CHAPTER 5 THE STATE OF PHYTOPLANKTON
(D. Nesterova et al.)

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5.1. Introduction

Phytoplankton as the foundation of marine trophic chain is among the best indicators for assessment of the state of eutrophication. Nutrient enrichment/eutrophication often gives rise to shifts in phytoplankton species composition (e.g. from diatoms to dinoflagellates) and an increase in the frequency and/or magnitude and/or duration of phytoplankton (including nuisance/potentially toxic) blooms. The present chapter analyzes the recent trends of changes in phytoplankton species composition and then highlights main features of its contemporary state along the Black Sea shelf waters. The assessments are based on the evaluation of historical data as well as those collected during the present decade within the framework of various international and regional field campaigns as well as national monitoring programs.

5.2. Species composition

Data compiled by many sources documented 750 phytoplankton species in the Black Sea (Ivanov 1965, Pitsyk 1950, Sorokin, 2002). Owing to considerable differences in hydrological and hydrochemical properties, phytoplankton composition differed considerably in different parts of the sea. In particular, the shallow, less saline and heavily euthrophied northwestern part of the sea sustained large number of brackish and freshwater species as compared with other parts (Ivanov, 1967).

Northwestern and Crimean shelves: A summary of the lists of phytoplankton species studied in 1973-2005 in the northwestern Black Sea shelf (NWS) (Nesterova, 1998; Guslyakov and Terenko, 1999; Nesterova and Terenko, 2000; Terenko, 2004; Nesterova and Terenko, 2007) showed that phytoplankton is represented by 697 species and interspecies pertaining to 11 phyla (Table 5.1). During 1973 - 2005, diatoms and dinophytes constituted main species as observed prior to 1973, but their ratio has changed in comparison to 1950s (Ivanov, 1967). The diatom species decreased from 48.3% to 34.9%, while dinophytes increased from 20.4 % to 28.5 %. Freshwater green algae species increased from 16.7% to 22.5%, while blue-green algae remained around 5-6%. Due to revised phytoplankton composition, representatives of new phyla of Cryptophyceae *Hillea fusiformis*, Prasinophyceae *Pterosperma cristatum*, *Pt. jorgensenii* and a Choanoflagellida *Bicosta spinifera* species appeared. An increase in the species diversity of dinophytes was noted in 1973 - 1993 when 36 new species were listed in the NWBS (Nesterova, 1998). Later, 48 species were added to the list of which 37 were new to the Black Sea (Terenko, 2004; 2005). The dinophytes included potentially toxic species *Alexandrium psedogonyaulax, Cochlodinium polykrikoides, Gyrodinium cf. aureolum* (Terenko, 2005, 2005 a) as well as a new species (*Prorocentrum ponticus*) and a new variety (*Prorocentrum micans var. micans f. duplex*) (Krakhmalniy and Terenko, 2002). Similarly, new green algae appeared as the genera *Monoraphidium* (*M. contortum, M. obtusum*) and *Scenedesmus* (*Sc. polyglobulus*). At present, the number of marine and marine-brackish species decreased from 60.3% to 50.5%. Simultaneously, there has been an increase in freshwater and freshwater-brackish species - 49.5% and 39.7%, respectively.

The bulk of phytoplankton abundance and biomass is represented by a massive development of a small group of species in certain seasons. In the 1950s - 1960s, it was 41 species (Ivanov, 1967), and increased to 85 species in the past two decades (Black Sea, 1998). Besides the usual representatives as S*keletonema costatum, Cerataulina pelagica, Chaetoceros socialis, Leptocylindrus danicus, Prorocentrum cordatum, Pr.micans,* other species like *Leptocylindrus minimus, Chaetoceros insignis, Gyrodinium cornutum,* cryptophytes *Hillea fusiformis,* coccolithophorides *Emiliania huxleyi,* freshwater diatoms *Skeletonema subsalsum, Stephanodiscus hantzschii,* blue-green algae of the genera *Gleocapsa Merismopedia* have entered into the NWBS phytoplankton bloom events. Common species including *Heterocapsa triquetra, Scripsiella trochoidea* were found in the NWBS in 1957-1961 (Ivanov, 1963). Besides, typical summer - autumn phytoplankton species like *Thalassionema nitzschioides, Chaetoceros curvisetus* were observed in 1950 - 1960, while *Pseudosolenia calcar avis* tended to decrease in frequency and abundance (Nesterova, 1987).

Table 5.1. Taxonomic composition of Black Sea phytoplankton in Ukraine waters

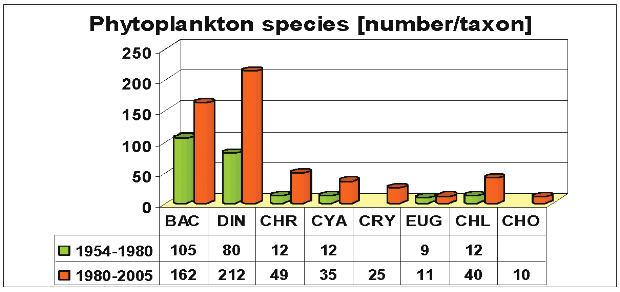
Phyla	Northwestern part		Southeastern coast of Crimea	
	1954-60*	1973-05**	1938-59***	1979-98****
Bacillariophyceae	**180**	**243**	**73**	**63**
Dinophyceae	76	199	39	69
Cryptophyceae	-	8	3	-
Chlorophyceae	62	158	4	3
Cyanophyceae	24	37	4	2
Prymnesiophyceae	9	25	19	-
Chrysophyceae	4	6	5	27
Dictyochophyceae	5	7	-	-
Prasinophyceae	-	2	-	-
Euglenophyceae	12	11	-	1
Choanoflagellidea	-	1	-	-
Total	372	697	125	165

*- Ivanov (1967); **- Nesterova (2006); Nesterova, Terenko, 2007; ***- Proshkina-Lavrenko (1955) and Ivanov (1965); **** - Senichkina et al. (2001)

Phytoplankton species in the southeastern coast of Crimea during the 1940-1960s included 125 species and interspecies taxa from 5 algal phyla (Table 5.1) (Stroykina, 1950; Koshevoy, 1959; Mironov, 1961). In more recent years (1979-1998), it increased to 165 species and varieties, which all indicated some changes in taxonomic composition. In contrast to the previous phase, dinophytes increased from 31.2 % to 41.8 and chrysophytes from 4% to 15.1%, while diatoms decreased from 58.4% to 38.1%. The species diversity of coccolithophorids rose to 74 new species which were common for the whole Black Sea, while 21 species were observed for the first time.

Compared to 211 species and varieties of planktonic algae recorded in the Sevastopol Bay in 1948 (Senicheva, 2000), there were 84 species in 1996 - 1997 and 173 species and varieties in 2001 - 2004. The latter was represented by 11 classes and 2 taxonomic groups; small flagellate algae and olive green cells. The basis of species diversity was similar to that of the NWBS and mainly composed of diatoms (45%), dinophytes (35%), and also Prasinophyceae (11%) (Polikarpov et al., 2003). The composition of dominant species of *Skeletonema costatum, Leptocylindrus danicus, Chaetoceros socialis* near Sevastopol for a period of 65 years has not undergone significant changes (Polikarpov et al., 2003). *Pseudo-nitzschia delicatissima* was an exception replacing *Cerataulina pelagica* in 2001 - 2004. Changes have been noted mainly in the composition of subdominant species replacing the dinophyte algae of the genera *Glenodinium, Protoperidinium, Prorocentrum* for *Prymnesiophyceae* genera of *Syracosphaera* and *Emiliania*. At the same time new diatom species have been encountered along the coast of Crimea, and a new variety has been described as *Chaetoceros diversus* var. *papilionis* (Senicheva, 2002) as well as dinophytes and silicoflagellates (Kuzmenko, 1966; Senichkina, 1973).

Western Black Sea shelf: The revision of phytoplankton check-list in 1980-2005 documented 544 species distributed among 8 classes (Fig. 5.1) which indicated more than two-fold increase as compared to 230 species listed in the 1954-1980 period. Although a part of this change was related to improved sampling strategy, microscope quality, frequency and regions of sampling, changing environmental conditions and introduction of exotic species also played a role (Moncheva, Kamburska, 2002). Diatoms (212 species) and dinoflagellates (162 species) constituted bulk of the phytoplankton pool; the Dinophyceae species contribution rose to about 40% of the total number, e.g. an increase of more than 3 times. The same also applies to other classes; for example, species from Cryptophyceae and Choanoflagellates groups have not been reported at all before 1980s. The presence of rare and new Bacillariophyceae (*Thallasiotrix longissima, Th. antarctica Lioloma elongatum, L. pacificum,Triblionella acuminate*), Dinophyceae (*Ceratium furca var. bergii, Ceratium furca var. eugramma, Cochlodinium archimedes, C. citron, Kofoidinium lebourae*), a number of Gymnodinium species (*Gymnodinium canus, G. cintum, G. dominans, Gymnodinium fuscum etc.*) Gyrodinium (*Gyrodinium spirale*), and numerous Cryptophyceae (*mainly from genus Chroomonas, Cryptomonas, Rhodomonas, Leucocryptos* etc), Chlorophyceae (*Kirchneriella, Trochiscia, Treubaria*), Chrysophyceae (*Braarudosphaera bigelowi, Octactis octonaria, Calciosolenia granii v. cylindrotheca,* etc.), and different microflagellates add significantly to the diversification of phytoplankton assembly. Most of the species listed above are mixo-heterothrophs, that might have important functional bearings at ecosystem level (Moncheva et al., 2005; 2006; Velikova et al., 1999; 2005). An apparent feature of phytoplankton communities after 2000 was further increase of species diversity and species richness per sample (normally above 40) as detected since the mid-1990's (Moncheva, 1999, Moncheva, 2003, 2005, 2006, 2007, Velikova et al., 1999, Velikova, 2004). More than 70% of the Shannon-Weaver biodiversity index was below the critical value of 2 in the 80-ies - the lowest being in summer of 1983-1985. This index dropped below 2 only during the winter-spring phytoplankton blooms in the 1990s, and this trend was maintained after 2000.



	BAC	DIN	CHR	CYA	CRY	EUG	CHL	CHO
🟩 1954-1980	105	80	12	12		9	12	
🟧 1980-2005	162	212	49	35	25	11	40	10

Fig. 5.1. Phytoplankton species diversity by taxonomic classes in the Bulgarian shelf.
BAC - Bacillariophyceae; DIN - Dinophyceae; CHR - Chrysophyceae; CYA - Cyanophyceae; CRY - Cryptophyceae; EUG - Euglenophyceae; CHL - Chlorophyceae; CHO - Choanoflagellates

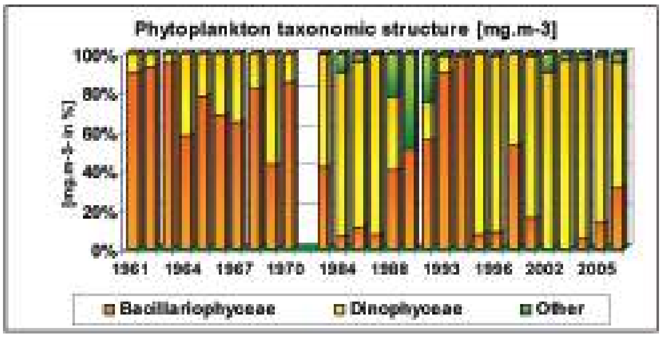


Fig. 5.2. Long-term changes in phytoplankton taxonomic structure by biomass (mg/m^3) in pcentage in spring (3 nm Cape Galata)

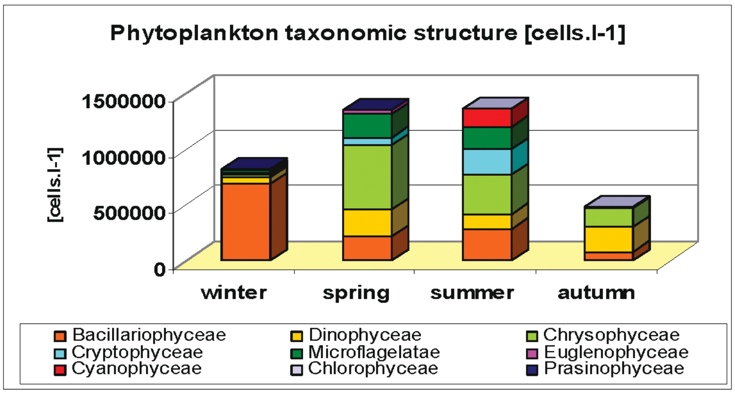


Fig. 5.2.a. Seasonal phytoplankton taxonomic structure by numerical abundance (cells/l^{-1}) averaged for the period 2000-2006 for the Bulgarian shelf waters

The long-term taxonomic structure of phytoplankton biomass shows a likely shift from a diatom dominant system (constituting 60-90% of total biomass in the 60-ies) to an apparent dominance of opportunistic dinoflagellates in the 80-ies (mixo/heterothrophs) building between 60-80% of the biomass in spring), a partly regained dominance of diatoms in the late 90-ies- early 2000s to an increased share of chrysophytes and microflagellates (about 20 %) during 2001-2007 (Fig. 5.2). Thus, the Bacillariophyceae to Dinophyceae taxonomic biomass ratio in spring diverged from the reference ratio (Petrova-Karadjova ,1984) of (10:1).

In winter, albeit the predominance of typical diatoms (*Skeletonema costatum, Detonula confervaceae, Pseudonitzschia seriata, Pseudonitzschia delicatissima*) by about 80%, species from other taxonomic groups (chrysophytes, microflagellates and mixothrophic dinoflagellates) often contributed to more than 50% of the total density and the large size dinoflagellates in the biomass (Fig. 5.2). In February 2005 the dinoflagellate *Alexandrium ostenfeldii* dominated the community (90%) in the Bay of Sozopol (Mavrodieva et al., 2007), and, *Akashiwo sanguinea* proliferated along the entire coastal area in February 2001, while *Apedinella spinifera* was a co-dominant species during the winter bloom of Skeletonema costatum in March 2003. The contribution of chrysophytes (*Emiliania huxlei*) in spring-summer 2003 oscillated between 40-80% of the total abundance, microflagellates between 20-50%. Dominance of Cyanophyceae and Chrysophytes marked atypical composition of phytoplankton community in autumn, along with the blooms of dinoflagellates (*Gymnodinium sp., Prorocentrum minimum, Alexandrium monilatum*) with biomass exceeding 15 g/m^3 in Cape Kaliakra and Cape Galata in November 2003 that resembles the eutrophication period, irrespective of the reduction of the total abundance as compared to the 1990s.

The species composition of algal blooms tended to have significant decadal changes in the Romanian shelf as well. The late 1980s were characterized by relatively low (<30%) diatom content but dominated mainly (about 60%) by dinoflagellates (Fig. 5.2b; upper). This structure reversed in favour of diatoms by the early 1990s. Between 2001 and 2005, diatoms covered 48-66% of the total algal density except 2002-2003 in which two Cyanophyceae species *Microcystis pulverea* and *M. aeruginosa* dominated the blooms during the warm season. In the biomass, the dinoflagellates were more often dominant due to their large bio-volume, representing up to 65% of the whole biomass (Fig. 5.2b; lower).

Southern Black Sea: Compared to the NWS, 172 taxa were identified until 1995, of which 103 belonged to Bacillariophyceae, 52 to Dinophyceae, 12 to Chlorophyceae, 3 to Cyanophyceae and 2 to Chrysophyceae. The studies conducted between 1995-2000 introduced 115 additional taxa - 1 from Cyanophyceae, 65 from Dinophyceae, 4 from Dictyochophyceae, 33 from Bacillariophyceae, 10 from Prymnesiophyceae, as well as 1 species of Euglenophyceae and 1 species of Acantharea. Only 6 taxa of Bacillariophyceae have been given as a new record for the Turkish coast after 2000. In total, 294 phytoplankton species consisting of 48.3% diatoms and 39.8 % dinoflagellates were identified in the Southern Black Sea so far (Table 5.2). The most important change observed within the last 10 years was the slight domination of dinoflagellates and other micro-nanoplankton species with respect to diatoms. The increase in the ratio of dinoflagellates could be related to the change in nutrient balance in addition to the temperature regime of the seawater.

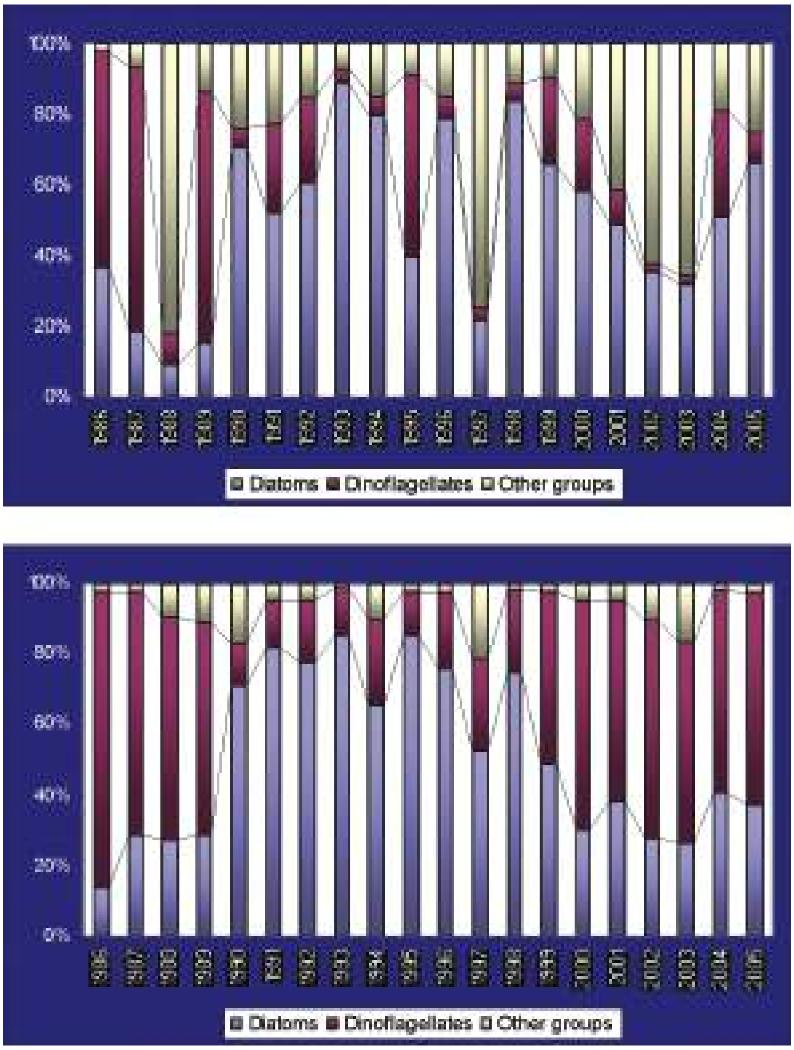


Fig. 5.2b. Percentage of main algal groups in density (upper) and biomass (lower) in front of Constanta waters during 1986-2005.

Table 5.3. Phytoplankton species distributed along the Turkish Coast of Black Sea.

References		1	2	3	4	5	6	6	7	8
Period		1989-1990	1993-1994	1995-1996	1999	2000	2002	2003	2002-2003	2004
Location		SW-BS	SW-BS	S-BS	S-BS	S-BS	S-BS	S-BS	S-BS	S-BS
Taxonomic Groups	Acantharea	-	-	1	-	-	-	-	-	-
	Chlorophyceae	-	1	-	3	1	-	-	-	-
	Chrysophyceae	-	2	-	1	-	-	-	2	-
	Cryptophyceae	-	-	-	1	-	1	-	-	1
	Diatomophyceae	59	56	88	50	27	40	39	84	40
	Dictyochophyceae	1	-	4	6	3	3	3	3	3
	Dinophyceae	36	36	84	69	36	60	51	46	59
	Ebriidea	-	-	-	1	-	-	-	-	-
	Euglenophyceae	1	5	1	3	2	2	3	2	2
	Cyanophyceae	1	2	1	2	1	2	2	2	2
	Prasinophyceae	-	-	-	3	-	-	-	2	-
	Prymnesiophyceae	-	1	1	11	1	2	1	1	2
	∑	**98**	**103**	**180**	**150**	**71**	**110**	**99**	**142**	**109**

(1: Feyzioğlu, 1990. 2: Feyzioglu, 1996. 3: Türkoğlu, 1998. 4: Büyükhatipoğlu et al., 2002. 5: Bircan et al., 2005. 6: Şahin, 2005. 7: Baytut, 2005. 8: Bat et al., 2005. SW-BS: South Western Black Sea. S-BS: Southern Black Sea)

Georgia shelf region: According to the data from the 1970s, 99 phytoplankton species were registered in the south-eastern part of the Black Sea: 116 phytoplankton species were identified in 1982-1987, and 155 species in the 1990s. The present species composition included 203 species and subspecies of Bacillariophyceae, Dinophyceae, Chlorophyceae, Cyanophyceae, Chrysophyceae, Euglenophyceae. Species diversity and total biomass was built mainly by representatives of 2 large groups: Bacillariophyceae (diatoms) and Dinophyceae (dinoflagellates). Most dominant diatom species included Skeletonema costatum, Chaetoceros socialis, Ch.curvisetus Ch.affinis Cyclotella caspia, whereas the dominant dinoflagellates were Prorocentrum cordatum, Pr. micans, Prorocentrum compressum, Protoperidinium pellucidum, P.steinii, Hetercocapsa triguetra, P.bipes, Cetarium fusus, C. furca. In some years, high abundance of blue green, green and euglena algae such as Microcystis acruginosa, Anabaena flos-aquae, Ankistrodesmus falcatus, Scenedesmus acuminatus, Trachaelomonas volvocina var. punctata and Euglena viridis was documented Most of them were recorded in estuaries where water salinity was as low as 8-10psu, in ports and sewage discharge regions.

Northeastern Black Sea: According to 2001-2005 monitoring data, in the Caucasian coast of the Black Sea 100-160 phytoplankton species were listed that included mixotrophic and heterotrophic species and benthic diatoms: about 60 Bacillariophyceae species (including common benthic diatoms like Thalassionema nitzschioides), 78 dinophyceae species (including heterotrophs traditionally accounting within phytoplankton, e.g. Ceratium spp., Dinophysis spp., Diplopsalis spp., Protoperidinium spp., etc.), 4 species of Silicoflagellates, 1 Chrysophyceae 5 Prymnesiophyceae, 1 Euglenophyceae, 1 Prasinophyceae, and 1 identified cyanobacterium. This number was close to the earlier data (119 species) from the same region based on one-year monitoring of microphytoplankton in Gelendjik coast (Zernova 1980).

Interior Black Sea: Long-term dynamics of phytoplankton communities in the interior basin has been studied using the phytoplankton data base, for the period from 1968 to 2007 (Mikaelyan, 2008). Stations are located in the Northern part of the Black Sea deeper than 150 m, mainly in its Northeastern area. Because of strong cross-shelf water exchanges, the key phytoplankton species in the shelf and deeper areas are usually the same and thus the data from stations shallower than 150 m were excluded from the analysis. Total number of stations and samples exceded 1000 and 2600, respectively

Long-term changes of 5 taxonomic groups were analyzed: Dinoflagellates, Diatoms, Coccolithophorids, Silicoflagellates and Flagellates for the upper mixed layer and lower part of the euphotic zone. Annual changes were studied for 4 time periods: spring (March-April), early summer (May-June), summer (July-September) and autumn (October-November). Due to the lack of data, winter season was not taken into consideration

The most striking feature of the spring season is a decreasing trend of diatoms abundance from 60-80% of the total phytoplankton biomass in 1970-1990 to 15-25% after 1995 (Fig. 5.3). They were replaced by dinoflagellates and phytoflagellates. The early summer season (May-June) was characterized by an increase of coccolithophorids abundance from 5-15% before the mid-1980s to 20 in the 1980s and 50% after 1994 until the present. On the contrary, dinoflagellate standing stock decreased from 60-80% to 15-25% during the same period. The role of diatoms increased from 1% to 60% in the upper mixed layer in summer season of the last two decades. The same trend was not so evident for the pycnocline layer where the most noticeable change was the reduction of silicoflagellate abundance. It comprised from 10 to 90% of the total phytoplankton biomass in 1969 and only from 0 to 5% after 1970's. For the autumn season, the role of dinoflagellates in phytoplankton biomass decreased from 60-90% to 10-40% in the upper mixed layer. An opposite trend was recorded for flagellates. Their input to the total phytoplankton biomass increased from 0-5% to 20-70%. Thus, phytoplankton species community was dominated by dinoflagellates in spring and early summer and diatoms in summer and autumn after 1994. Phytoflagellates also became a dominant component of the community with contribution more than 20% throughout the year. Coccolithophorids also became a predominant part of the community during May-June as also supported by the ocean color data (Cokacar et al., 2003).

