooplancton dans les conditions d'eutrophisation des eaux du litoral roumain de la mer Noire, V-es Journees Etud. Pollutions, CIESM, Cagliari, 881-886.

Sergeeva, N. G., V. E. Zaika & T. V. Mikhailova, 1990. Nutrition of ctenophore Mnemiopsis mccradyi (Ctenophora, Lobata) in the Black Sea. Zool. J. Ecologia Morya 35: 18-22 (in Russian).

Shiganova, T.A., 1998. Invasion of the Black Sea by the Ctenophore Mnemiopsis leidyi and Recent Changes in Pelagic Community Structure, Fisheries Oceanography-GLOBEC Special Issue, Coombs, S., Ed.: 305-310.

Shiganova, T.A., 2000. Certain Results of Studying Biology of Invader M. leidyi (A.Agassiz) in the Black Sea, Grebnevik Mnemiopsis leidyi (A.Agassiz) v Azovskom i Chernom moryakh i posledstviya ego vseleniya (Comb Jelly Mnemiopsis leidyi (A.Agassiz) in the Sea of Azov and Black Sea and Consequences of Its Settling), Volovik, S.P., Ed., Rostov-na-Donu,: 33-75.

Shiganova, T.A., E. I. Musaeva, Y. V. Bulgakova et. al., 2003. Ctenophores invaders Mnemiopsis leidyi (A. Agassiz) and Beroe ovata Mayer 1912, and their effect on the pelagic ecosystem of the northeastern Black Sea.. Biological Bulletin 2: 225-235.

Shiganova T.A., Dumont H. J. D, Mikaelyan A. , Glazov D. M., Y. V. Bulgakova, E. I. Musaeva, P. Y Sorokin, .L A. Pautova, Z. A. Mirzoyan & E I. Studenikina. 2004. Interaction between the Invading Ctenophores Mnemiopsis leidyi (A. Agassiz) and Beroe ovata Mayer 1912, and their Influence on the Pelagic Ecosystem of the Northeastern Black Sea Edc. Dumont, H., T. Shiganova & U. Niermann - The Ctenophore Mnemiopsis leidyi in the Black, Caspian and Mediterranean Seas and other aquatic invasions - NATO ASI Series, 2. Environment-. Kluwer Academic Publishers: 33-70.

Shiganova, T.A., E. I. Musaeva, Y. V., Slabakova N., Alexandrova V., 2006. Spatial variability of zooplankton community structure along euthrophication gradient (a case study Varna Bay-Varna lakes costal area). International scientific conference "Problems of biological oceanography in the XXI century" devoted to 135-th anniversary of IBSS, September 19 - 21, 2006, Sevastopol, Ukraine.

Shushkina, 1991. The estimation of population characteristics of Aurelia aurita in the Black Sea. Oceanology, 31: 434-441.

Shushkina E. A. and Arnautov, G. N. (1987) Medusas Aurelia in the Plankton of the Black Sea. In: Present-Day Condition of the Black Sea Ecosystem, Ed. by M. E. Vinogradov and M. V. Flint. Nauka, Moscow, 186-196 (in Russian).

Shushkina E. A. and Musaeva, E. I. (1990) The Amount of the Invader Ctenophore Mnemiopsis in the Black Sea Continues to Grow (Expedition on Aboard R/Vs Akvanavt and Gidrobiolog in April 1990), Okeanologiya 30(4), 702-703.

Stefanova K., Kamburska L., Gubanova A., Altukhov D., 2006a. State and trends of zooplankton community in the coastal Black Sea ecosystems of Varna and Sevastopol bays. 1st Biannual Scientific Conference Black Sea Ecosystem 2005 and Beyond- Dedicated to the 10th Anniversary of the Strategic Action Plan for Rehabilitation and Protection of the Black Sea. 8-10 May 2006, Istanbul, Turkey.

Stefanova K., Kamburska L., Moncheva S., Doncheva V., Slabakova N., Alexandrova V., 2007. Zooplankton community changes along the eutrophication gradient Varna Lakes- Varna Bay (Western Black Sea), Rapp. Comm. int. Mer Médit., 38, 605.

Temnykh, A., Melnikov, V., Zagorodnyaya, Y., Moryakova, V. (2006) The variability of the Black Sea zooplankton as a derivative of long term dynamics in the water hydrological structure. In: Black Sea Ecosystem 2005 and Beyond, May 8 2006, Istanbul, Turkey.

Tsikhon-Lukanina, E.A., Reznichenko, O.G., and Lukasheva, T.A., 1991.Quantitative Aspects of Nutrition of Comb Jelly Mnemiopsis leidyi in the Black Sea, Okeanologiya, 31(2), 272-276.

Tsikhon-Lukanina, E.A., Reznichenko, O.G., and Lukasheva, T.A., 1993. Level of Fish Fry Consumption by Mnemiopsis in the Black Sea Shelf, Okeanologiya, , vol. 33(6), 895-899.

Unal, E., (2002). Seasonality of zooplankton in the Southern Black Sea in 1999 and Genetics.

Ustun, F., 2005. The composition and seasonal distribution zooplankton in the region of Sinop Cape of the Black Sea, Turkey. M.S. Thesis, O.M.U. Fen Bilimleri Enstitüsü, Samsun, pp. 172.

Ustun, F., Bat, L., Sahin, F., Satilmis H., Ozdemir, Z.B., Kideys, A.E., (2007). Annual cycle of zooplankton off Sinop, the Southern Black Sea, in 2003-2004. Rapport Du 38e Congrés De La Commission Internationale Pour L'Exploration Scientifique De La Mer Méditerranéé, CIESM, Monaco, pp.628.

Valkanov A., 1935. Remarks on our brackish water, 1 - Annual of Sofia University, Sofia, 31: 1-55 (in Bulgarian).

Velikova V. and Chipev N. (2005). Large-scale disturbances (regime shifts) and recovery in aquatic ecosystems: challenges for management towards sustainability, Proceedings UNESCO Workshop, 13-17 June 2005, Varna, Bulgaria, http://www.ecolab.bas.bg/main/events/past-new/unesco-ws/docs/ws-rep/.

Vinogradov, M.E., Shushkina, E.A., Musaeva, E.I., and Sorokin, P. Y., 1989.New Settler in the Black Sea-Comb Jelly Mnemiopsis leidyi (Agassiz), Okeanologiya, vol. 29, no. 2: 293--299.

Vinogradov, M.E., Sapozhnikov, V.V., and Shushkina, E.A., 1992.Ekosistema Chernogo morya (Ecosystem of the Black Sea), Moscow: Nauka: 112 pp. (in Russian).

Zaika V.E., Andruszhenko A.A. 1996. Taxonomic diversity of the Black Sea phyto- and zooplankton. Hydrobiological Journal, 3, 12-19.

Zaitsev Yu.P. (1998) Marine hydrobiological investigations of National Academy of Science of Ukraine during 90s in XX century: Shelf and coastal water bodies of the Black Sea. Gydrobiol. zhurn., 34(6), 3-21 (in Russian).

Zaitsev, Y.P. and Aleksandrov, B.G., 1997 .Recent Man-Made Changes in the Black Sea Ecosystem, Sensivity of North Sea, Baltic Sea and Black Sea to Antropogenic and Climatic Changes, Ozsoy, E. and Mikaelyan, A., Eds. Kluwer Academic, 25-32.