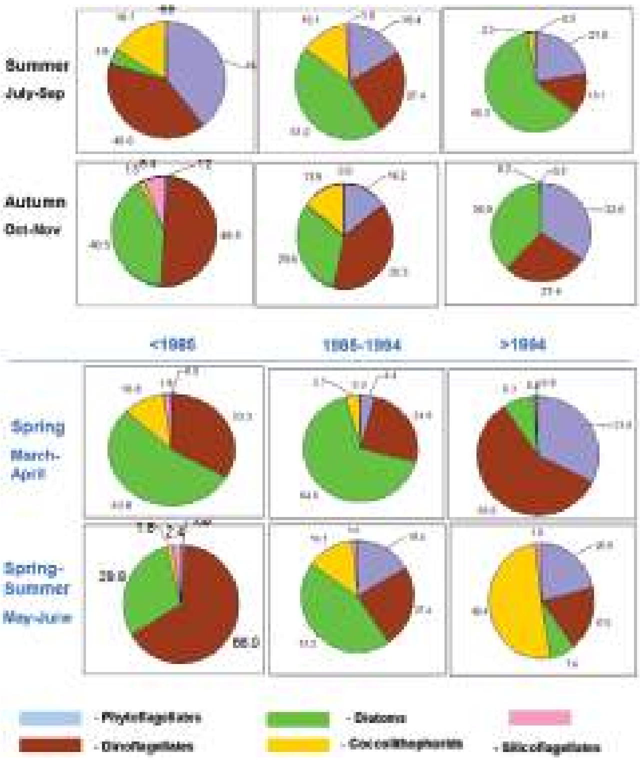


Fig. 5.3. Phytoplankton community structure within the interior basin in different seasons prior to 1985, during 1985-1994 and after 1994.

The most remarkable changes occurred during the seasonal plankton successions in the cold climate period 1985-1994. The predominance of diatoms in spring shifted to the prevalence of dinoflagellates and phytoflagellates. Substantial increase of coccolithophorids was reported in spring-summer instead of dinoflagellates. Dinoflagellates replaced by diatoms in summer and silicoflagellates by phytoflagellates in autumn. Thus, the classical seasonal phytoplankton succession with the spring diatoms bloom followed by proliferation of dinoflagellates and then phytoplagellates was not observed any longer. They all indicated a "regime shift" in phytoplankton community structure during the early 1990's. This mode still prevails and the phytoplankton community structure of the deep Black Sea has not yet return to the state observed during the 1960-70s.

5.3. Long-term changes in algal blooms

Northwestern Black Sea shelf: For the 1973 - 2005 period, 158 bloom cases were registered by 50 species and varieties of algae (see Table 5.5 in Appendix) including 25 species of diatoms, 7 of dinophytes, 11 of blue-green, 4 of green, 2 of crysophytes algae and 1 of Euglenophyceae. 53 bloom events were registered in 1973 - 1980 over more than half of the northwestern Black Sea area (Nesterova, 2001). The most remarkable outbursts were caused by *Prorocentrum cordatum*, which initiated "a red tide" at the sea surface in September 1973, (Nesterova, 1979) after a similar event that occurred in Sevastopol Bay in 1909 (Zernov, 1913). Also "blooming" of *Cerataulina pelagica* and *Emiliania huxleyi* was first noted in 1973-1980 (Nesterova, 2001).

From 1980 to 1990, the number of phytoplankton blooms decreased to 33. However, outbursts of rare species such as (*Leptocylindrus minimus*), and of new species (*Microcystis pulverea, Gleocapsa minima,* etc.) increased in number. Most frequent "blooms" were caused by *Skeletonema costatum, Cerataulina pelagica, Prorocentrum cordatum, Chaetoceros socialis.* In 2001, outbursts of dinophytes - *Gymnodinium simplex, G. sphaeroideum, Scrippsiella trochoidea and Akashiwo sanguinea* were also recorded.

Massive algal outbursts were rarely observed along the Crimean coast, and their maximum abundance was always lower than in the NWS (Mashtakova and Roukhiyainen, 1979; Senichkina, 1993). For instance, Skeletonema costatum abundance along the Crimean coast reached 0.9 millon per liter (Senichkina, 1993), while it was 30.6 millon per liter in the NWS (Nesterova, 2001).

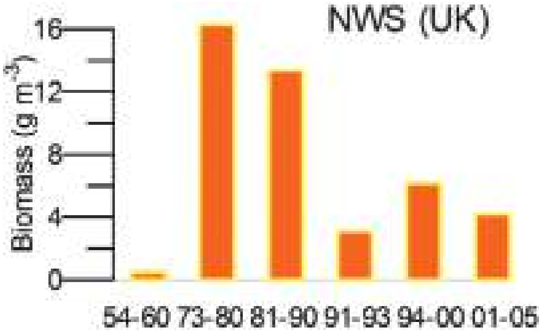


Fig. 5.4. Changes in phytoplankton biomass in 1954-1960s and in 1973 - 2005s in the northwestern Black Sea shelf.

The highest values of phytoplankton biomass in the NWS were observed in 1973 - 1980 (Fig. 5.4) and attributed to the heavy eutrophication (Nesterova, 1987). The average phytoplankton biomass increased almost 17 times - from 0.9 g m $^{-3}$ to 16.0 g m $^{-3}$ as compared to the 1950-1960s (Nesterova, 1987). From 1981 to 1993 the phytoplankton biomass started to decrease gradually with a minimum biomass registered in 1991-1993. In 1994 - 2000, the biomass was around 6.0 g m $^{-3}$ and the contribution of dinophyte algae tended to decrease in contrast to more intense development of diatoms (Derezyuk et al., 2001). The proliferation of *Skeletonema costatum* was more intensive as an indicator of hypereutrophic waters (Nesterova, 2003). The decrease in phytoplankton biomass to around 4.0 g m^{-3} in 2001-2005 was accompanied by an increased role of dinophytes. In 2005, a "red tide" dominated by *Scrippsiella trochoidea* and blue-green algae was documented near the Odessa coast.

Phytoplankton data for the period 1988 - 2004 from the estuarine part of the Danube - the main source of Black Sea eutrophication (Zaisev at al., 1989) have been analyzed for three different periods (Nesterova, 1998; Nesterova, Ivanov, 2001; Nesterova, 2005). The phytoplankton abundance did not change much during these periods and was on the average 3.6 million cells.l-1 (Fig. 5.5a). More recent data for 2003-2008, on the other hand, show large interannual variability in the range of 0.5-15 million cells.l-1 (Fig. 5.5b). The biomass gradually decreased from 38.0 g m $^{-3}$ in the 1980s to ~5.0 g m $^{-3}$ in 2000-2004, mostly due to the reduction in dinophytes (*Heterocapsa triquetra*) in spring and increase in diatoms (small-size species, such as *Skeletonema costatum*, *Chaetoceros socialis*). The latter average value included extreme cases such as 14.5 g m $^{-3}$ in 2003 and 2 g m $^{-3}$ in 2004. The biomass manifested an increasing trend after 2004 up to 8 g m $^{-3}$ in 2008. A similar decrease in phytoplankton biomass from the 1980s to the 1990s and enhanced growth of *Skeletonema costatum* was also observed in the Odessa area (Nesterova and Terenko, 2000) where the number of blooming species changed irregularly year-to-year (Fig. 5.5c).

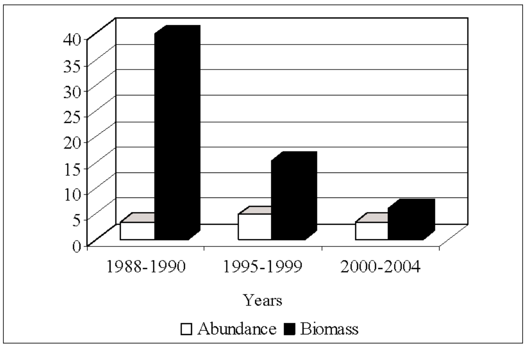


Fig. 5.5a. Change in abundance (million cells.l-1) and phytoplankton biomass (g.m^{-3}) of the Danube estuarine area (1988-2004).

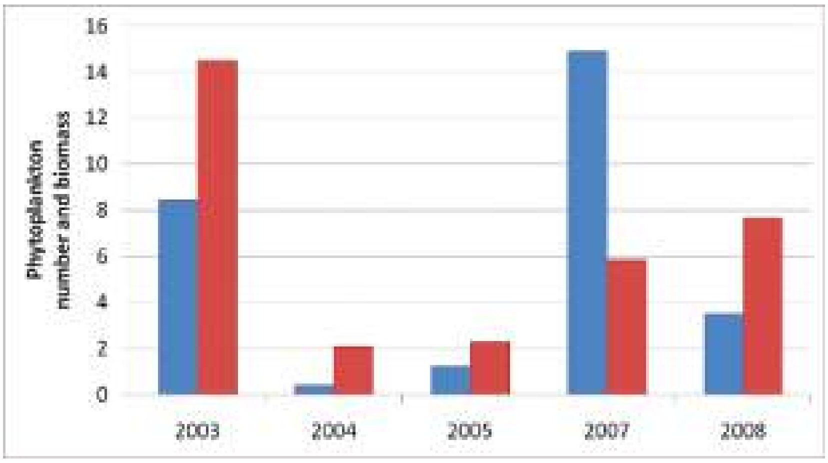


Fig. 5.5b. Change in abundance (blue bars; million cells.l^{-3}) and phytoplankton biomass (red bars; g.m^{-3}) of the Danube estuarine area (2003-2008).

Near southeastern coast of Crimea the abundance and biomass of phytoplankton have also increased in the past 50 years. Small size species of diatoms (*Skeletonema costatum*) and coccolithophorids (*Emiliania huxleyi*) dominated phytoplankton blooms (Kuzmenko at al., 2001). Dominance of coccolithophorids in the summer-autumn period was particularly prominent in the coastal zone near Sevastopol in 2001-2003 (Polikarpov at al., 2003).

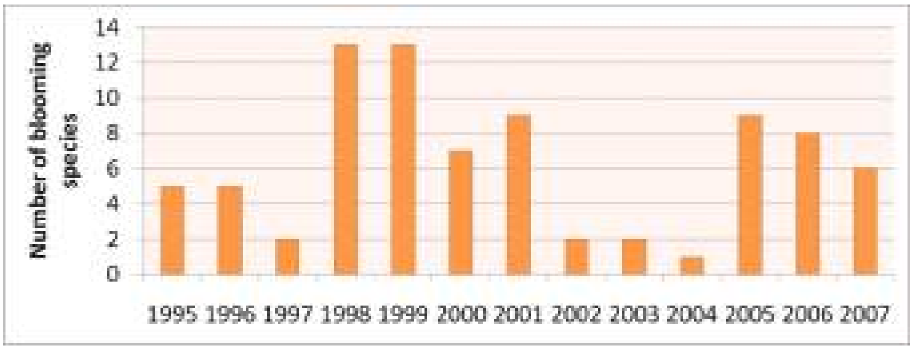


Fig. 5.5c. Number of blooming species in the coastal area of the Odessa Bay.

To summarize, the phytoplankton structure and dynamics in the NWS have been altered not uniformly in the different areas of the shelf during the past 50 years. The phytoplankton species diversity increased and this increase was accompanied by changes in the ratio of diatoms and dinophyte algae in favour of dinophytes and declining contribution of diatoms during the 1970-1980s. In the Sevastopol area and the southeastern coast of Crimea, the species diversity of coccolithophorids increased. A reverse trend was observed after 2000 characterized by elevated diatom contribution and reduction of dinophyte abundance along with a decrease in the total phytoplankton biomass that imply a decline of eutrophication impact and a partial recovery of the northwestern shelf ecosystem (Nesterova, 2003).

Romanian shelf area:

The phytoplankton density and biomass followed the general tendency of decrease in the Romanian Black Sea waters after the 1980's as well. Both abundance and biomass in coastal waters near Constanta underwent a significant reduction during 2001-2005 that accounted for 75% and 55% decrease relative to the 1980's (Table 5.3 and Fig. 5.6) and approaching to values comparable to the 1960s. Algal bloom frequency and concentration declined: out of 24 blooms, only three exceeded 50 million cells/l whereas this number was 15 in the 1980s and 4 in the 1990s (Table 5.3). Besides, diminished number and intensity of algal blooms, the number of blooming species reaching density higher than 10 million cells/l was reduced from 11 in the 1990s to 9 in 2001-2005 (Fig. 5.7). Cyclotella caspia (maximum 78.6 $\cdot 10^6$ cells/l), dinoflagellates *Prorocentrum cordatum* (15.3$\cdot 10^6$ cells/l), *Scrippsiella trochoidea* (25.2$\cdot 10^6$ cells/l) and *Heterocapsa triquetra* (16.0 $\cdot 10^6$ cells/l), cyanophytes *Microcystis pulverea* (16.7 $\cdot 10^6$ cells/l), *M. aeruginosa* (15.0 $\cdot 10^6$ cells/l) and *M. orae* (271.9 $\cdot 10^6$ cells/l), diatoms *Tabellaria* sp. (maximum 17.1 $\cdot 10^6$ cells/l) and *Navicula* sp. (maximum 67.5$\cdot 10^6$ cells/l) produced the most significant blooms. The last five species were alochtonous fresh-brackish water species introduced into the sea mainly by the River Danube, the blooms occurring in regions of relatively low salinity and warm water. The relatively large phytoplankton biomass in 2007 (Fig. 5.6) was due to large-size dinoflagellate bloom, but the abundance was low (Fig.5.6).

Table 5.3. Mean phytoplankton density and biomass in the shallow waters in front of Constanta and number of blooms registered in Romanian marine waters during different periods.

Period	Density (10^6 cell/l)	Biomass (g/m3)	Number of blooms	Number of Blooms, density > 50$\cdot 10^6$ cell/l
1959-1965	0.887	2.00		
1983-1990	5.870	7.14	49	15
1991-2000	2.261	5.960	29	4
2001-2005*	1.481	3.22	24	3

* *Mean minus extreme values/atipique from August and September, 2000 and 2001.*

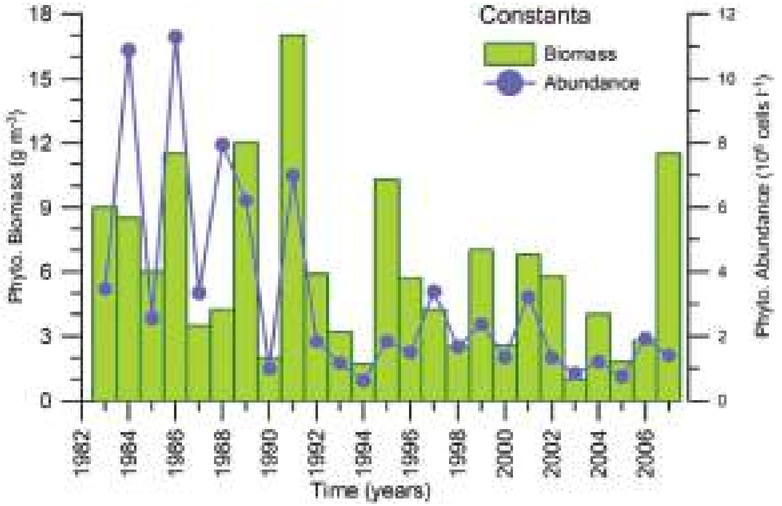


Fig. 5.6. Change in annual-mean density and biomass of phytoplankton in 1983-2006 in Constanta.

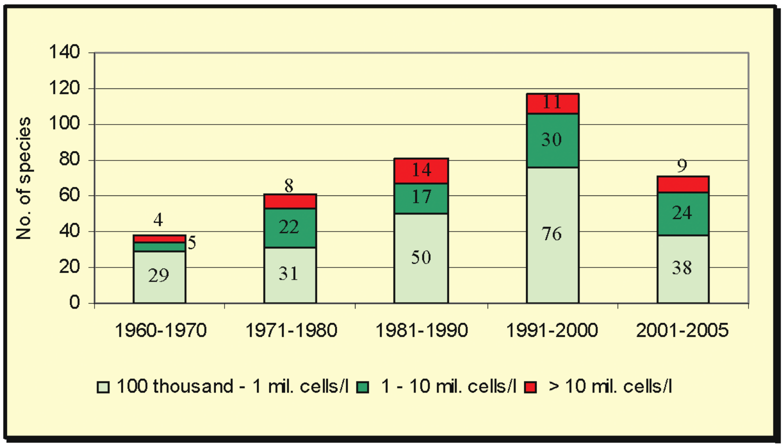


Fig. 5.7. Number of phytoplankton species contributing to blooms in Romanian waters between 1960 and 2005.

Bulgarian shelf area: The 1980's and the early 1990s were characterized by most intense blooms and a shift to r-strategy species (Moncheva, Krastev, 1997). A total of 31 monospecific blooms occurred, out of which seven attained densities higher than 50 mil cells.l^{-1} and the biomass varied between 10 and 20 g m^{-3}. Starting by the mid-1990s, an overall decreasing trend in the density and biomass of all dominant species was observed down to a total biomass of about 3 g m^{-3} after 2000 (Fig. 5.9). Along with the reduction of frequency, duration, and intensity of phytoplankton outbursts (only 3 cases of abundance exceeding 50 mil cells.l^{-1} reported in the late 1990s and none in the period after 2000), a decline in the extent and duration of exceptional events, especially in summer was documented. The list of bloom producing species was further diversified and several species contributed to a single bloom event (Moncheva et al., 1995, Velikova et al. 1999, Moncheva et al., 2001) - Fig.5.8.

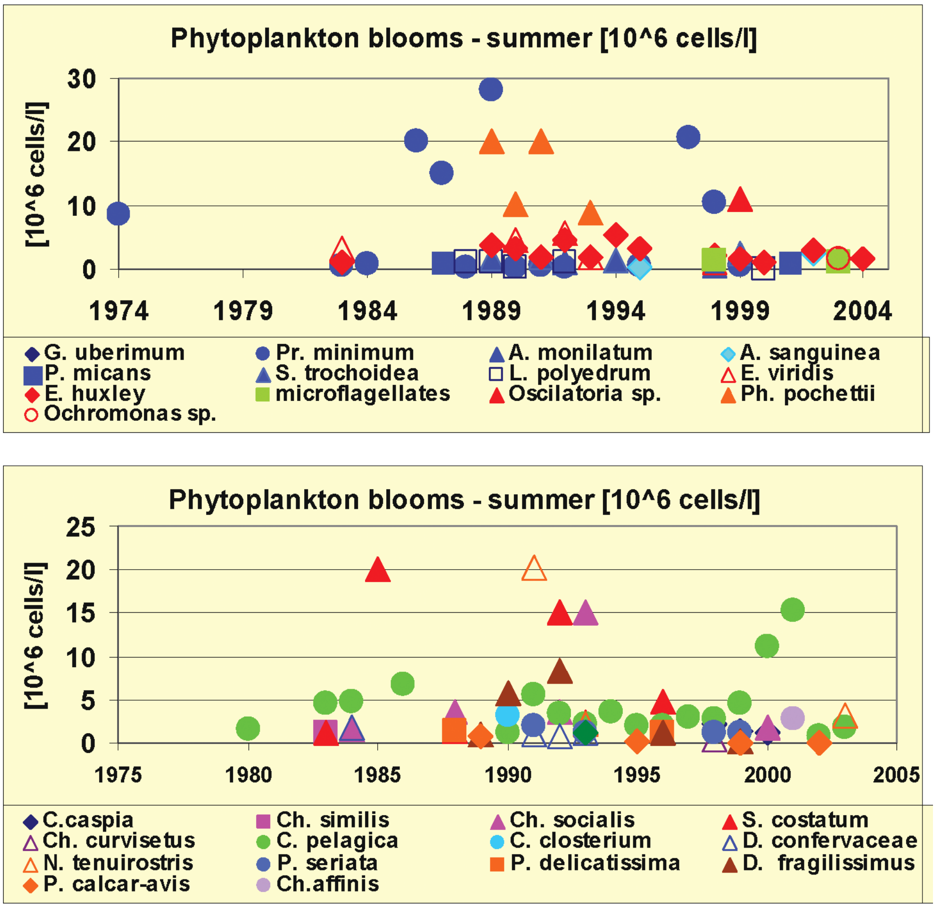


Fig. 5.8. Phytoplankton species contributing to summer blooms in Bulgarian coastal area between 1975 and 2005

After 2000, a number of controversial trends were evident in summer, such as proliferation of large diatoms (*Pseudosolenia calcar avis and Cerataulina pelagica*) at the level of red-tide biomass (higher than 20 g/m^3 in August 2002), elevated occurrence of small heterothrophic microflagellates and large dinoflagellates (*Akashiwo sanguinea* and species from genus *Ceratium*), and almost recurrent blooms of *Emiliania huxleyi* (Moncheva et al., 2006). The presence of species from genus *Dinophysis* (*D. acuta* - 4.4 $x10^3$ and *D. caudata* - 1.7 $x10^3$ - Petrova and Velikova, 2003) and *Pseudonitzschia* cited as toxic for other areas of the world ocean all together signify perturbed phytoplankton succession and ecosystem instability.

The summer frequency distribution of EQ classes during the period 1990-2000 and 2000-2007 based on chlorophyll-a and phytoplankton biomass (Moncheva and Slabakova, 2007) revealed a reduction of "poor/bad" conditions from more than 70% to less than 40% in the Varna Bay and to none at station 201 near Cape Kaliakra, and to about 40% at station 301, near Cape Galata (Fig. 5.10), indicating an improvement in the environment of the region. Nonetheless the "good" class frequency maintained below 50% in Varna Bay implies a continuation of eutrophic conditions of ecological concern.

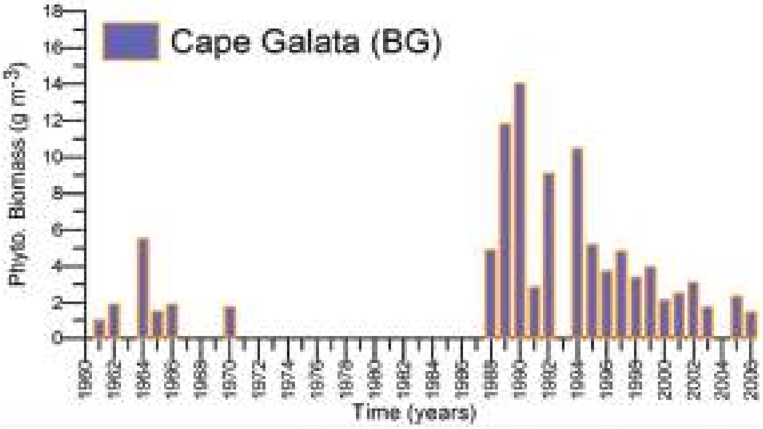


Fig. 5.9. Long term changes of phytoplankton biomass at 3 nm away from the Cape Galata. The data prior to 1970 were taken from Petrova-Karadjova (1984 and 1990).

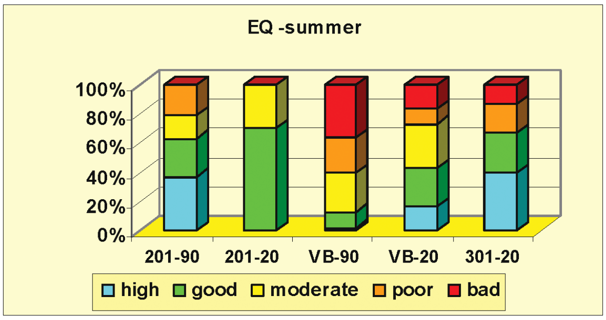


Fig. 5.10. Frequency of EQ classess of summer phytoplankton blooms averaged for 1990-2000 (indicated by "90") and 2000-2007 (indicated by "20") for coastal stations (201 near the Cape Kaliakra and 301 near the Cape Galata, and VB-Varna Bay).

Southern Black Sea: The analysis of the data collected along the Turkish coast during two different hydrological phases: stagnant period (where significant nutrient injection is possible due to deeper mixed layer in cold seasons) and non-stagnant period (shallower mixed layer; warm seasons) suggested a common trend of lower phytoplankton abundance after 1994 (Fig. 5.11), most likely related to improvement of eutrophic conditions in the southern Black Sea coastal waters. Relatively high abundance in the stagnant periods reflected mainly the contribution of the spring blooms.

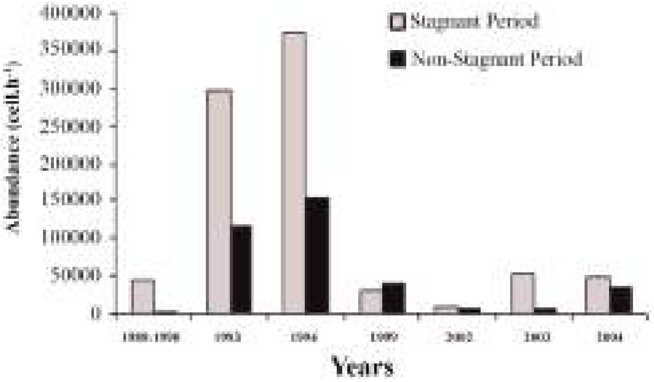


Fig. 5.11. Comparison of phytoplankton abundance during two contrasting periods (i.e. stagnant and non-stagnant) in 1989-2005.

Georgia shelf region: Since 1981, phytoplankton was sampled along 8-12 transects at standard depths (0, 5, 10, 25, 50, 75, 100m) and 68-70 stations along the Georgian coast from Chorokhi River up to Bzibi River. The average annual abundance and biomass during 1992, 1998, 1999 and 2005 (Fig. 5.12) indicated a rather uniform level during the 1990s (around 100-150x10^3 cell l^{-1} and 2.5 g m^{-3}) in coastal waters between Poti and Batumi. The exceptionally high density and biomass of phytoplankton (788 x10^3 cell l^{-1} and 11.7 g m^{-3}) were recorded in both regions during 2005 that were associated with proliferation of large Bacillariophyceae species *Coscinodiscus granii, Hyalodiscus ambiguus, Pseudosolenia calcar avis, Dactyliosolen fragilissimus, Prorocentrum micans.*

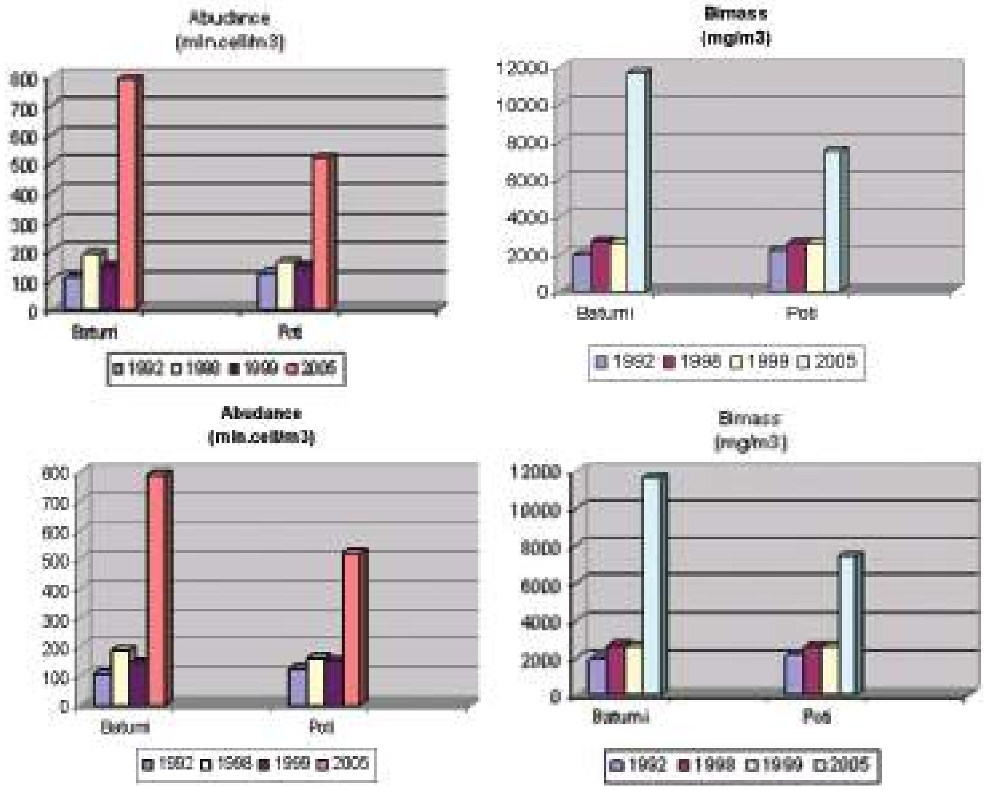


Fig. 5.12. Average annual abundance and biomass of phytoplankton in Georgian waters in 1992-2005.

Interior Black Sea: Phytoplankton biomass as an average of all measurements conducted within the interior basin at stations deeper than 150 m also indicate distinct decadal changes (Fig. 5. 13). The biomass which was only about 2 g m^{-2} during the 1960s increased up to 10 g m^{-2} after the mid-1970s and then to about 20 g m^{-2} in the 1980s and the early 1990s, exceeding even 50 g m^{-2} in 1985 and 1992. By the mid-1990s, phytoplankton biomass oscillated annually between 5 g m^{-2} and 20 g m^{-2} and therefore is still comparable with the conditions of eutrophication phase.

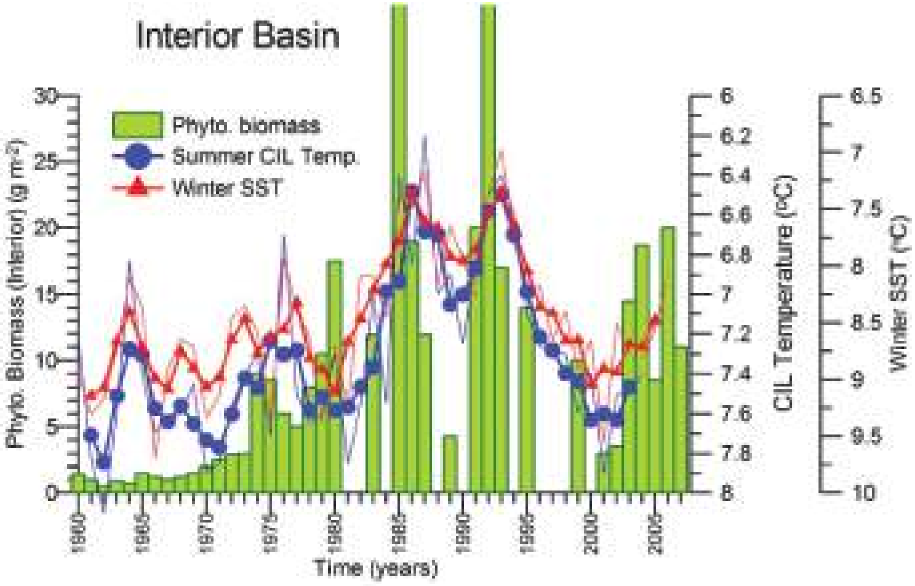


Fig. 5.13. Long-term changes of total phytoplankton biomass within the water column of interior basin (g m^{-2}) compiled from all available measurements at locations deeper than 100 m during May-September, and the December-March mean SST (°C) as an average of various data sets (Hadley, Reynolds-NCEP, Pathfinder), and the mean temperature of CIL during May-October.

As the spring-summer phytoplankton productivity is mainly driven by the amount of nutrients entrained into the euphotic zone by winter convection, it is expected that phytoplankton biomass should be proportional to severity of winters that is indicated in Fig. 5.13 by the winter-average SST and mean temperature of the Cold Intermediate Layer (CIL) during May-October. As shown in Fig. 5.13, phytoplankton biomass follows closely temperature variations with higher (lower) biomass during cold (warm) years. This close relation implies that a part of the biomass increase in the 1980s was imposed by climate impact, in addition to eutrophication. The recent increase in biomass after 2002 may also be attributed to the climate as there is no evidence of increase in eutrophication within the interior basin during the recent years.

5.4. Seasonal dynamics

The averaged data for the NWS during 1975-2005 suggest three particular peaks in the annual dynamics of phytoplankton biomass. The first one occurred in April, usually dominated by diatoms (*Skeletonema costatum,* species of the genera *Thalassiosira*), the second- in June-July dominated by dinoflagellates (*Prorocentrum cordatum*) making up 84.6 % of the total biomass, and the third and highest one in September-October due to diatoms (*Cerataulina pelagica, Pseudonitzschia seriata, Ps. delicatissima, Leptocylindrus danicus*) and dinophyte (*Prorocentrum cordatum, Goniaulax polyedra*), which contributed to biomass irregularly (Fig. 5.14). During diatoms outbursts, they build up about 70% of the biomass while dinophyte contribution decreased to 22%. Because of their small cell-size coccolithophorids contributed to only 8% of the biomass. The most important feature was an almost one order of magnitude increase of the monthly phytoplankton biomass during 1973-2005 as compared to 1954-1974 - Fig. 5.14

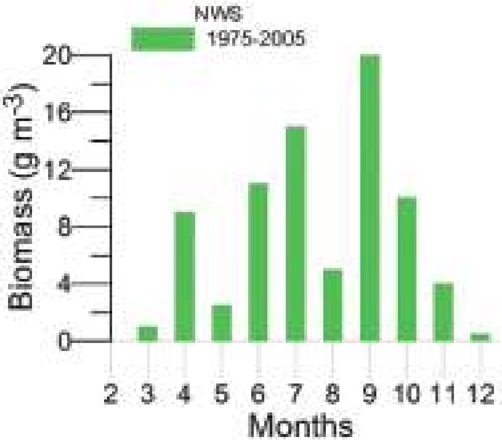


Fig 5.14. Monthly changes of mean phytoplankton biomass in the northwestern coastal waters during 1975-2005.

During the summer outbursts the bulk of phytoplankton biomass was concentrated in the upper 0-10 m, except in shallow waters. The difference in the abundance between the surface and near bottom layers increased from spring to summer, decreasing in the autumn. The highest abundance and biomass were observed in the Danube River runoff impacted zone of the NWS, with frequent and intensive blooms, while the abundance and biomass declined sharply by several orders of magnitude beyond this zone. During spring and autumn intense diatoms outbursts were registered locally near river estuaries. In summer during permanent blooms, large areas of high phytoplankton biomass were covered between the estuaries of the Dnieper-Bug Liman and the Danube.

In the Bulgarian shelf area, during the cold years of the 1980s as well as in 1994, the annual phytoplankton biomass manifested pronounced late-winter and spring peaks, often exceeding 10 g m^{-3} - to more than 30 g m^{-3} as observed in the 1990 spring (Fig. 5.15). The biomass decreased considerably since 1995 down to less than 5 g m^{-3} after 2000, associated with the onset of a decade-long climatic warming phase along with the reduction of nutrients and the shift in their ratios (Moncheva et al, 2008). Contrary to the cold climate phase, there was no clear seasonal pattern, and the timing of phytoplankton intensive growth varied irregularly.

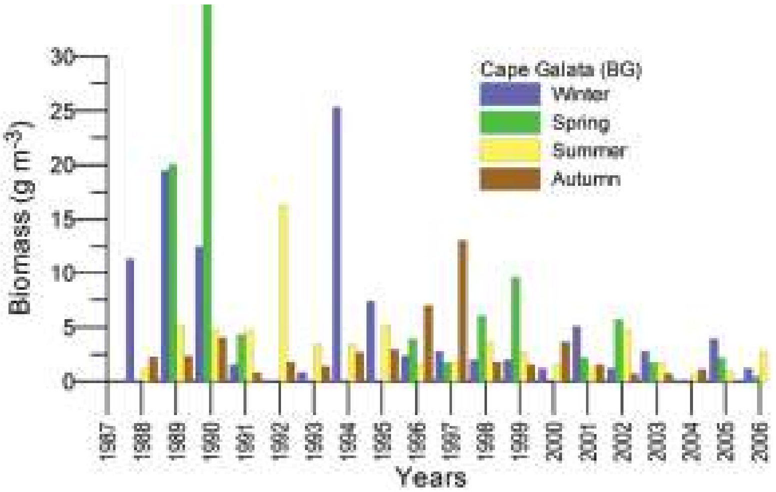


Fig. 5.15. Long term changes of phytoplankton biomass at different seasons 3 nm away from the Cape Galata.

In the northeastern shelf, the phytoplankton growth started in February by proliferation of small diatoms, usually *Pseudo-nitzschia pseudodelicatissima* most frequently co-dominated by *Skeletonema costatum, Dactyliosolen fragilissimus, Cerataulina pelagica, Hemiaulus hauckii,* and *Chaetoceros spp.* and nanoplankton flagellates. In 2004, *Thalassiosira spp.* alone reached a density of 100 000 cell l^{-1}. The spring peak of phytoplankton diversity and abundance occurred in April. At this time, large diatoms (e.g. *Pseudosolenia calcar avis, Proboscia alata*) and heterotrophic dinoflagellates dominate in the community biomass. The diversity and abundance decreased in May-June, with the exception of cases of massive proliferation of coccolithophores or a re-intensified growth of *P.pseudodelicatissima and/or Thalassiosira spp.,* populations.

The beginning of most intensive and longest period of phytoplankton growth and maximum diversity was in July, culminating in early August, parallel to the annual maximum of surface water temperature. The phytoplankton abundance is dominated by dinoflagelates. Monospecific blooms may also occur like *Cochlodinium polykrikoides* bloom at Bolshoy Utrish (Krasnodar Krai) in 2001 (Vershinin et al., 2005). September-October was a time of gradual decline of phytoplankton community: total cell density and biomass decreased, and the portion of dinoflagellate species also. The intensity and duration of this annual phytoplankton succession at Caucasian coast varied from year to year, but the general pattern was maintained.

The succession cycle in the northeastern Black Sea coastal waters starts typically with the outburst of a single species of high growth rate, or less frequent, several of several species - small diatoms and/or coccolithophores. Then, they are replaced by heterotrophic dinoflagellates at temperatures higher than ~15°C. The data suggested that biotic factors (life cycle, growth rate and grazing, etc.) drive the start and evolution of each succession cycle, whereas the initiation, intensity and duration are determined mostly by water temperature.

5.5. Conclusions and recommendations

The overall analysis provided rather contrasting trends of phytoplankton assembly during the present decade. On the one hand, the increased species diversity and richness, reduced frequency and magnitude of phytoplankton blooms and thus decrease of total biomass and abundance, reduced frequency of "bad/poor" EQ classes all point to an improvement of the ecological state of the Black Sea. On the other hand, concomitantly with still high nutrient concentrations, the increased dominance of heterotrophic dinoflagellates and elevation of abundance and biomass of "other" species (e.g. coccolithophores and phytoflagellates) reflect features of a perturbed transitional state and an ongoing ecological instability. The seasonal species succession manifested irregular pattern and varied regionally and from year to year. A notable character of the annual phytoplankton structure is the substantial increase of coccolithophorids in May-June all over the basin.

Due to the high sensitivity of phytoplankton communities to external forcing as well as highly dynamic internal structure of the ecosystem, the frequency of sampling is critical for setting an adequate monitoring system for phytoplankton related indicators. Occasional high phytoplankton blooms observed during the present decade in many coastal waters requires a systematic monitoring. Monthly sampling is strongly recommended, while sampling during spring and summer is an imperative. Remote sensing ocean color data with an improved algorithm for coastal waters are crucial especially in spring-summer for capturing the spatial features of bloom events.

Appendix

Table 5.4. Abundance (cells/l) and biomass (mg/m3) of dominant and blooming phytoplankton species along the Bulgarian shelf in different periods.

	1954-1970			2000-2005		1980-2000
Taxa	**[10^6 cells/l]**	**B [g/m^3]**	**Taxa**	**[10^6 cells/l**	**B [g/m^3]**	**[10^6 cells/l**
Winter			**Bacillariophyceae**			
Skeletonema costatum	4.2 -5.7		*Skeletonema costatum*	2.3- 6.4 -3.9-15.0		43.47
Detonula confervaceae	2.4 -4.4-7.3		*Detonula confervaceae*			4.4
Pseudonitzschia seriata	2.6-4.3		*Pseudonitzschia seriata*			3.1
Cerataulina pelagica	9.8		*Pseudonitzschia delicatissima*			
Chaetoceros similis			*Chaetoceros similis*		0.9	7.7
Chaetoceros curvisetus			*Ditylum brightwellii*			
			Chaetoceros affinis			
			Dinophyceae			
Glenodinium sp.			*Gyrodinium lachryma*		1.06	
Ceratium fusus			*Cyst Alexandrium*		0.6	
Prorocentrum cordatum			*Heterocapsa triquetra*		0.8	24
Prorocentrum micans			*Protoperidinium divergens*		0.97	
			Protoperidinium grannii			
			Ceratium furca, C. fusus			
			Akashiwo sanguinea			
			Microflagellates			
			Microflagellates			

	1954-1970			2000-2005		1980-2000
Taxa	**[10^6 cells/l]**	**B [g/m^3]**	**Taxa**	**[10^6 cells/l**	**B [g/m^3]**	**[10^6 cells/l**
			Chrysophyceae			
			Apedinella spinifera *Coccolithus sp.*	1.7		
Spring			**Bacillariophyceae**			
Cerataulina pelagica		22.9	*Cerataulina pelagica*	3.7		6.3
Chaetoceros curvisaetus		5.2	*Chaetoceros socialis*	11.8		3.5
Pseudonitzschia delicatissima		1.3	*Pseudonitzschia delicatissima*			3.1
Skeletonema costatum	10		*Skeletonema costatum*			35.8
Cyclotella caspia			*Cyclotella caspia*	2.3		9.9
Thalassionema nitszchioides			*Chaetoceros similis*		0.9	
Detonula confervaceae			*Shroderella delicatula*			4.8
Pseudosolenia calcar-avis						3.6
			Dinophyceae			
Prorocentrum micans			*Prorocentrum cordatum*	3.7	3.1	30.5-96.8
Ceratium fusus			*Heterocapsa triquetra*	1.7-3.7	14.3	7.7-39.5
Protoperidinium crassipess			*Scrippsiella trochoidea*	1.8		
Peridinium divergens			*Ceratium fusus*		0.66	
			Dinophysis acuta		12.24	
			Akashiwo sanguinea			
			Ceratium tripos			
			Chrysophyceae			
			Emiliania huxleyi	3.88-4.33- 4.7		3.2
			Microflagellates			
			Microflagellates	1.1-33.0		42.8

	1954-1970			2000-2005		1980-2000
Taxa	**[10^6 cells/l]**	**B [g/m^3]**	**Taxa**	**[10^6 cells/l**	**B [g/m^3]**	**[10^6 cells/l**
Summer	**Bacillariophyceae**					
Cerataulina pelagica			*Cerataulina pelagica*	1.8-6.4	11.3-15.3-12.0-2.5	6.8
Pseudonitzschia delicatissima			*Pseudonitzschia delicatissima*			1.4
Pseudosolenia calcar-avis			*Pseudosolenia calcar-avis*		23	1.8
Cyclotella caspia	0.6-2.1		*Cyclotella caspia*	1.1		
Thalassionema nitzschioidea			*Thalassionema nitzschioidea*		2.8	
			Dactyliosolen fragilissimum		0.42	5.7-8.4
			Nitszchia longissima	3.2-5.9		
			Nitschia tenuirostris			
			Chaetoceros affinis *Chaetoceros socialis*	2.7		 35.5
Dinophyceae						
Prorocentrum cordatum	5.4		*Prorocentrum cordatum*	1.1	2.06-1.9	480
Prorocentrum micans			*Heterocapsa triquetra*			
Ceratium fusus			*Scrippsiella trochoidea* *Prorocentrum micans*		 0.7	
Peridinium crassipess Dinophysis caudat			*Ceratium fusus* *Ceratium furca*		 1.1	

	1954-1970			2000-2005		1980-2000
Taxa	**[10^6 cells/l]**	**B [g/m^3]**	**Taxa**	**[10^6 cells/l**	**B [g/m^3]**	**[10^6 cells/l**
			Gyrodinium spirale			
			Dinophysis acuta			
			Akashiwo sanguinea		12.24	
			Ceratium tripos			
			Chrysophyceae			
			Emiliania huxleyi	1.7-1.8-2.3-3.1		52.9
			Phaeocystis pouchettii	4.4		90
			Cryptophyceae			
			Ochromonas sp.	1.5	0.7-1.6	
			Microflagellates			
			Microflagellates	1.7		
			Euglenophyceae			
			Eutreptia lanowii			4.6

	1954-1970			2000-2005		1980-2000
Taxa	**[10^6 cells/l]**	**B [g/m^3]**	**Taxa**	**[10^6 cells/l**	**B [g/m^3]**	**[10^6 cells/l**
Autumn			**Bacillariophyceae**			
Sceletonema costatum	1.6		*Skeletonema costatum*	1.31-2.2-2.4		57.2
Pseudosolenia delicatissima	5.7	14.8	*Pseudosolenia delicatissima*			4.2
Dytilum Brightwellii			*Pseudosolenia calcar-avis*			
Cerataulina pelagica		7.3	*Pseudonitzschia seriata*		2.6	
			Dinophyceae			
Prorocentrum micans			*Alexandrium monilatum*		15.8	
Dinophysis caudate *Dinophysis sacculus*			***Gymnodinium sp.***		2.34	
Prorocentrum cordatum	0.4		*Prorocentrum cordatum*	1.02-3.48		60
			Goniaulax spinifera	2.9		
			Prorocentrum micans			2,9
			Ceratium furca			*1,2*
			Chrysophyceae			
			Emiliania huxleyi **Microflagellates**	2.11-4.08		4.2

Table 5.5. Maximum abundance (million cells/l) of species that caused phytoplankton blooms in the northwestern Black Sea in the 1954-1960s and in 1973-2005.

Species	1954-1960s*	1973-2005
Bacillariophyceae		
Melosira granulata (Her.) Ralfs	1.8	2.9
Skeletonema costatum (Grev.) Cl.	32.0	30.6
Sk. potamos (Weber) Hasle		8.4***
Sk. subsalsum (A.Cl.) Bethge	-	8.5
Thalassiosira parva и Th. subsalina Pr.-Lavr.	2.7	54.0
Cyclotella caspia Grun.	5.2	6.2
C. glomerata Bachm.		22.5***
Stephanodiscus hantzschii Grun	-	20.8
St. socialis Makar. Et Pr.-Lavr	-	4.9**
Leptocylindrus minimus Grun.	-	16.0
L. danicus Cl.	72.0	28.0
Dactyliosolen fragilissimus (Bergon) Hasle.	0.1	12.2**
Chaetoceros affinis Laud.	-	1.9
Ch. Insignis Pr.-Lavr.	-	1.7
Ch. karianus Grun.	-	4.0
Ch. socialis Laud.	5.4	16.7
Ch. rigidus Ostf.	-	14.0**
Cerataulina pelagica (Cl.) Perag.	0.6	37.0
Diatoma elongatum (Lyngb.) Ag.	0.7	6.7
Synedra actinastroides Lemm.	-	1.9
Asterionella formosa Hass.	-	2.3
Nitzschia tenuirostris Mer.	-	28.6
Cylindrotheca closterium (Ehr.) W.Sm.	-	16.0
Pseudo-nitzschia seriata (Cl.) H. Perag.	-	12.4
Surirella ovata var.salina (W.Sm.) Hust.	-	10.7
Dinophyceae		
Prorocentrum cordatum (Ostf.) Dodge	4.3	224.0
Pr. micans Her.	-	15.4**
Gymnodinium sphaeroideum Kof.	-	4.0
G.simplex (Lohmann) Kof. et Sw.	-	251.1
Akashiwo sanguinea (Hirasaka) G. Hans. et Moestr.	-	140.0
Heterocapsa triquetra (Her.) Stein.	-	18.0
Scrippsiella trochoidea (Stein) Balech ex Loeblich III	-	125.4
Cyanophyceae		
Microcystis aeruginosa Kutz.	4.3	15.0
M. pulverea (Wood) Elenk. F. pulverea	-	94.8
Gleocapsa minor (Kutz.) Hollerb. Ampl.	-	2.6
G. minima (Keissl.) Hollerb.	-	4.4
Merismopedia glauca (Her.) Nag.	-	1.0
M. minima (Keissl.) Hollerb.	-	22.0
M. punctata Meyer	-	8.1
M. tenuissima Lemm.	44.8	8.2
Anabaena spiroides Kleb.	2.5	6.3
Aphanizomenon flos-aquae (L.) Ralfs	0.9	34.0
Oscillatoria kisselevi Anissim.	-	147.0
Chlorophyceae		
Monoraphidium arcuatus Korsch.	-	1.9
Scenedesmus obliquus (Turp.) Kutz.	-	8.6
Sc. quadricauda (Turp.) Breb. Var. Quadricauda		1,4***
Micractinium pusillum Fr.	-	6.6
Chrysophyceae		
Emiliania huxleyi (Lohm.) Hay & Mohler	-	9.0
Dinobryon sp.	-	4.0
Euglenophyceae		
Eutreptia lanovii Steuer	-	1.7

* - Ivanov (1967); ** -Terenko, Terenko (2000); -*** Nesterova, Terenko, 2007

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

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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.

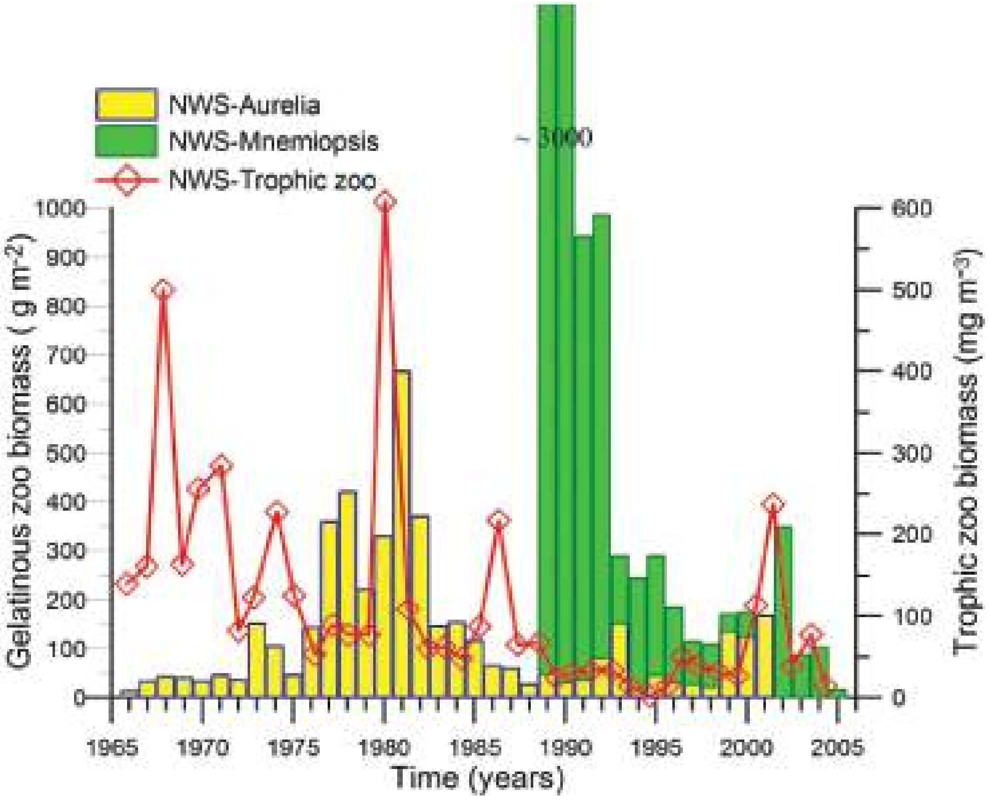

Fig. 6.1a. Long-term biomass changes of *Aurelia, Mnemiopsis* (left axis) and edible zooplankton (right axis) in the northwestern sector of Ukranian shelf waters. No *Aurelia* biomass data were reported after 2001. Data source: YugNIRO, Kerch, Ukraine, sorted out by Dr. A. Grishin, see Velikova V. and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

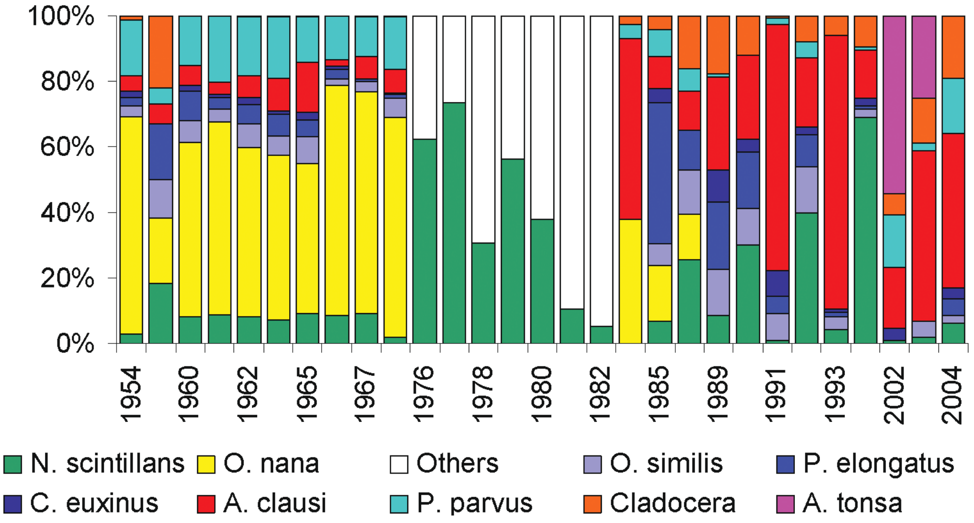

Fig. 6.1b. Long-term changes in abundance (%) of mesozooplankton species in the Northwest part of the Black Sea (after Temnykh et al. 2006).

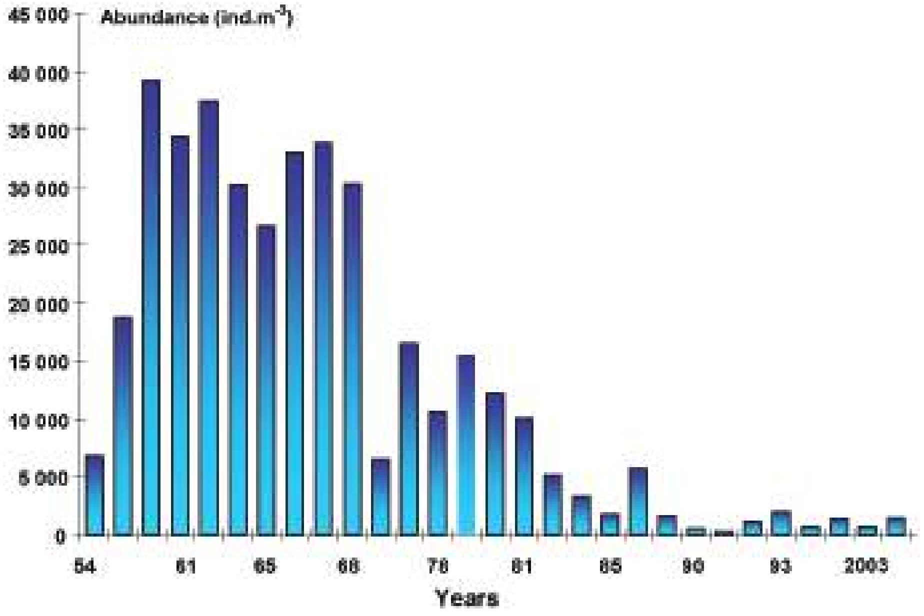

Fig. 6.1c. Long-term changes of mesozooplankton abundance (ind. m^{-3}) in the Northwest part of the Black Sea (after Temnykh et al. 2006).

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. polyphemoide*s	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

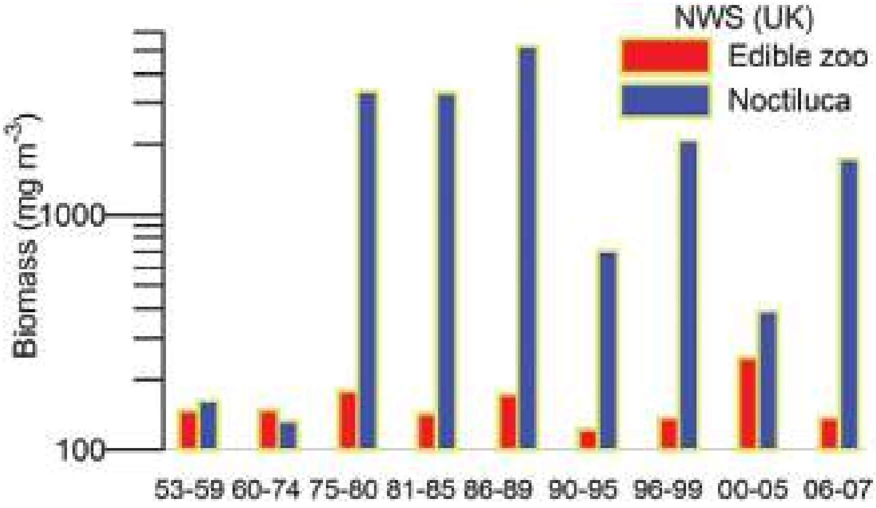

Fig. 6.1d. Biomass (mg·m^{-3}) of edible zooplankton and Noctiluca scintillans in the Ukrainian (UK) coastal waters of the northwestern Black Sea (NWS) during 1953-2007.

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.

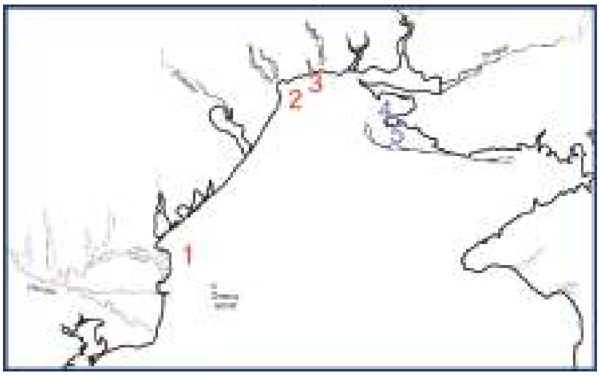

Fig. 6.2. The regions studied most extensively in the NWS coastal waters during 2000-2007: 1 - Danube river mouth (Ukrainian part of the Danube Delta), 2 - Odessa Bay area, 3 - Grygorivsky Liman, 4 - Yagorlytska Bay, 5 - Tendrivska Bay.

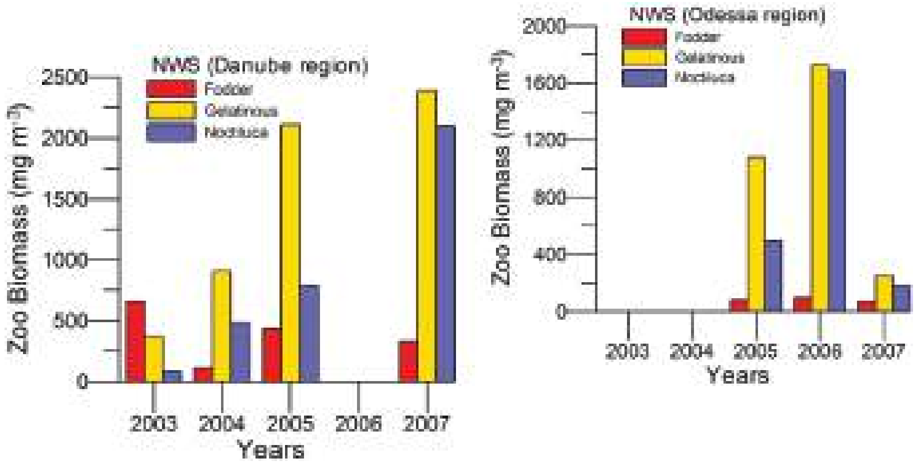

Fig. 6.3. Edible, gelatinous, and Noctiluca biomass changes during 2003-2007 in the Danube discharge and Odessa regions.

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.

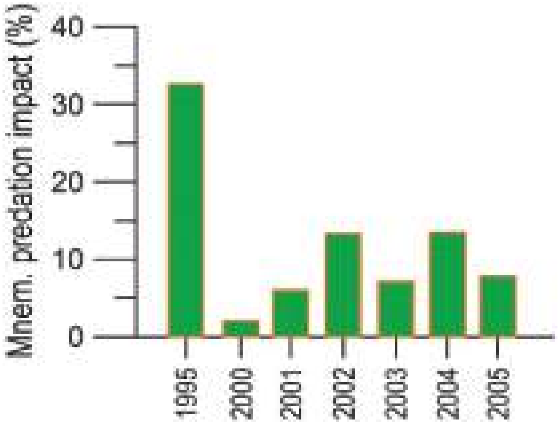

Fig. 6.4a. Mnemiopsis predation impact on mesozooplankton during July in Sevastopol Bay. Data source: Finenko et al. (2007).

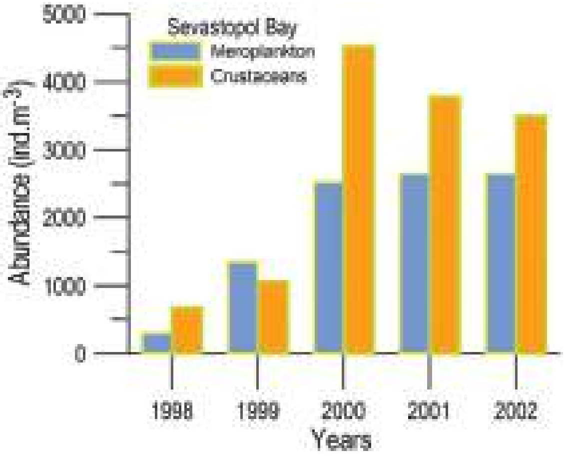

Fig. 6.4b. Meroplankton and Crustacean abundances during spring-autumn 1999-2002 in the Sevastopol Bay. Data source: Finenko et al. (2007).

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).

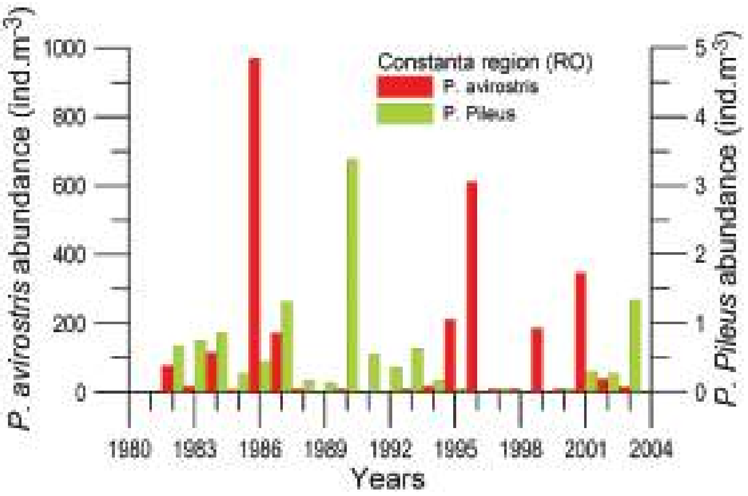

Fig. 6.5. Changes in Penilia avirostris and Pleurobrachia pileus abundances in Constantza region during 1982-2003.

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.

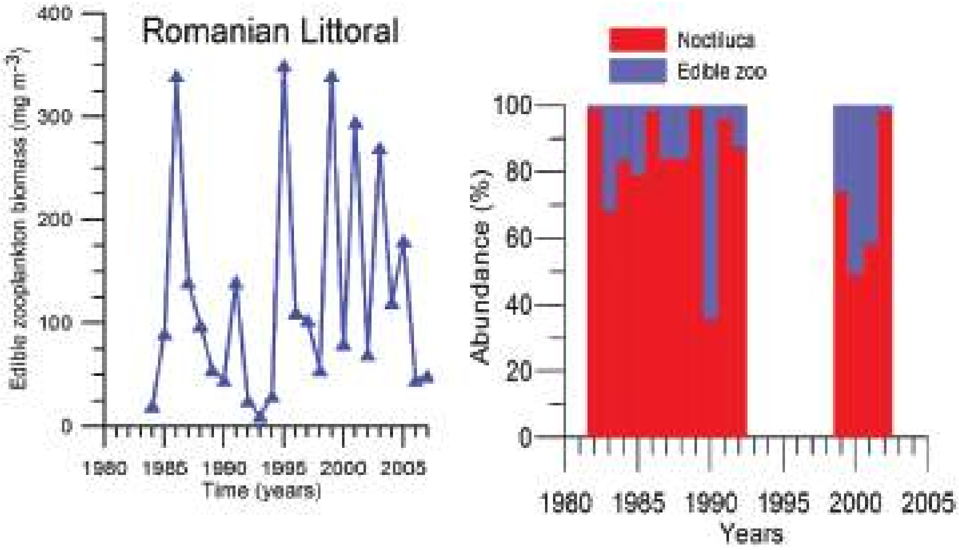

Fig. 6.6. Annual variations of edible zooplankton biomass (left) and relative abundances of edible zooplankton and Noctiluca (right) in the Romanian littoral zone 0-10 m layer.

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).

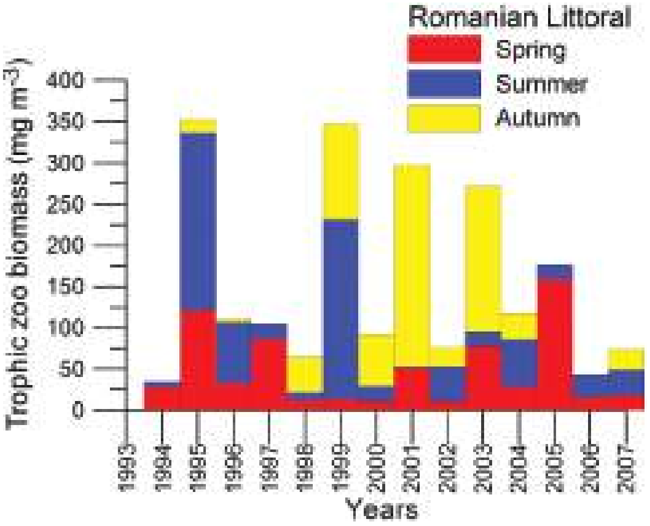

Fig. 6.7. Seasonal changes of trophic zooplankton along the Romanian littoral zone in the upper 10 m layer during 1994-2007.

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.

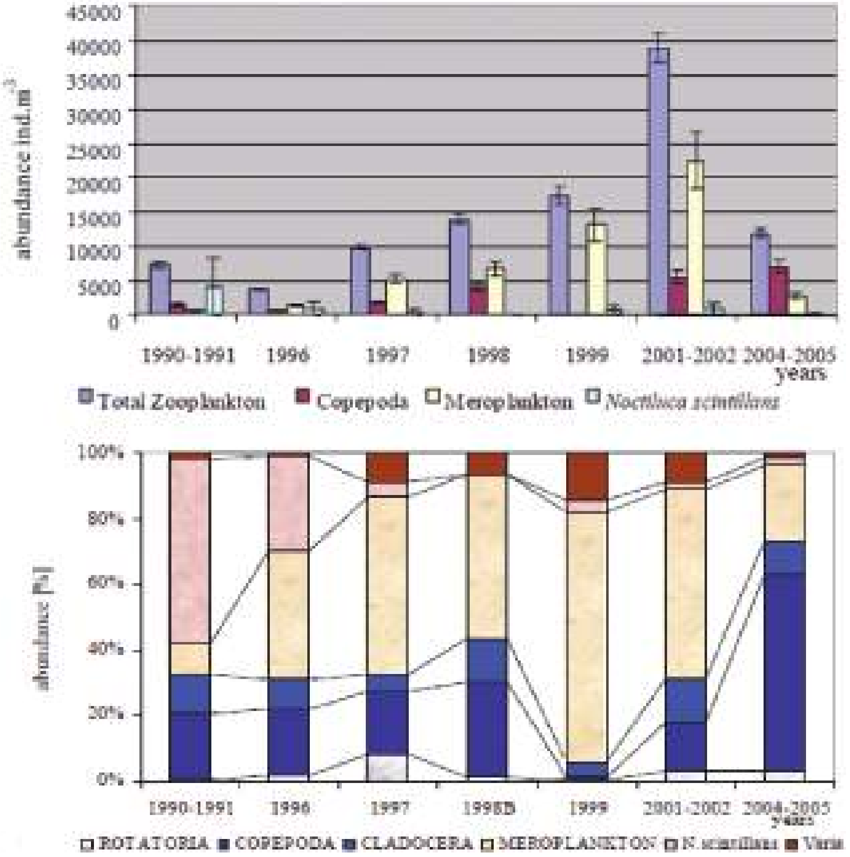

Fig. 6.8. Interannual variations of total zooplankton abundance (ind. m^{-3}) and percent share of key taxonomic groups in Varna Bay.

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 %.

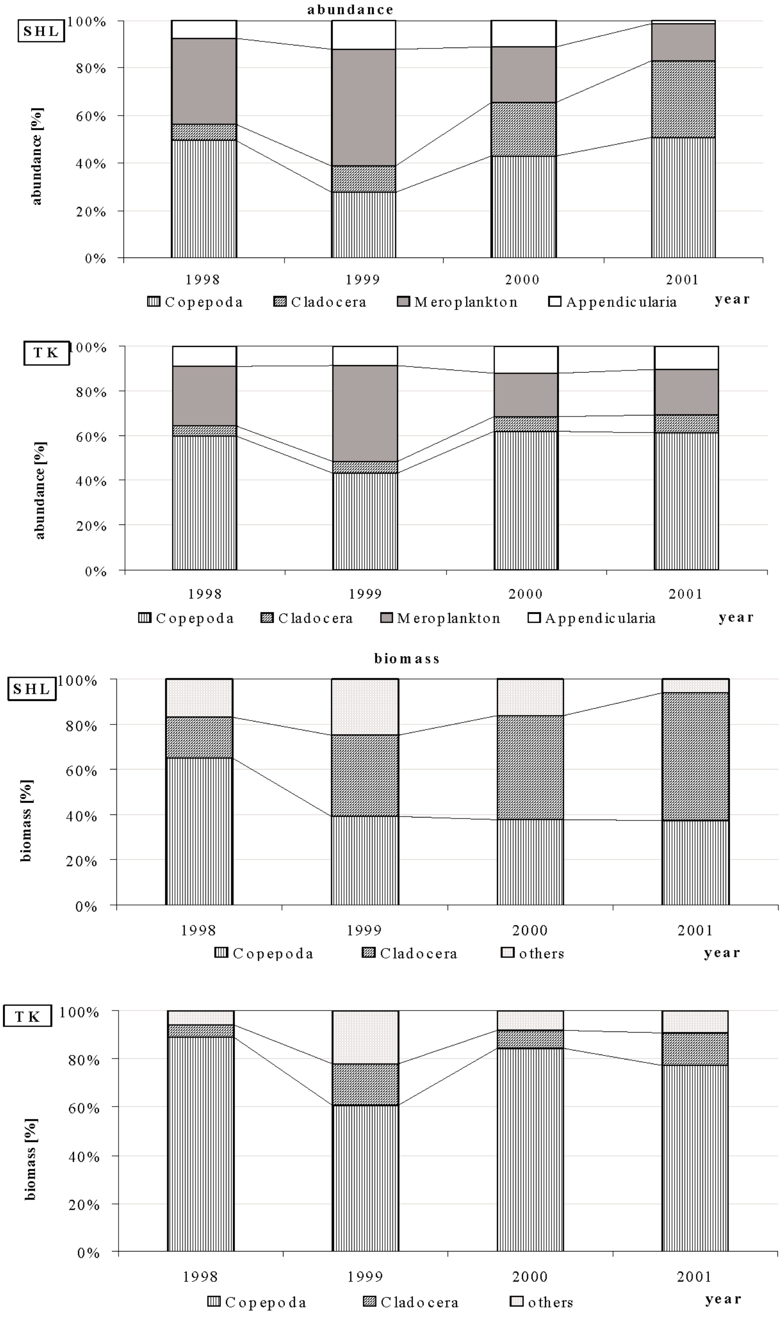

Fig. 6.9. Vertical distribution of total edible zooplankton abundance and biomass by taxonomic groups [in %] in surface homogeneous layer (SHL) and the sub-thermocline layer (TK) off the Bulgarian Black Sea coast during summer period 1998-2001.

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).

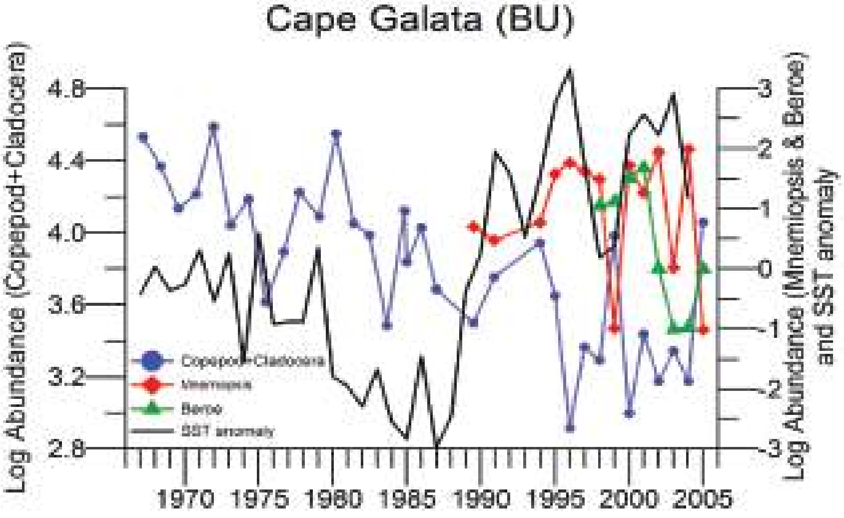

Fig. 6.10. Long-term changes of Copepoda+Cladocera, *M. leidyi* and *B. ovata* abundances (log transformed) and SST anomaly at 3 miles off the Cape Galata during summer 1967-2005 (from Kamburska et al., 2006b).

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	-

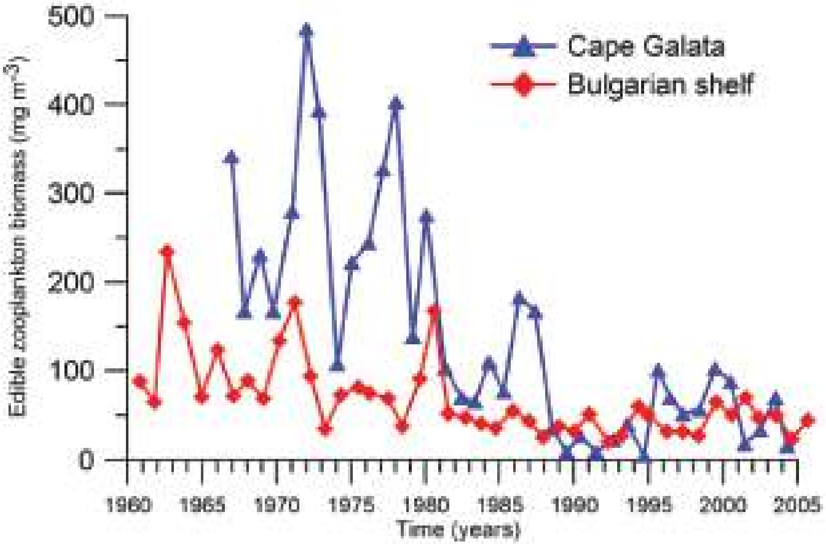

Fig. 6.11. Long-term changes of annual-mean edible zooplankton biomass at 3 miles off the Cape Galata and its average over the Bulgarian coastal waters.

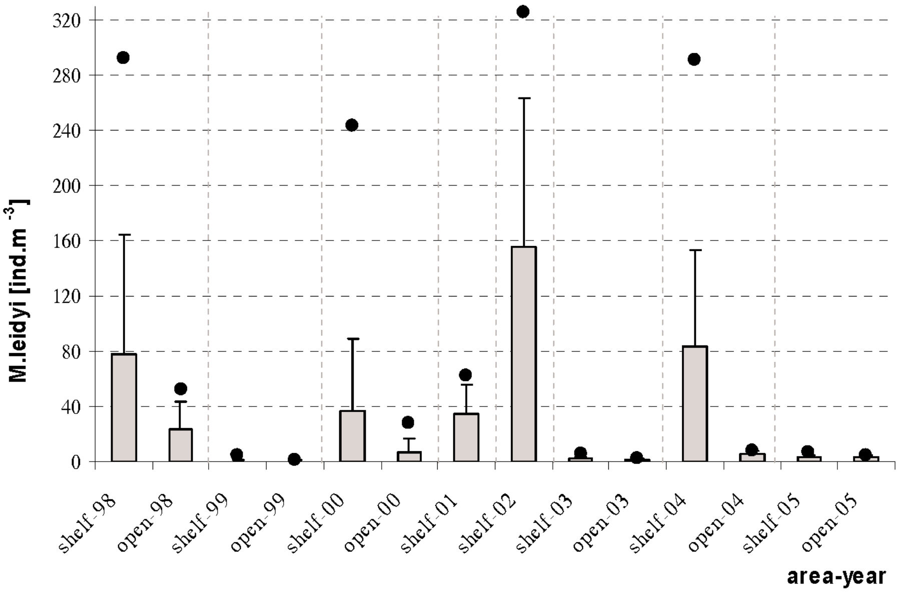

Fig. 6.12. Mean and maximum abundances of Mnemiopsis leidyi [ind.m^{-3}] in the Bulgarian shelf and open sea areas during summer 1998-2005 (number of observations n=172).

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}.

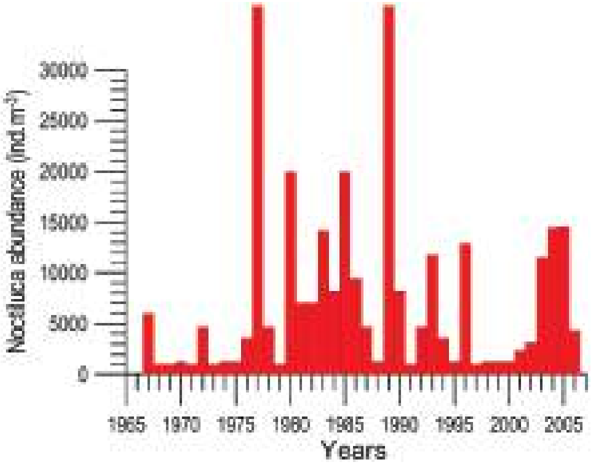

Fig. 6.13. N. scintillans spring-autumn mean abundance (ind.m^{-3}) along the Bulgarian coastal waters.

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*.

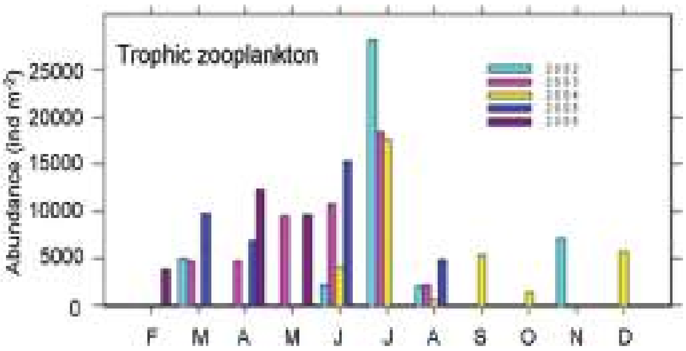

Fig. 6.14a. Seasonal changes of trophic zooplankton abundance along the Bulgarian shelf waters in 2002-2006.

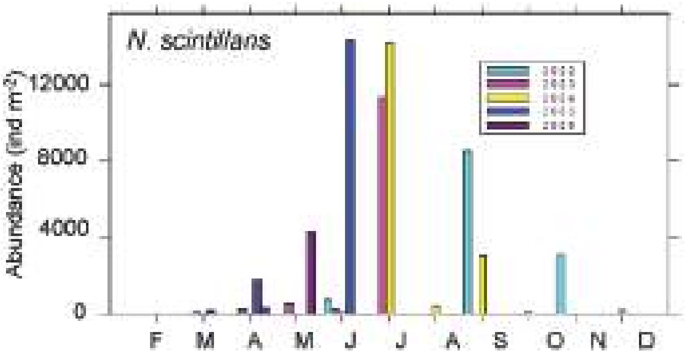

Fig. 6.14b. Seasonal changes of Noctiluca scintillans abundance along the Bulgarian shelf waters in 2002-2006.

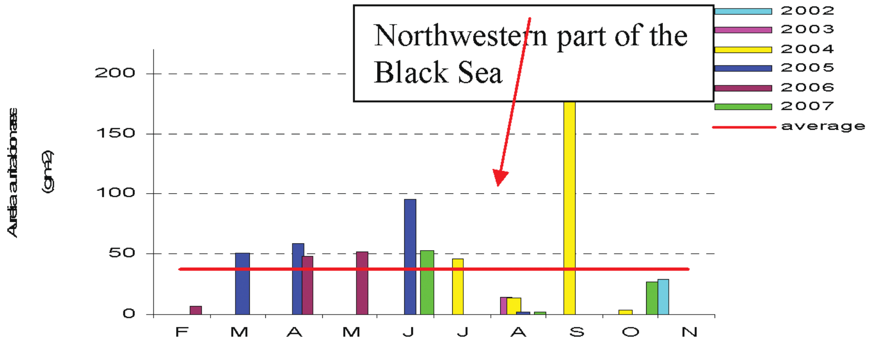

Fig. 6.14c. Monthly changes of *Aurelia aurita* biomass (g m^{-2}) along the Bulgarian shelf waters in 2002-2007 (with data from the north-western region in 09.2004). The red line depicts the average of all monthly data in Bulgarian waters.

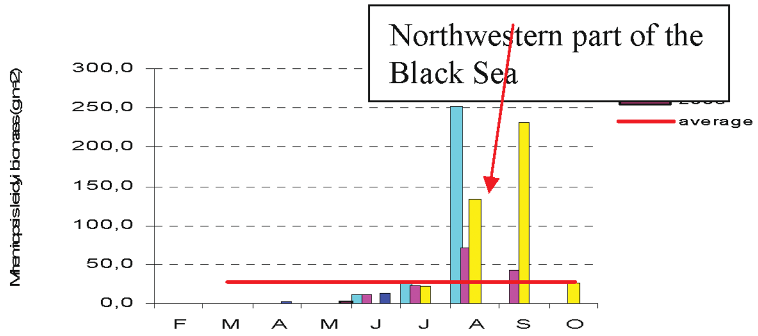

Fig. 6.14d. Monthly changes of *Mnemiopsis leidyi* biomass (g m^{-2}) along the Bulgarian shelf waters in 2002-2006 (with data from the north-western region in 09.2004). The red line depicts the average of all monthly data in Bulgarian waters.

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).

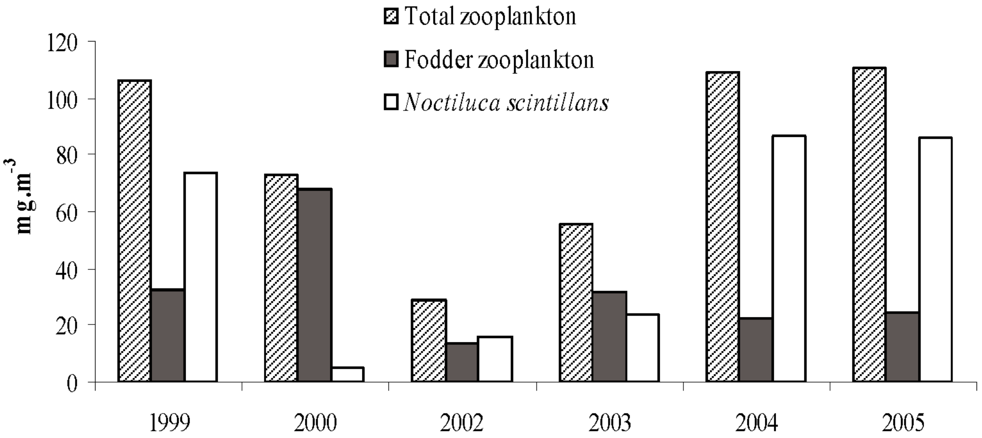

Fig. 6.15. Annual mean biomass (mg.m^{-3}) of the total zooplankton, fodder zooplankton and Noctiluca scintillans off the Cape Sinop (in the central sector of the southern coast) during 1999-2005. Data sources: Unal, (2002), Ustun (2005), Bat et. al. (2007), Ustun et. al. (2007).

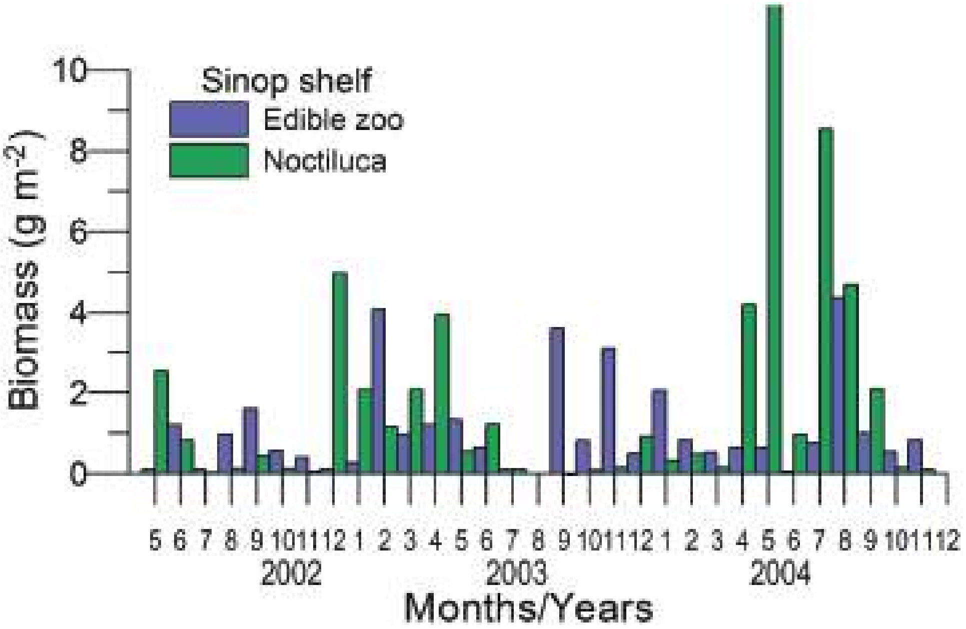

Fig. 6.16. Monthly biomass (g.m^{-2}) changes of edible zooplankton and Noctiluca scintillans off the Cape Sinop (in the central sector of the southern coast) during 2002-2004. Data source: Ustun (2005).

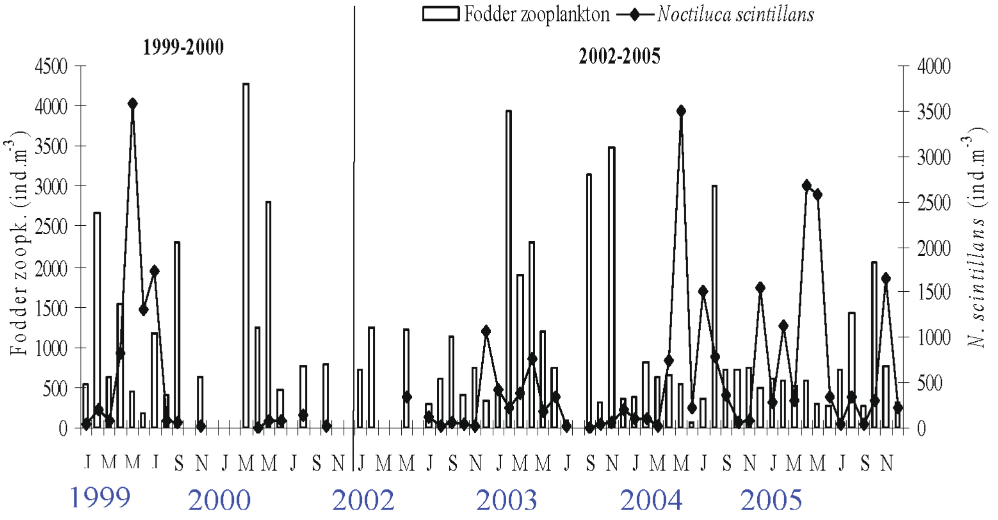

Fig. 6.17. Abundance (ind.m^{-3}) variations of trophic zooplankton and N. scintillans off the Cape Sinop (in the central sector of the southern coast) during 1999-2005.

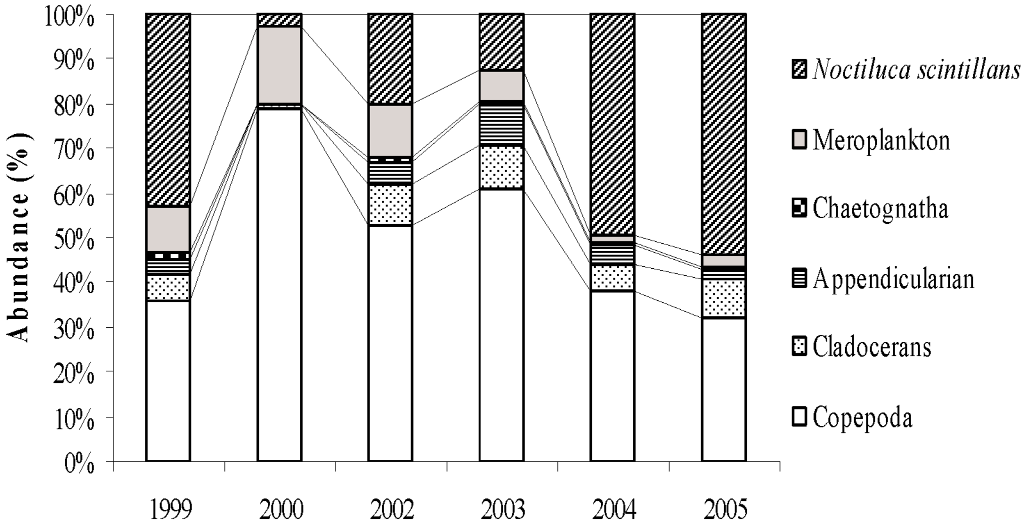

Fig. 6.18. Annual variation of zooplankton community structure abundance (%) in in the sea off Sinop.

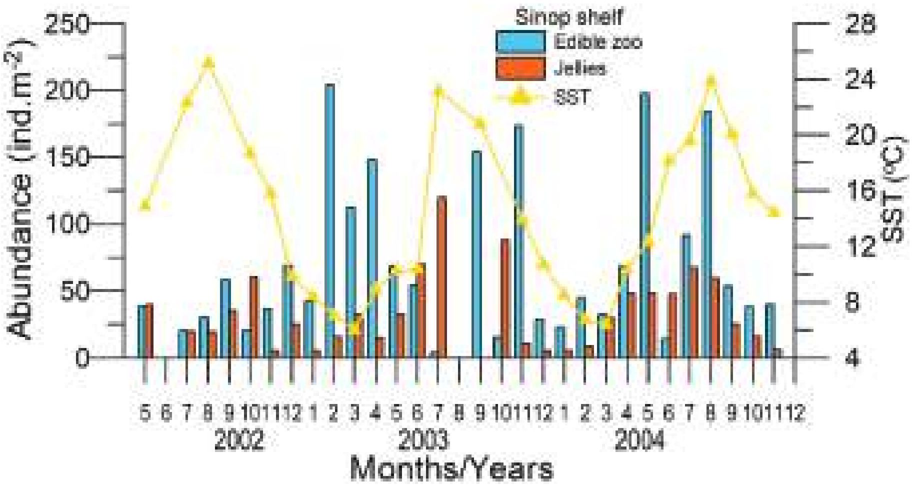

Fig. 6.19. Variations of edible zooplankton and jelly abundance (ind.m^{-3}) and sea surface temperature off the Cape Sinop (in the central sector of the southern coast) during 2002-2004.

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

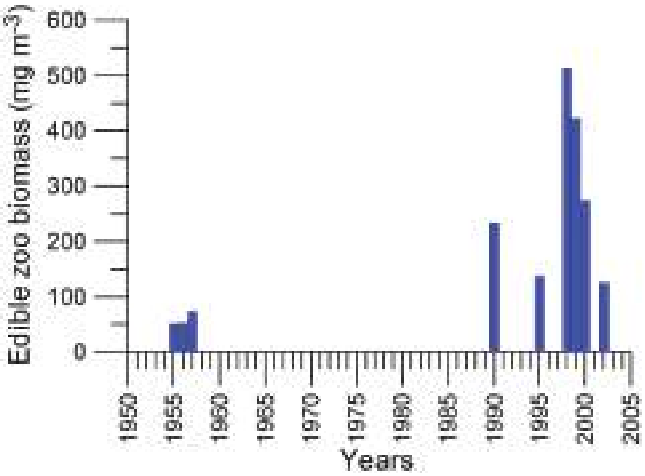

Fig 6.20. Annual-mean trophic zooplankton (Protozoa, Copepoda, Cladocera) biomass (mg m^{-3}) variations in the Georgian waters during 1955-1957 and 1990-2002 within the upper 100 m layer.

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.

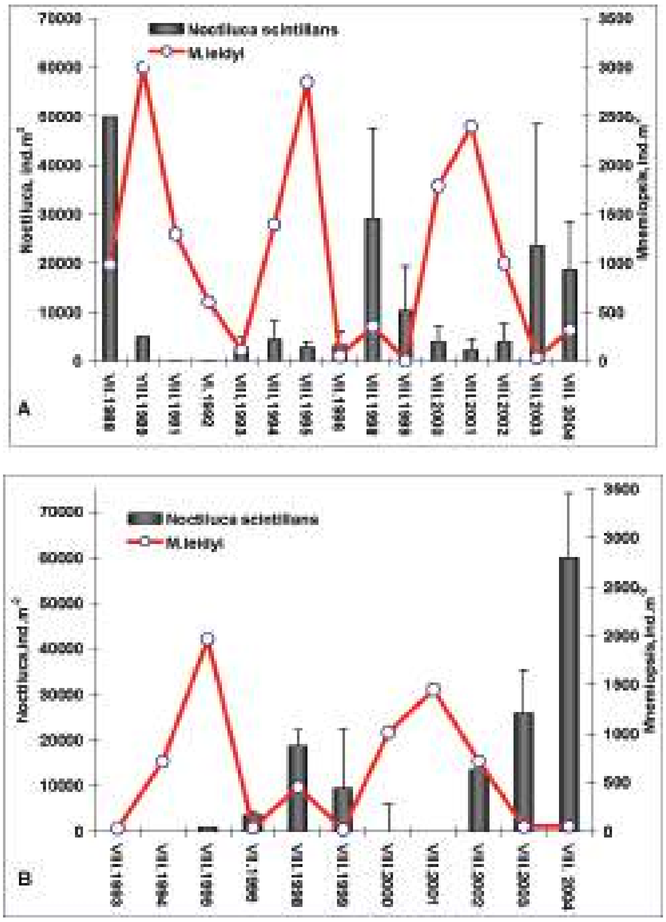

Fig. 6.21. Interannual variations of summer *M. leidyi* and *N. scintillans* abundances indicating their negative correlation for (a) inshore waters ($r = -0.3$) and (b) offshore waters ($r = -0.4$ $p < 0.02$) of the north-eastern basin.

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.

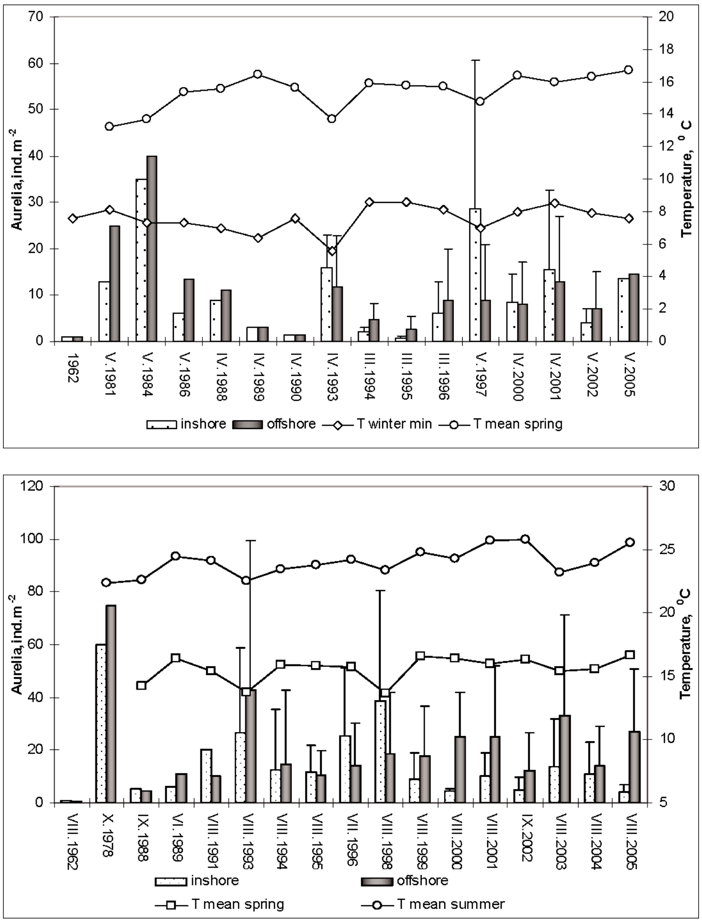

Fig. 6.22. Interannual variations of *Aurelia aurita* abundance in near-shore and offshore waters during (a) spring and (b) summer months, as well as of the mean spring and summer temperatures. The data are complied from various sources: Shushkina and Musaeva (1983); Shushkina and Arnautov (1987); Flint,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

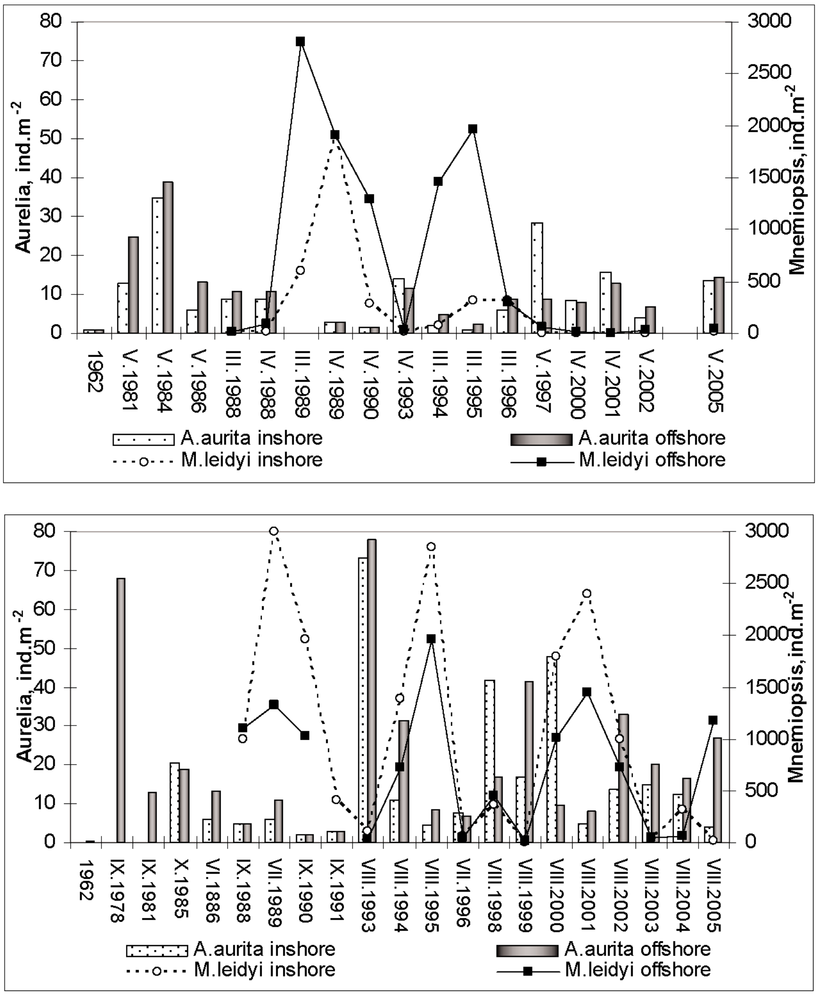

Fig. 6.23. Interannual variations of Aurelia aurita and Mnemiopsis leidyi abundances in coastal and offshore waters of the northestern basin during (a) spring, (b) summer months.

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).

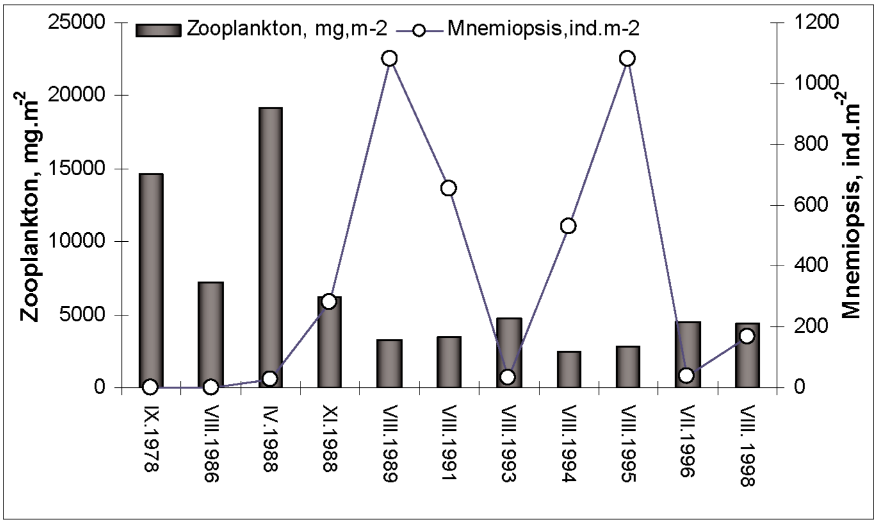

Fig. 6.24. Interannual variations of zooplankton biomass (mg m^{-2}) and M. leidyi abundance (ind. m^{-2}) before the B. ovata appearance.

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).

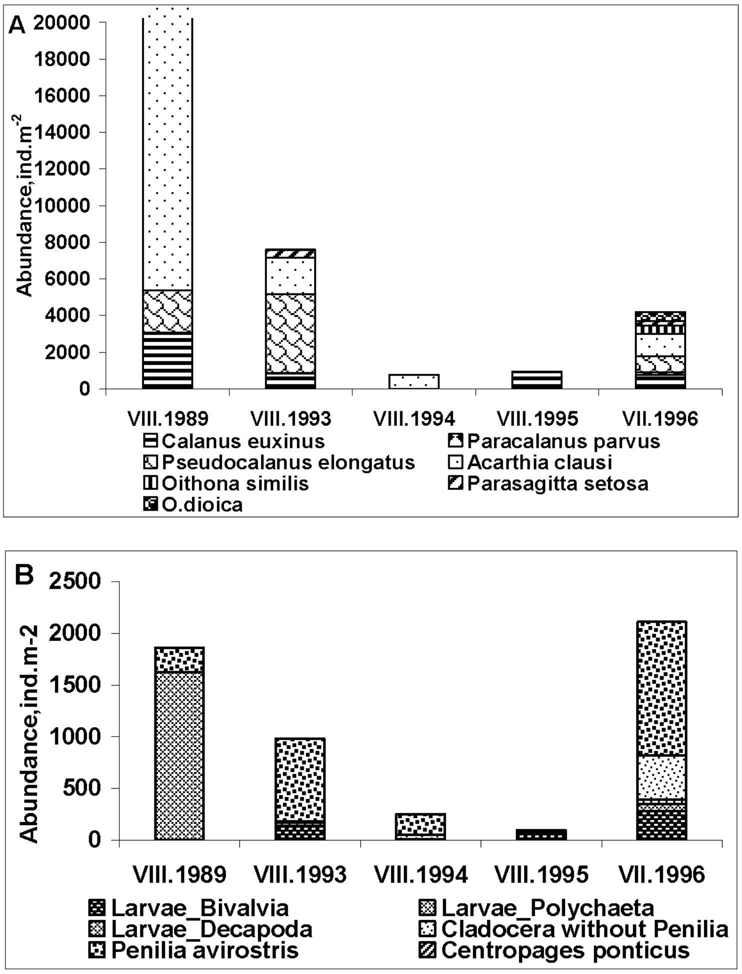

Fig. 6.25. Interannual variations of species composition and abundance of edible zooplankton in the inshore waters in August after the introduction of M.leidyi: (A) coldwater and eurythermal species, and (B) thermophilic species.

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}.

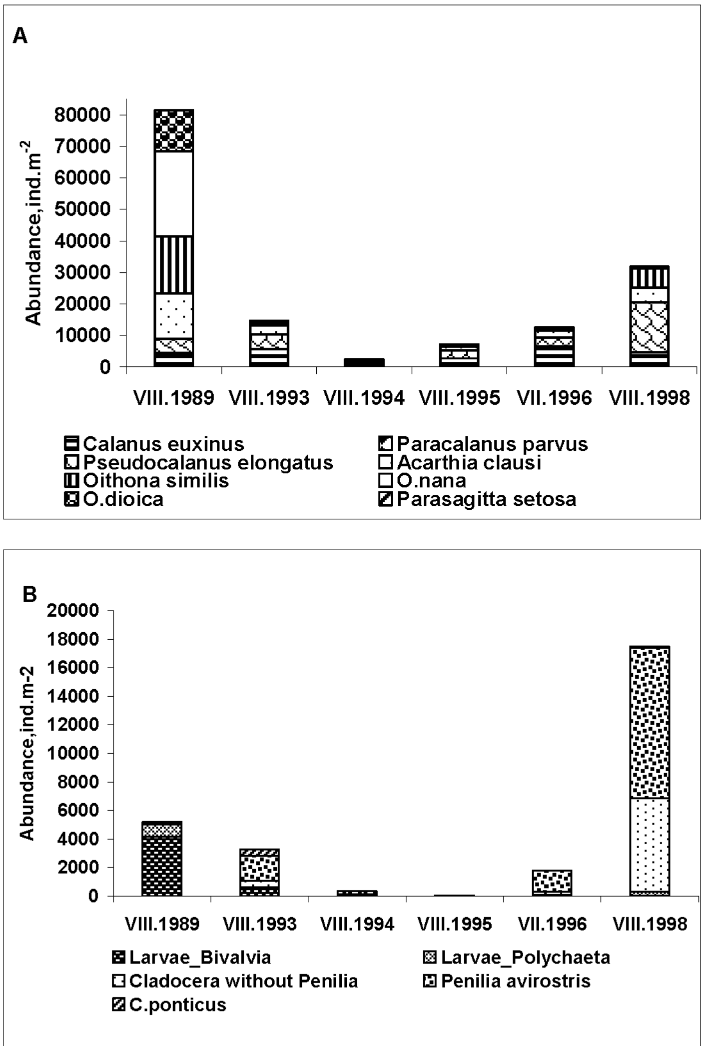

Fig. 6.26. Interannual variations in the species composition and abundance of edible zooplankton in the open sea waters in August after the introduction of M.leidyi: (A) coldwater and eurythermal species and (B) thermophilic species.

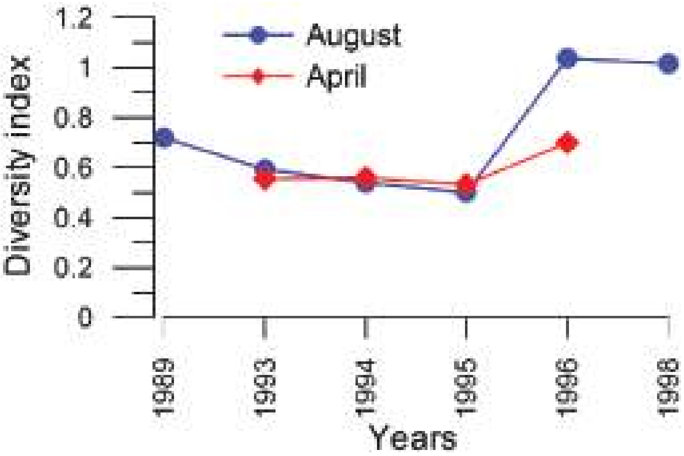

Fig. 6.27. Interannual variations in zooplankton biodiversity index of edible zooplankton (as an average of the inshore and offshore data) in the spring and August after the introduction of *M. leidyi*.

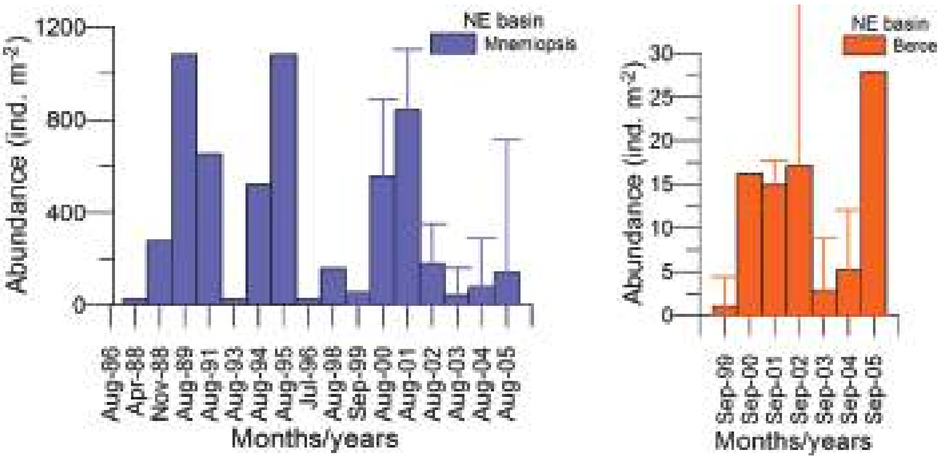

Fig. 6.28. Interannual variations of Mnemiopsis and Beroe abundances (ind.m^{-2}) in August and September, respectively.

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).

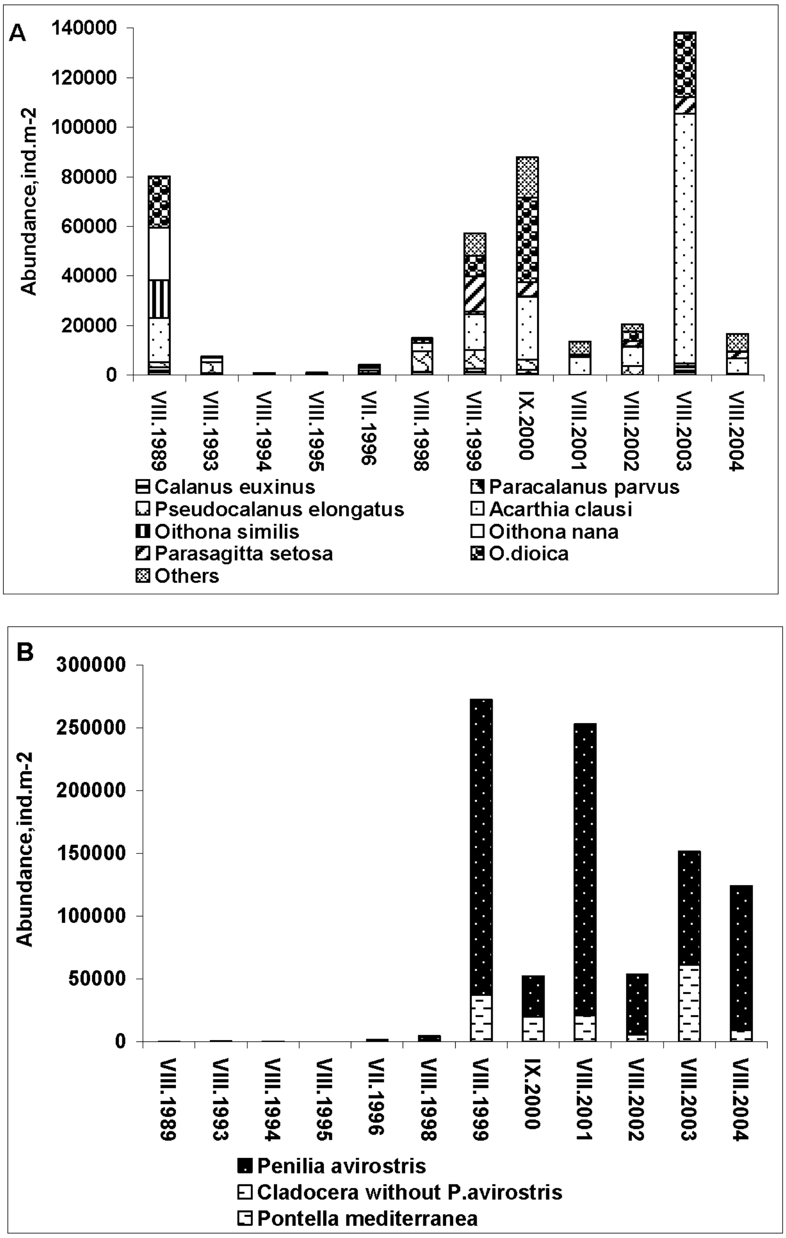

Fig. 6.29. Interannual variations in the species composition and abundance of edible zooplankton in the inshore waters in August: (A) coldwater and eurythermal species and (B) thermophilic species.

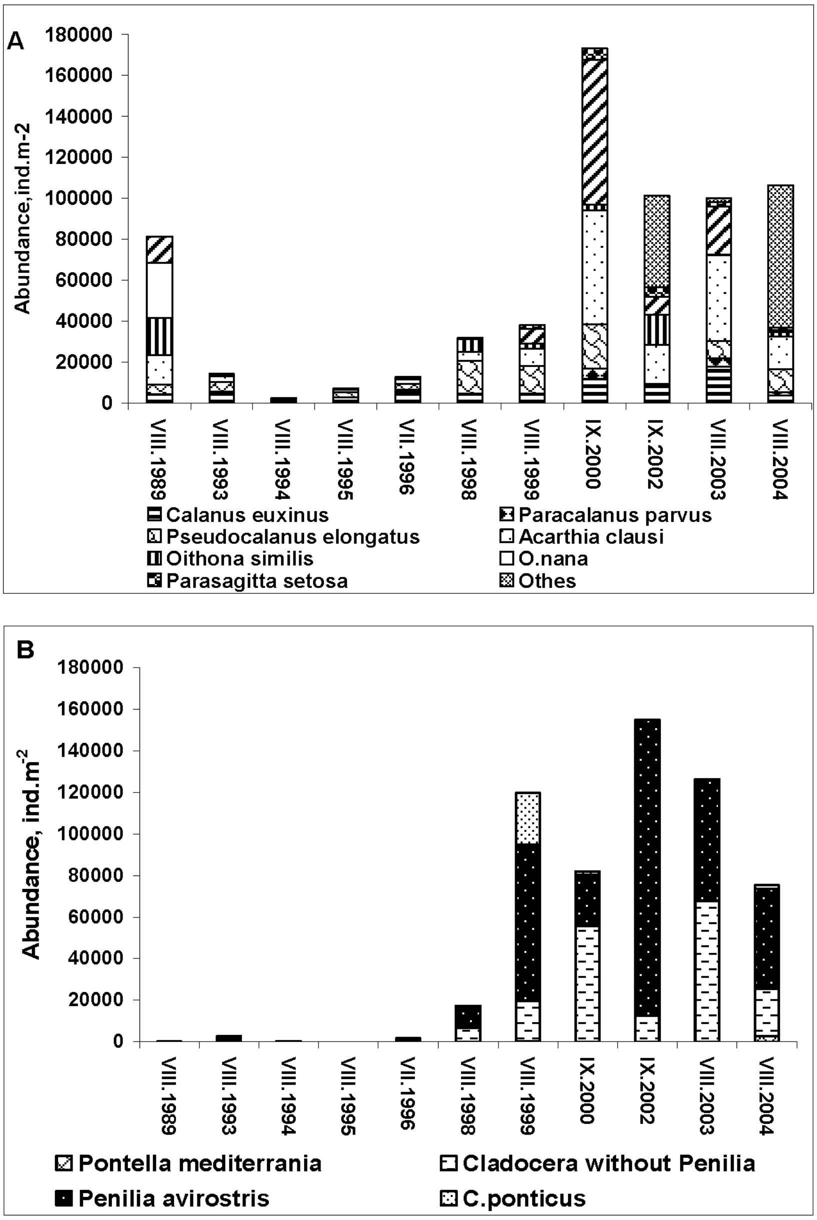

Fig. 6.30. Interannual variations in the species composition and abundance of zooplankton in the open sea waters in August: (A) coldwater and eurithermal species and (B) thermophilic species.

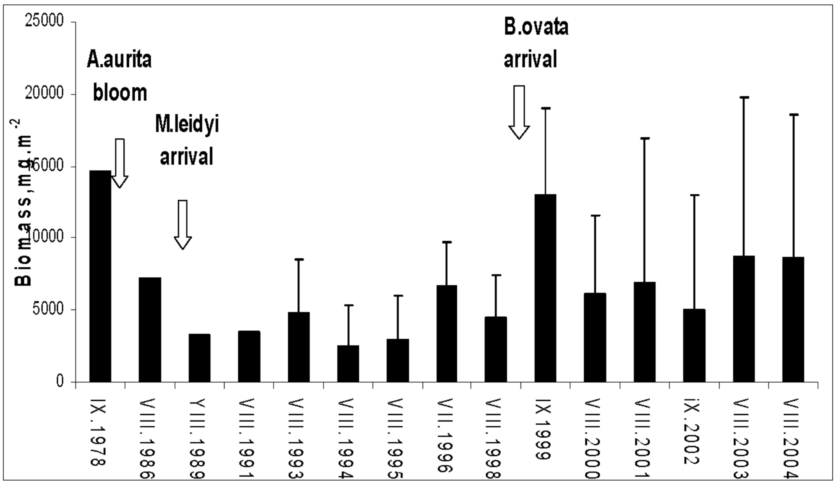

Fig. 6.31. Long-term changes of edible zooplankton biomass in the northeastern Black Sea during August-September, 1978-2004. The data for 1978-1991 were taken by Vinogradov et al. (1992) and for 1993-2004 by Shiganova et al. (2004).

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.

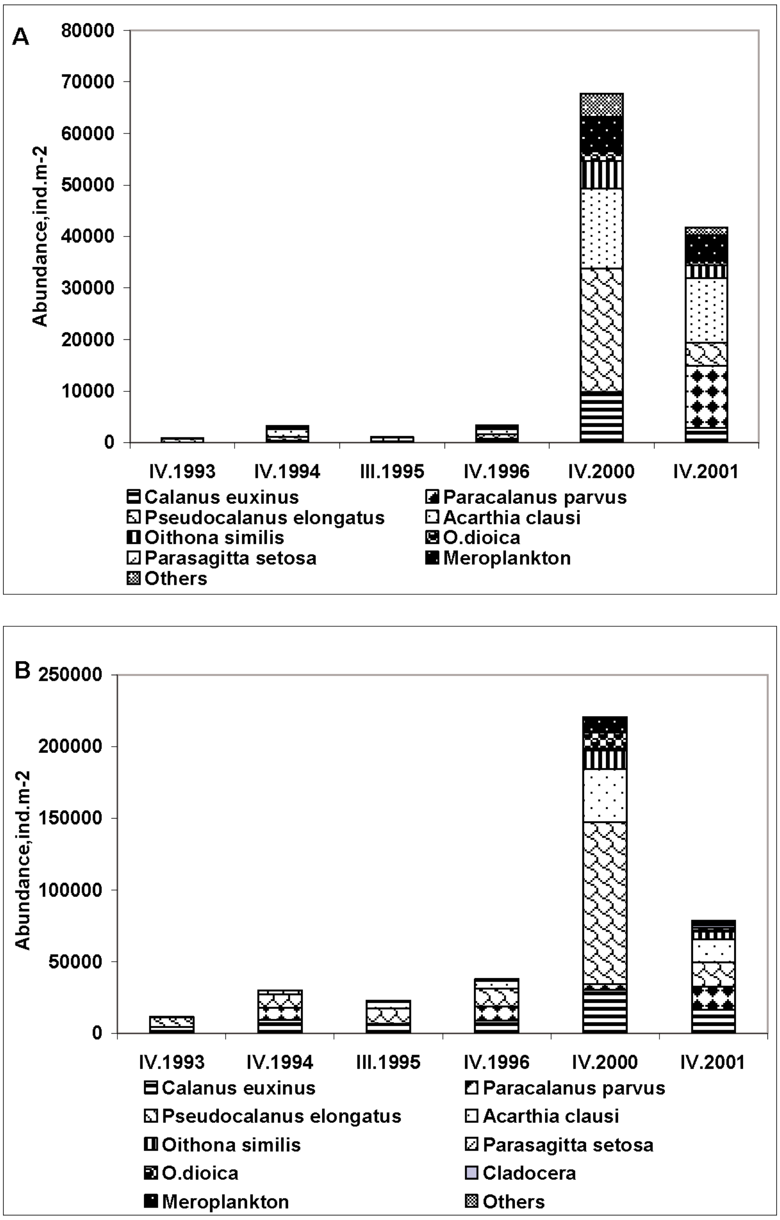

Fig. 6.32. Interannual variations in the species composition and abundance of edible zooplankton in the spring: (A) in the inshore zone and (B) in the open sea waters.

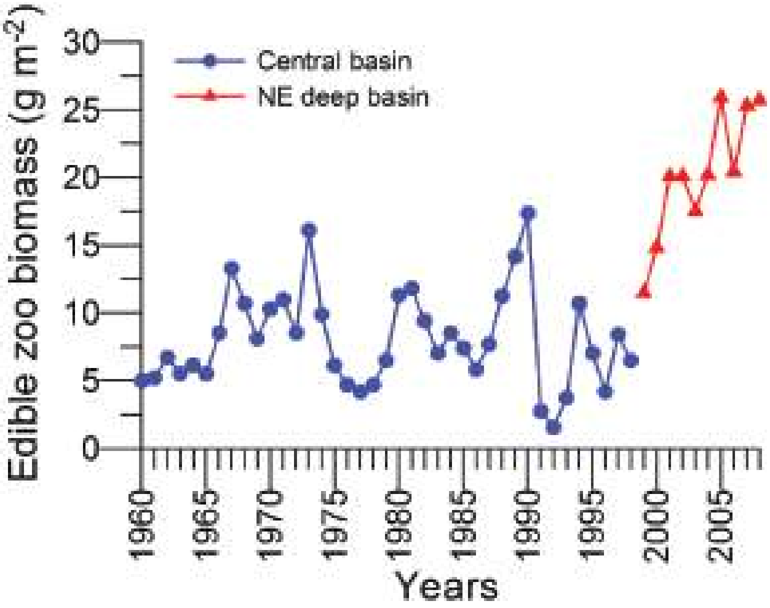

Fig. 6.33. long-term changes of edible zooplankton biomass within the deep interior basin of the Black Sea. The data shown by dots and triangles are provided by Kovalev et al. (1998) and Arashkevich et al. (2008a) for the northeastern basin.

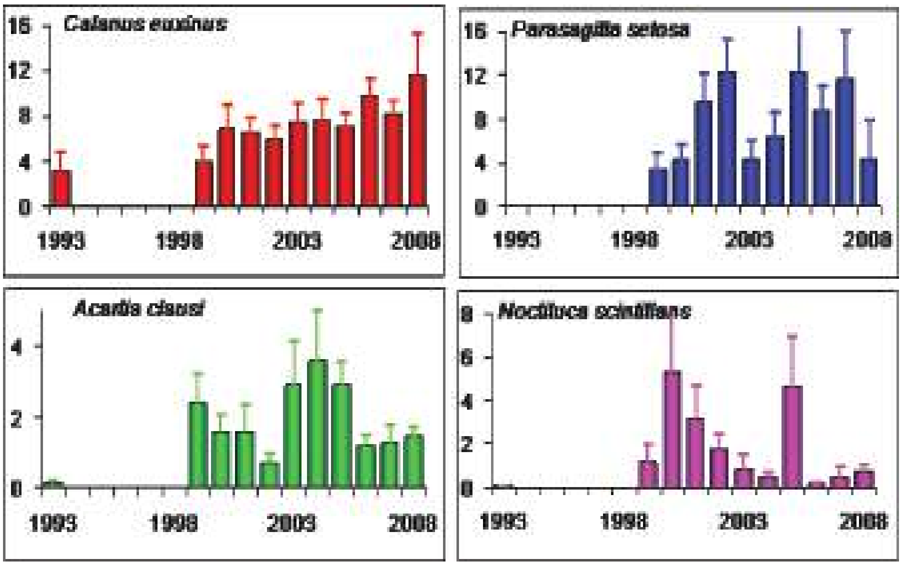

Fig. 6.34. Inter-annual biomass (g m^{-2}) variations of dominant zooplankton groups during 1998-2008 (after Arashkevich et al., 2008a).

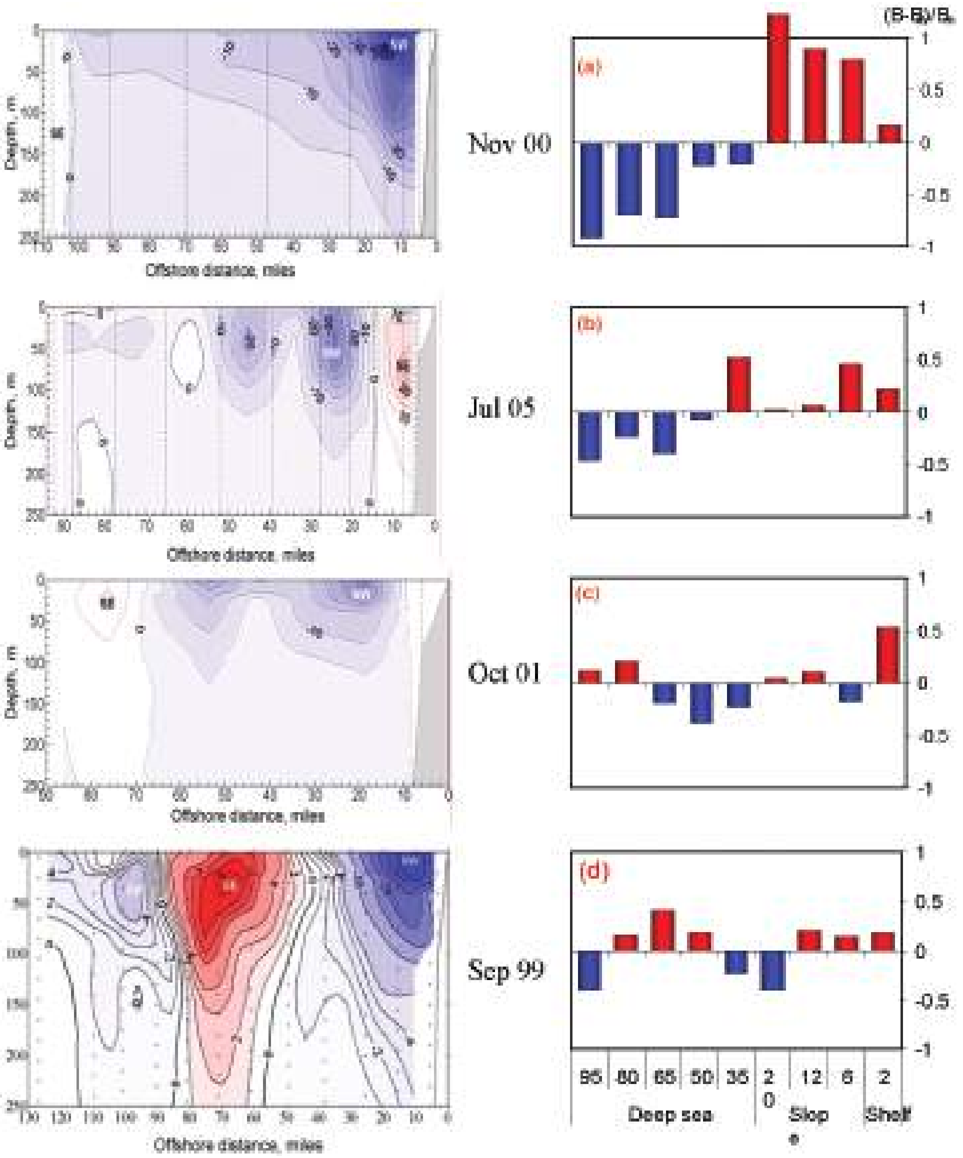

Fig. 6.35. The relation between mesoscale variability of the circulation system (left) and zooplankton biomass distribution (right) along an offshore-onshore transect in the NE basin. Zooplankton biomass was expressed by its normalized difference with respect to the mean biomass of each set of measurements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

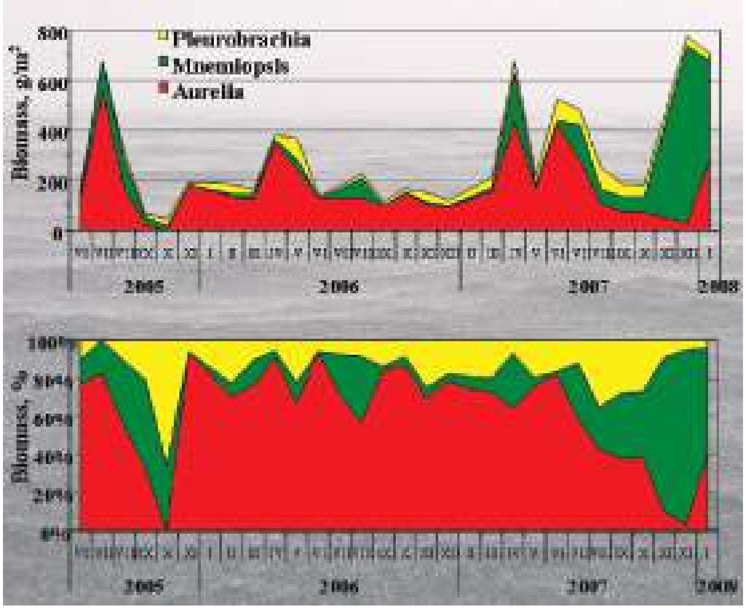

Fig. 6.36. Monthly changes of gelatinous predators Aurelia, Mnemiopsis, and Pleurobrachia as the mean of measurements at three stations within the northeastern coastal waters during 2005-2007 (after Araskevich et al., 2008b).

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.

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CHAPTER 7 THE STATE OF MACROPHYTOBENTHOS
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7.1. Introduction

The Black Sea bottom algoflora is the impoverished derivative of the Mediterranean one. The species list today comprised 80 Chlorophyta, 76 Phaeophyceae and 169 Rhodophyta (Milchakova, 2002; 2003a,b, 2007). Many of them, however, have either disappeared completely or impoverished, whereas some others flourished during the last decades due to the severe impact of eutrophication on the bottom phytocoenosis. The most well-known sign of the transformations in macrophytobenthos community was the loss of *Phyllophora* in the region of Zernov's Phyllophora Field of the northwestern Black Sea. The drastic decrease of macrophytes diversity and almost total disappearance of perennial algae were among the most important changes that had occurred as a result of natural and man-made factors. Given the importance of macroalgae as food and refuge for animals, as well as source of external metabolites and oxygen, their decline affected the entire benthos life. The present chapter reviews the recent changes took place in the macrophytobethos community and assesses its recent status in different coastal environments of the Black Sea

7.2. Ukrainian shelf area

More than 70% of species diversity of macroalgae as well as six species of higher flowering plants (*Zostera marina* L., *Z. noltii Hornem., Zannichellia major* Boenn. Ex Reichenb, *Ruppia cirrhosa* Grande, *R. maritime* L., *Potamogeton pectinatus* L., and highly developed algae from the phylum *Charophyta*) have been present in the northwestern sector of the Black Sea, including the Crimean coastline. The region extending from the Danube Delta (Zmeiny Island) to Tarkhankut Cape 45°N latitude and the Crimean coastal zone are two particular areas with different floristic composition and structural-functional organization of macrophytobenthos communities. The former is affected by the runoff from large rivers (Danube, Dniester, Bug, and Dnepr) and includes numerous limans and shallow water bays. The second region is characterized by a large amount of hard substrate and embayments suitable for settling of macrophytes. Higher salinity and lower level of eutrophication also support richer species diversity. While ~50% of species composition was made up of representatives of red algae in both areas, lower salinity and higher eutrophication in the northwestern part prevailed the development of green algae and to a lesser extent the brown algae (Table 7. 1 and Fig. 7.1).

Table 7.1. Number of macroalgae species (underlined) and its percentage (bold) in the total floristic composition of the northwestern coastal waters of the Black Sea (Milchakova, 2007; Eremenko, Minicheva, Kosenko, 2006).

Area	**Taxonomic phyla**			**Total**
	Chlorophyta (Green algae)	Phaeophyta (Brown algae)	Rhodophyta (Red algae)	
Northwestern coast	54 **29**	45 **24**	87 **47**	186* **57****
Crimean coast	56 **24**	62 **27**	115 **49**	233 **71**

* - number of species

** - percentage of Black Sea floristic composition

Fig. 7.1. Photos for the brown algae Cystoseira barbata (left), Desmarestia viridis (center) and the red algae Polysiphonia elongata (right).

The long-term changes in the species composition of algae of the Zernov's Phyllophora Field are summarized in Table 7.2. During the 1970s of intense eutrophication, the greatest change in the phytobenthos structure of the northwestern shelf was the disappearance of the brown algae *Cystoseira barbata* (Fig. 7.1) from the coastal phytocenose of the Danube - Dnepr interfluves. However, other brown algae of arctic-boreal flora, *Desmarestia viridis* (Fig. 7.1) was introduced into this area in the 1990s that then spread rapidly and became the dominant species in the cold periods of the year along the Odessa coast within the next 5-6 years. Massive covering of *D. viridis* thallus with dimensions of 30-50 cm have been often observed along the beaches in

March - April. Its specific surface of the population index [(S/W)p], that indicates the amount of active thalloma surface per 1 kilogram mass of the macrophyte population, reached 70 m2 kg -1. Besides, the early 1990s of the northwestern Black Sea experienced intense developments of red algae Polysiphonia sanguinea and Pylaiella littoralis with high (S/W)p index values of 78.3 ± 1.9 m^2 kg $^{-1}$ and 140.2 ± 5.1 m^2 kg $^{-1}$, respectively.

Table 7.2. Long term changes in the species composition of algae of the Zernov Phyllophora Field.

Species	1964*	1986*	1989*	2004	2006	2008
Chlorophyta						
Bryopsis plumosa (Huds.) C.Ag.	+	+	-	-	+	-
Chaetomorpha mediterranea (Kutz.) Kutz.	-	-	+	-	-	-
Cladophora albida (Nees) Kütz.	+	+	-	+	-	+
C. liniformis Kütz.	-	+	-	-	+	-
Ulva rigida Ag.	-	-	-	-	-	+
Enteromorpha compressa (L.) Nees	+	-	-	-	-	-
Rhizoclonium tortuosum (Dillw.) Kütz.	-	-	-	+	-	-
Stigeoclonium tenue Kutz.	-	-	-	-	-	+
Ulothrix implexa Kutz.	-	-	-	-	-	+
Ochrophyta						
Cladostephus spongiosus f .verticillatus	+	+	+	-	-	-
Cystoseira barbata (Gooden et Woodw.)C. Ag.	+	+	-	-	-	-
Feldmannia irregularis (Kütz.) Hamel.	+	+	-	-	+	-
Ectocarpus fasciculatus Harv.	+	-	-	-	-	+
E. siliculosus (Dillw.) Lyngb.	+	-	-	-	-	+
Giraudya sphacelarioides Derb.et Sol.	+	-	-	-	-	-
Ralfsia verrucosa (Aresch.) J. Ag.	+	-	-	-	-	-
Stictyosiphon adriaticus Kütz.	+	-	-	-	-	-
Stilophora rhizodes (Ehrh.) J. Ag.	+	-	-	-	-	-
Sphacelaria cirrosa (Roth.) Ag.	+	-	-	-	+	+
S. saxatilis (Kuck.) Sauv.	+	+	-	-	-	-
Striaria attenuata (C. Agardh) Grev.	+	+	-	-	-	-
Spermatochnus paradoxus (Roth.) Kütz.	+	-	-	-	-	-
Desmarestia viridis (O. Mull. in Hornem.)	-	-	-	-	+	-
Rhodophyta						
Acrochaetium savianum (Menegh.)	-	-	-	-	-	+
Rhodochorton purpureum (Lightf.) Rosevn.	+	-	-	-	-	+
Antithanmion cruciatum (Ag.) Näg.	+	+	-	-	-	-
Callithamnion corymbosum (Sm.) Lyngb.	-	-	-	-	+	-
Ceramium diaphanum (Lightf.) Roth	+	+	+	+	-	+
C. deslonchampii Chauv.ex Duby	+	-	-	-	-	-
Dasyopsis apiculata (Ag.) A. Zin.	+	-	-	-	-	-
Lithothamnion sp.	+	-	-	+	-	+
Lomentaria clavellosa (Turn.) Gail.	+	-	-	-	-	+
Lophosiphonia obscura (Ag.) Falkenb.	+	+	+	-	-	-
Pneophyllum fragile Kütz.	+	-	-	+	+	+
Peyssonnelia rubra (Grev.) J. Ag.	+	-	-	+	-	+
Phyllophora truncata (Pall.) Zinova	+	+	+	+	+	+
Ph. crispa (Huds.)P.S.Dixon	+	+	+	+	+	+
Ph. pseudoceranoides (S.G.Gmel.) Newr., Tayl.	+	+	+	-	+	+
Polysiphonia denudata (Dillw.) Kütz.	+	+	-	-	-	+
P. elongata (Huds.) Harv.	+	+	+	+	+	-
P. sanguinea (Ag.) Zanard.	-	-	-	+	+	+
Total number of species	31	16	8	10	12	19

* Kalugina-Gutnik and Evstegneeva (1993) and Milchakova (2003a), Tsarenko, Wasser and Nevo (2006).

Table 7.3. Variability of morphological structure of thallus for some common macroalgae of the Ukrainian coast.

Structural element	**Specific surface (S/W)p, m2.kg-1**		
	Cystoseira barbata	Polysiphonia elongata	Desmarestia viridis
Main axis (stem)	2.78 ± 0.17	3.70 ± 0.02	13.62 ± 0.36
Lateral branches, 1-st order	5.84 ± 0.71	4.60 ± 0.11	23.90 ± 0.49
Lateral branches, 2-nd order	11.87 ± 0.45	6.10 ± 0.10	37.98 ± 0.80
Lateral branches, 3-rd order	14.82 ± 0.52	18.80 ± 0.49	68.68 ± 2.35
Apical branches	18.42 ± 0.82	88.50 ± 2.18	102.75 ± 2.78
Total for thallus	11.62 ± 0.42	26.88 ± 3.21	76.72 ± 3.56
S/W variability for thallus (%)	135	315	103

In the 1990s, expansion of *P. elongata* of the *Polysiphonia* genus was also recorded in the northwestern part of the Black Sea. *P. elongata* was constantly observed in communities of the Crimean coastal zone in eutrophic and oligotrophic reserve areas (Karadag, Tarkhankut, and Utrish) as well as along the northwestern coast (Milchakova and Kireeva, 2000). Both thick main branches and very thin posterior branches with two-fold greater (S/W)p indices of *P. elongata* with respect to *Cystoseira* and *Phyllophora* (Table 7.3) provided a high intensity metabolic processes and adaptation to diverse conditions in eutrophic and oligotrophic waters at depths up to 50 m, and thus successfully taking over the vacant ecological nich in the mid-1990s.

Severe eutrophication in the northwestern Black Sea has therefore led to a distinct dynamics of structural-functional organization of macrophyte communities. The species with (S/W)p < 15 m^2 kg^{-1} ceased to develop due to the increasing level of eutrophication during the early 1970s and 1980s (Minicheva, 1998), (Fig. 7.1A). In this period Cystoseira was replaced by algal communities of the genus Ceramium, Cladophora, Enteromorpha and the total phytobenthos biomass declined from 3.0 kg.m^{-2} to 1.0-1.5 kg.m^{-2}.

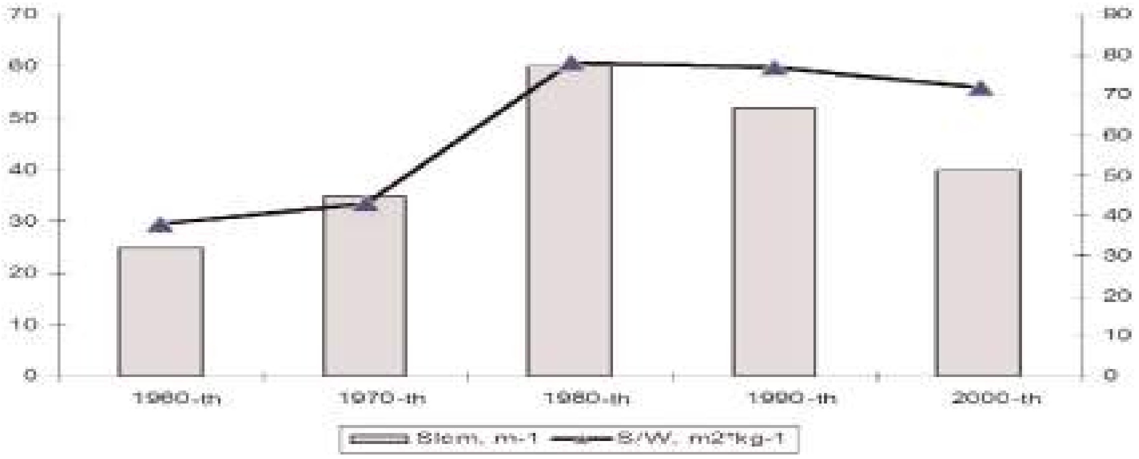

Fig. 7.1A. Dynamics of changes in surface index (SIcm) and average value of specific surface (S/W) of species composition of phytobenthos of the Danube-Dnepr interfluves.

The end of the 1980s and the early 1990s may be considered as the period of stabilization. This was followed by a significant reduction in the productivity of opportunistic algae species after the mid-1990s that suggested weakening of the eutrophication process. In the autumn 2004, July 2006 and March 2008 surveys, some of the extinct species of Zernov's *Phyllophora* field have been emerged again. The finely branched, ecologically active *P. sanguinea* began to develop in communities of *Phyllophora crispa* = *Phyllophora nervosa* with (S/W)p = 10.4 m^2 kg^{-1} and *Phyllophora truncata* = *Phyllophora brodiaei* with (S/W)p = 11.5 m^2 kg^{-1}, forming up to 20-30% of the vegetative biomass in the summer period. The expansion of *P. elongata* at the beginning of the present decade may be considered an intermediate stage in the restoration process, the length of which depends on the rate of decrease of the eutrophication and the climatic conditions. If the present day tendency persists, it is quite possible to expect restoration of the *Cystoseira* community in the Danube-Dnepr interfluves and more favorable conditions for development of *Phyllophora* on the northwestern shelf. Table 7.4 summarizes four stages in the transformation of the macrophytobenthos of northwestern Black Sea.

The decreasing trends in average macrophyte biomass and production (Fig. 7.2) also support restoration of the system along the northwestern coast. The sharp peaks in 2002-2003 suggest the impact of anomalous climatic conditions. The winter of 2002-2003 was the coldest one in the last 50 years (Adobovskiy and Bolshakov, 2004) which altered the seasonal dynamics of macrophytes. The Odessa coastal zone was characterized by an intense development of winter species *D. viridis, Punctaria latifolia* Grev., and *Ectocarpus confervoides* (Roth.) Le Jolis until the mid-June 2003 but dominated by *Enteromorpha intestinalis* (L) Link and *Cladophora laetevirens* (Dillw.) Kutz in June- July 2003. The data therefore suggest that such anomalous future climatic conditions may introduce important biological changes in addition to the effects of eutrophication processes.

The stages shown in Table 7.4 for the changes of the coastal phytobenthos structure coincided with the changes in *Cystoseira* and *Phyllophora* phytocoenoses in the less eutrophic offshore waters of the northwestern shelf as well. They comprised the background state from the late 1950s to the early 1970s; degradation state from the mid-1970s to the late 1980s; negative changes from the late 1980s to the early 1990s; partial restoration state towards the 1950s after the mid-1990s (Milchakova, 1999). At present, restoration of *Cystoseira* phytocoenoses has been limited to the shallow water (1-3 m) coastal zone in open areas (Cape Aya, Cape Sarych, Karadag) and in embayments and bays (Sevastopol Bay, Karkinitsky Bay) as evident by their increasing species diversity and shares of edificatory species (large, perennial species). *Cystoseira* and *Phyllophora* occupied 7.42 and 1.62 km² area with stocks of 9200 and 993 tones, respectively, in the Sevastopol Bay (Milchakova, 2003b). The stocks of *Gracillaria verrucosa* (Huds.) Papenf., *G. dura* (Ag.) J. Ag. in Kasachya and Novorossiskay embayments of the Crimean coast also made up 55 and 42 tonnes, respectively (Mironova, 2005).

An improvement of ecological conditions can also be seen in seaweed distributions in deep waters. For instance, congestions of green filamentous algae *Cladophora* sericea (Huds.) Kutz. were found in the southwest Crimea shelf at the depth range of 40-100 meters in spring 2004 (Boltachev and Milchakova, 2004). The green lamellar algae *Ulva rigida* Ag. was recorded at 35-60 meter depth range in autumn 2005. Even the coastal ecosystem of the Danube-Dnepr interfluve which has been greatly subject to eutrophication started producing some macrophyte development at depths from 5-7 to 12-14 m in 2005-2007.

Table 7.4. The periods of alteration of community structural-functional organization for the macrophytobenthos of northwestern part of the Black Sea.

Stage	Period	Main characteristics
Pre-eutrophication state	Before the 1960s	Dominant of communities - a large perennial brown alga Cystoseira barbata with a low specific area (S/W - 12 m^3·kg-1). Multilayer complex communities with average biomass of 3-5 kg·m-^{2}.
Intensified Eutrophication	From the early 1970s to the 1980s	Species with S/W lower than 15 m^2·kg-1 ceased developing C. barbata succeeded the algal community of the genus Ceramium, Cladophora, Enteromorpha. The phytobenthos biomass fell to 1.0-1.5 kg·m-^{2}. The S/W index of the floristic algae composition increased more than two-folds.
Immobility	Mid-1990s	Mass development of species of aliens and previously rare species (Desmarestia viridis, Polysiphonia sunguinea) with S/W ~ 70 m^2·kg-1.
Decreasing Eutrophication	The present decade	The red algae Polysiphonia elongata (S/W - 26.88 m^2·kg-1) has intensively widened its range, as a step towards restoration of the macrophytobenthos structure.

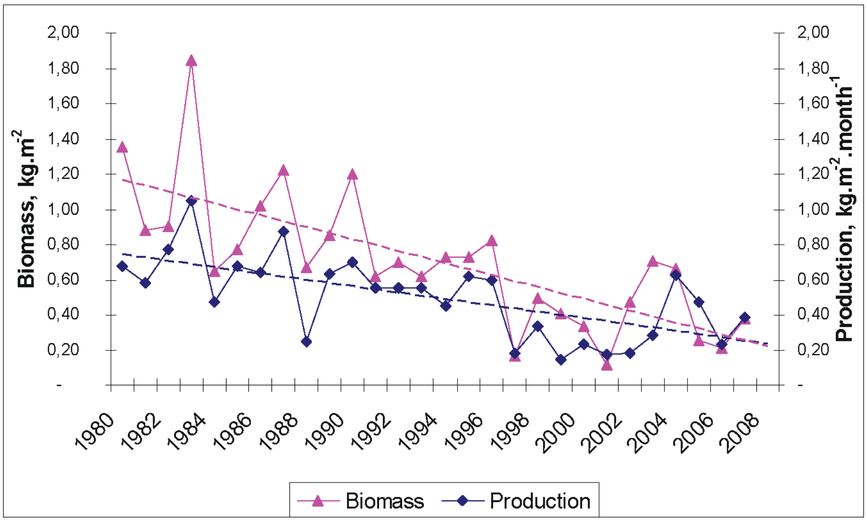

Fig. 7.2. Annually dynamic of biomass and production of macrophytes community of Danube-Dnepr interfluves.

7.3. Romanian shelf area

Long term changes (1950-2005): Macrophytes in the Romanian coast until the 1970s comprised 154 species (47 Chlorophyta species, 2 Xanthophyta, 30 Phaeophyta, and 79 Rhodophyta) that have been identified as early as 1935 by Celan (1935). They decreased gradually to 86 species in 1970s (Bavaru, 1981), 55 in the 1980s and 31 in the 1990s as depicted in Table 7. 5.

Table 7.5. Number of macroalgal species at the Romanian coast, between 1977 and 2005 by different authors

Phyllum	1977(1)	1976-1995(2)	1996-2005(3)
Chlorophyta (green algae)	31	22	16
Phaeophyta (brown algae)	14	9	5
Rhodophyta (red algae)	41	24	10
Total	86	55	31

Data sources: (1) Bavaru (1981), (2) Vasiliu (1984), (3) Bologa and Sava (2006).

The cold winter of 1971-1972 represented a special situation in which drifting ice mechanically destroyed benthic vegetation up to 2-3 m of depth. 80% of the loss of the perennial brown algae *Cystoseira barbat*a stocks was the result of this particular phenomenon. Silt and nutrients from coastal human activities aggravated the unsuccessful macrophytes stocks rehabilitation. *Cystoseira* continued to be present only in the form of small aggregations mostly in the southern part of the Romanian shore because of the weaker influence of the Danube River in this region. Epiphytic flora and associated fauna also decreased, and as a result perennial algae damaged considerably. The almost complete disappearance of extended belts of *Cystoseira* had important ecological implications in terms of forming as a substratum and shelter for various other epiphytic macrophytes and animals, especially fish. The disappearance of numerous brown and red algae was mainly related to the depletion of those *Cystoseira* fields. *Phyllophora* is a perennial algae, dominant in the famous "Zernov's field" (Skolka, 1956), nowadays being present only as scattered islands in the northern Constanta area.

Considerable diminution of phanerogames *Zostera marina* and *Z. nolti* (eelgrass) was also observed in former decades. In the last 30 years the standing stock of eelgrass has decreased tenfold in shallow water. Eelgrass served as a favourable biotope for many species of invertebrates and fish. The main reason for the degradation of *Zostera* communities was the mobilizing of silt when dredging in the coastal zone. These impoverishments in macrophyte community were noticed in many rocky bottom areas (Celan, 1977; Celan & Bavaru, 1973, 1978; Skolka *et al.,* 1980; Bavaru, 1970, 1981; Bavaru and Vasiliu, 1985; Bologa, 1989; Sava *et al.,* 2003) and led to the present decrease of biodiversity in the north-western Black Sea (Bologa, 2002; Bologa *et al.,* 1995).

Hard substratum, earlier populated by slow developing brown alga *Cystoseira*, was then covered by short life cycle species with fast growth. Most frequent species are *Enteromorpha, Cladophora* and *Ceramium,* followed by *Ulva, Bryopsis* and *Callithamnion* but their biomass is not comparable with high biomass of *Cystoseira* in the last decades (Sava, 1999). Most obvious feature of macrophytes community in 1990s was low number of species at the Romanian shore, but they could produce high biomasses, some genera (*Enteromorpha, Cladophora, Ceramium*) covered 80% of the bottom (Bologa, 1989). An average of 6 kg/m^2 wet biomass has been measured in 2004, proportion of green algae being higher in the north, red algae predominating towards the south of the Romanian coast (Sburlea and Mircea, 2006).

Due to large amount of suspended particles and plankton, the transparency of sea water was significantly decreased in 2005 compared to 1980s. The position of the compensation depth changed as a result, and bottom seaweeds growing deeper than 7 to

8 m became shaded (Bologa and Sava, 2006). The latter accounted for the large decline of macrophytes, in spite of the high nutrients levels. The changes of the ecosystem and community structure led to the replacement of some phytocoenoses by others. The consequence was a shift in the seasonal and multiannual dynamics of the algal communities.

As a result of biological pollution, the exotic and toxic species *Desmarestia* (Phaeophyta) has been observed along the Romanian shore in 2004 and 2005. First recorded in 1992, this particular species has already populated hard substrates of the Odessa harbour and is considered toxic for the neighbouring algae. At present, the rehabilitation of macrophytes community is delayed by secondary eutrophication and human activities such as harbour constructions, industry, and tourism.

With respect to the categories proposed by the World Conservation Union (IUCN) and considering national concerns regarding endangered species, a comprehensive red list of extinct and endangered, rare and insufficiently known benthic macrophytes from the Romanian Black Sea sector has been compiled (Bologa and Bavaru, 1998/99). The list comprised 24 extinct and endangered species (6 Chlorophyta, 6 Phaeophyta, and 12 Rhodophyta), 42 rare species (13 Chlorophyta, 2 Xanthophyta, 9 Phaeophyta, 18 Rhodophyta) and 4 insufficiently known species (1 Phaeophyta, 3 Rhodophyta).

Peculiarity of macrophytobenthos during 1990-2005: Along the Romanian Black Sea shore, the compact, discontinuous and variable rocky bottom characterizes the supra-, medio-, and infralittoral between Cape Midia (44° 20' N) and Vama Veche (43° 45' N). This substratum constitutes the most varied environment of the benthic domain. During the decades, this benthic zone has shrunk to a narrow inshore strip at the depth of 5-7 m that comprised the only region with sufficient light penetrating within the water column for photosyntesis (Sava, 1999).

The inventory of benthic macrophytes along the Romanian shore in the last decade presents 33 species (Bologa and Sava, 2006): 16 Chlorophyta, 10 Rhodophyta, 5 Phaeophyta and 2 Phanerogama. Usually, *Enteromorpha* species are mixed with species of *Cladophora*. Occasionally *Bryopsis plumosa* (in the warm season) and *Entocladia viridis* (endophyte in the cellular membranes of *Ceramium* species) have been observed. After the green algae belt, starting with low depths up to 8 to 9 m were covered by the species of *Ceramium*. They occupy almost all substrata, contributing with *Enteromorpha,* to the physiognomy of the present vegetation. *Polysiphonia, Callithamnion* and *Porphyra* constituted other common species at lower quantities during various seasons of the year.

There is, however, a clear quantitative and qualitative difference between the macrophyte community of the northern and southern littoral zones of the Romanian coastline (Fig. 7.3). Reduced hard substratum suitable for macrophytes development and more intense pollution caused much lower macrophyte community along the northern Romanian littoral zone. Suspensions in large quantities negatively affected light penetration in the water body and seed germination.

Half of macrophytes species encountered on the Romanian shore at 2 to 4 m depth exist also as epiphytes on *Cystoseira* developing interstitial spaces suitable for zoobenthos settlement and creating a complex trophic chain (Sburlea and Bologa, 2006). Considering this influence on benthic communities, *Cystoseira* is ranked as key species.

Fig. 7.3. Location of sampling stations along the Romanian Black Sea coast during 2000-2005 observations (left) and quantitative proportion of red and green algae along the Romanian Black Sea shore (right).

Some species that were considered as disappeared until recently such as *Lomentaria clavellosa* (Rhodophyta), were found recently in "2 Mai-Vama Veche" Marine Reservation area, thus making this species easier to monitor and protect. A few thalli of exotic brown alga *Desmarestia* was observed as stranded to shore but it is not known if they were carried by coastal currents from the north or it was growing on Romanian shelf (Environmental State Report - NIMRD).

Nowadays biomass values are much lower compared with previous published data. High values of macrophyte biomass were found at depths of 2-3 m where there was still enough light and the physico-chemical conditions were relatively good (Sava, 1999). Hard substratum, earlier populated by community of brown alga Cystoseira, is now covered by *Enteromorpha, Cladophora* and *Ceramium,* seasonal macrophytes with short life cycle. Their mass development led to a homogenization of benthic communities on extended areas but their biomass is not comparable with high biomass of *Cystoseira* (Sava, 1999). Starting with 1990, in spite of diminished number of species, a trend of quantitative recovery of Chlorophyta (green algae) and Rhodophyta (red algae) that are more tolerant to eutrophication has been registered on several beaches between Mamaia (in spite of sandy bottom) and Vama Veche.

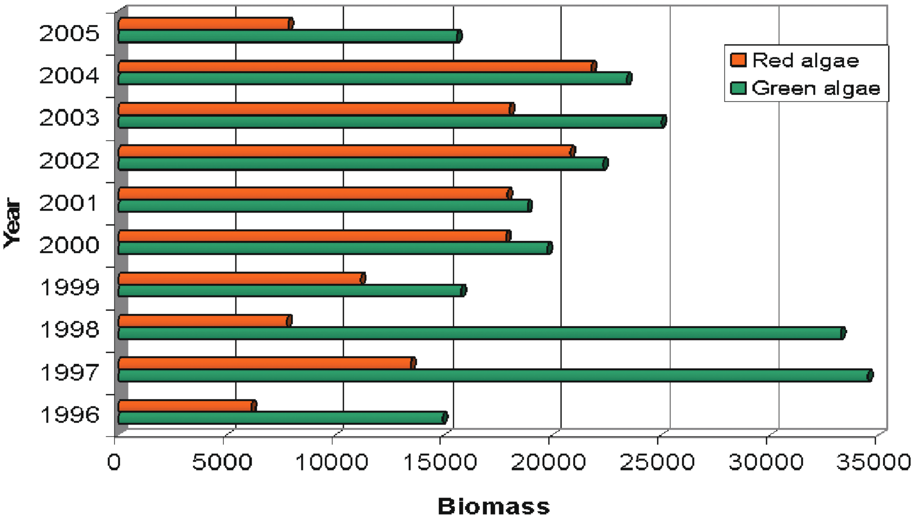

Fig. 7.4. Annual evolution of biomass (g,m^{-2}) of green and red algae along the Romanian littoral between 1996 and 2005 (Bologa and Sava, 2006).

The research carried out during 2000-2005 at seven sites between Constanta and 2 Mai both in warm and cold seasons suggested that the new algal communities consisted of very small number of species of mostly green, red algae and brown algae. The perennial associations of the past have declined and the substratum previously populated by *Cystoseira* is now covered by opportunistic species with a short life cycle and rapid growth. The evolution of biomass since 2000 (Fig. 7.4) showed that green algae were dominant and comprised by the species belonging to the genera *Ulva, Enteromorpha* and *Cladophora* that develop all year round, together with *Ulothrix* and *Urospora* that develop only during the cold season (spring and autumn). Its maximum development took place in 2003 (25,000 g/m^2), but similar values were also registered in 2002 (22,310 g/m^2) and 2004 (23,410 g/m^2). In 2005, a significant decrease of Chlorophyta biomass was evident; its total value (15,581 g/m^2) was almost half of the 2003 value. The red algae acquired the maximum biomass (21,722 g/m^2) in 2004 with slight differences to previous years, whereas its biomass reduced more than half of its value in 2000. They were dominated by the species of *Ceramium,* found on rocky bottom during the entire year due to its high capacity of both asexual and sexual reproduction. During spring, *Porphyra* and sometimes *Polysiphonia* and *Callithamnion* contributed to the total red algae biomass. The latter two species were found in appreciable quantities in samples only in the warm season. The reduction in biomass of both green and red algae in 2005 could be related to the improvement of the state of the ecosystem along the Romanian shore and could have beneficial consequences on the whole algal vegetation.

7.4. Bulgarian shelf area

The long-term observations in the Varna Bay region indicated a decreasing trend of macrophyte species in general and of oligosaprobic species in particular in response to increased level of eutrophication (Dimitrova, 1978; 1996) as summarized in Tables 7.6 and 7.7. The total loss of macrophyte species accounted for more than half as compared to the first half the last century, particularly in the Rhodophyta and Phaeophyta species

(Table 7.6), whereas Chlorophyta species increased by 50% during the same period. For example, the average biomass of the Phaeophyta species *Cystoseia barbata* was estimated as 7 kg.m^{-2} in 1966-1969 with respect to 1.1kg.m^{-2} in 1997 up to 2 m depth. It was mostly substituted by *Enteromorpha intestinalis, Cladophora vagabunda, Ceramium rubrum.*

Table 7.6. Changes in species structure of different types of macrophytes in Varna Bay.

Type	1904-1939	1962-1972	1994	1999	2001	2002
Chlorophyta	10	9	13	13	13	15
Phaeophyta	11	6	4	3	4	4
Rhodophyta	37	23	14	8	11	8
Total	58	38	31	24	28	27

Table 7.7. Changes in saprobic structure of macrophytes in Varna Bay in the years of investigation.

Period	1904 - 39	1969-72	1994	1999	2001	2002
Oligosaprobic	37	23	3	3	3	3
Mesosaprobic	16	11	21	13	18	17
Polysaprobic	5	4	7	8	7	7

In terms of saprobic structure of macrophytes in Varna Bay, major loss occurred in oligosaprobic species which became almost extinct since the 1990s (Table 7.7). Typical oligosaprobic species such as *Ralfsia verrucosa, Stilophora tuberculosa, Nereia filliformis, Dictiota dichotoma, Cladostephus verticillatus* were not registered during the last two decades in this region. The most dominant species, in terms of their biomass, are the polysaprobic and mesosaprobic species such as *Ceramium rubrum, Callithamnion corrymbosum, Enteromorpha intestinalis, Ulva rigida, Bryopsis plumosa.* This floristic structure was similar to the Odessa Bay further north (Minicheva, 1998).

In 1994, the macrophytobenthos along the Bulgarian Black Sea coast was found to contain 157 species, which constituted 53% of the total Black Sea macroflora. They belonged to 82 genera, 43 families and 25 classes of Rhodophyta, Phaeophyta and Chlorophyta. The first group was the richest with about 55% of all species, followed by the rest with approximately even number of species (Table 7.8). In comparison with the Russian (75%), Romanian (40.7%) and Turkish coast (24%), the Bulgarian Black Sea coast ranked second regarding to macroflora species diversity (Kalugina-Gutnik, 1975).

The comparison of the floristic indices of macrophytobenthic coenoses for 1904-1972 and 1994-2002 periods may be used to assess the level of eutrophication along the Bulgarian coast (Table 7.9). The floristic index increases with enhancement of the level of eutrophication. For example, in Varna Bay being the most eutrophic part of the Bulgarian coastline, it was increased from 4.3 during 1904-1939 to 5.3 in 1969- 1972 and to more than 6.0 in the 1990s and the present decade. In 1994, the lowest floristic index was in the Cape Maslen and the highest in Kavarna (P=7.5), followed by Varna Bay (P=6.5) (Table 7.9). It acquired intermediate values for Irakly and Zelenka (P= 5.0) and for Bjala and Balchik transects (P= 6.0).

Table 7.8. Bulgarian and Black Sea macroalgae taxonomic composition.

Regions	Group	Order	Family	Genus	Species
Bulgarian coast	Rhodophyta	8	18	39	86
	Phaeophyta	10	16	26	37
	Chlorophyta	7	9	17	34
	Total	25	43	82	157
Black Sea	Rhodophyta	8	23	61	142
	Phaeophyta	11	25	46	77
	Chlorophyta	7	14	36	74
	Total	26	62	143	293

Table 7.9. Comparison of floristic indices along the Bulgarian coastline.

Transect	Floristic index (P)	Saprobic Index (X)
Cape Maslen	3.6	1.170
Zelenka	5.0	0.330
Irakly	5.0	0.350
Bjala	6.0	0.285
Balchik	6.0	0.280
Varna Bay	6.5	0.220
Kavarna	7.5	0.176

The values of saprobic index that decreased with enhancement of the level of eutrophication also indicated high eutrophication tendency along the Bulgarian coast in 1994. The highest saprobic index value was estimated for Cape Maslen (X=1.17) and the lowest one for Kavarna (X=0.176), followed by Varna Bay (Table 7.9). They are consistent with the highest values total macrophytes biomass in the Cape Maslen (4184.18 g.m^{-2}) and the lowest level in Kavarna (1367.15 g.m^{-2}) and Varna Bay (1413.65 g.m^{-2}) at 5 m depth (Fig. 7.5). Irakly and Zelenka (X=0.35, X=0.33), Bjala and Balchik (X=0.285, X=0.28) have been identified by intermediate saprobic index values and hence intermediate level total macrophytes biomass. The biomass distribution from different types of algae was characterized by the following peculiarities. The highest biomass of brown algae was registered in the Cape Maslen (2320.07 g.m-2), it was 1.1 lower at Zelenka, 2.3 fold lower in Bjala, 22 times lower in Varna Bay, and it was of significant value in Kavarna. The highest biomass of Chlorophyta (1785.16 g.m-2) and Rhodophyta (616.28 g.m^{-2}) representatives was estimated in the Bjala transect (Fig. 7.5). Phaeophyta prevailed in the Cape Maslen and Zelenka, and Chlorophyta in Varna Bay, Bjala and Kavarna (Fig. 7.5).

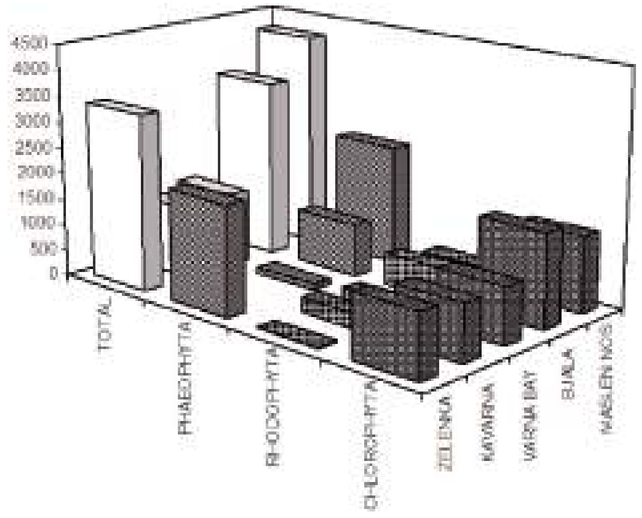

Fig. 7.5. Biomass distribution of macrophytes along the investigated transects in 1994.

The low biomass of Phaeophyta (Brown algae) species *Cystoseira* is considered as a reliable indicator for the estimation of the level of eutrophication. It was registered in greater values in the Cape Maslen area (2320.07 g.m^{-2}) where it constituted 55.4% of the total biomass whereas only 7.5% in more eutrophic Varna Bay region. On the contrary, the mass development in biomass of the Chlorophyta species *Ulva rigida, Enteromorpha intestinalis* and the Rhodophyta species *Ceramium rubrum* and *Callithamnion corimbosum* is an indication of increased content of organic matter and nutrients, and hence eutrophication (Kalugina-Gutnik, 1975; Bologa, 1989; Minitcheva, 1990). They were dominant in Varna Bay as identified by *Ulva rigida* (max. biomass 1913.7 g.m^{-2}), Enteromorpha intestinalis (2287 g.m^{-2}), Ceramium rubrum (312.5 g.m^{-2}), Callithamnion corimbosum (624.8 g.m^{-2}).

The highest percentage of oligosaprobic algae and the values of saprobic and floristic indices therefore indicated a lower eutrophication level in the Cape Maslen in comparison with the other investigated areas along the Bulgarian coast. The highest level of eutrophication was detected in Varna Bay and Kavarna as further confirmed by low biomass of macrophytobenthos. Zelenka, Balchik, Bjala, Irakly characterized moderately eutrophic regions.

A direct relation exists among the nutrient loading, increasing phytoplankton growth, restricted light penetration and reduction of macroalgae biomass (Hough et al., 1989). In support to this, our results showed that the bulk of biomass in the Cape Maslen area spread at 5m depth. It was 6 times higher than that in Varna Bay due to permanent blooms of phytoplankton and high level of eutrophy. Besides, the highest biomass of *Cystoseira* (2320.07 g.m^{-2}), preferring waters with low nutrient loading, was registered in the Cape Maslen area, compared with the other regions, especially Varna Bay and Kavarna.

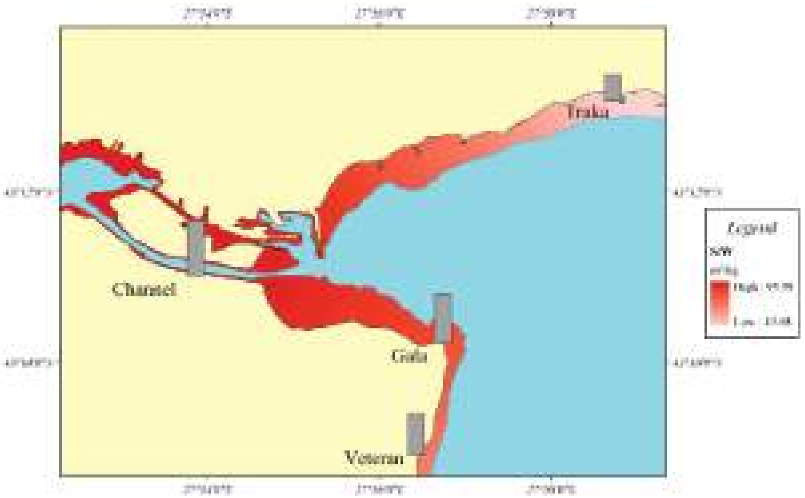

Fig. 7.6. Average multi-annual specific surface values ($m^2.kg^{-1}$) along the Bulgarian coastline during 1999-2002.

The floristic composition of plant communities along the Bulgarian coast in 1999-2002 can be divided into three categories according to their specific surface values: under 10 $m^2.kg^{-1}$ (indicating lower eutrophication), from 10 to 30 $m^2.kg^{-1}$ (indicating intermediate level eutrophication), and over 30 $m^2.kg^{-1}$ (indicating higher eutrophication). It should be noted that a high specific surface value corresponds to a macrophyte biomass and indicates a higher eutrophication level. According to this classification, in Trakata, 33% belong to macrophytes with specific surface from 10 to 30 $m^2.kg^{-1}$ and 67% belong to macrophytes with specific surface value over 30 $m^2.kg^{-1}$ (species with specific surface value under 10 $m^2.kg^{-1}$ are not registered). Traka therefore represented the least eutrophic zone with respect to the other regions. Its average specific surface value for 1999-2002 is 43.68 $m^2.kg^{-1}$ (Fig. 7.6). The most eutrophicated zone turns out to be the channel between the Varna Bay and its lake in which 92% belong to species with specific surface value over 30 $m^2.kg^{-1}$ (the mean value = 95.79 $m^2.kg^{-1}$). It is followed by Galata (83%), Veteran and (72%). Accordingly, the 1999-2002 average value of macrophyte biomass along the coast decrease from Trakata (911.8 $g.m^{-2}$) to Veteran (613.83 $g.m^{-2}$), Cape Galata (512.7 $g.m^{-2}$) and the channel (484.6 $g.m^{-2}$) (Fig. 7.7).

The major change during the recent years was biomass decrease of Cystoseira (species indicator of high quality waters) in the Varna Bay. This olygosaprobic macrophyte with low specific surface and big size is replaced by other polysaprobic species such as *Cladophora, Enteromorpha, Ceramium* with higher specific surface, especially in more eutrophic areas (Dencheva, 1994).

The calculated macroalgal production is highest in Trakata and the Channel regions. The high values in the channel are due to presence of species with high specific surface and intensity of functioning and short life cycle and biomass. The high production in Traka is because of the presence of Cystoseira (high biomass, low specific surface).

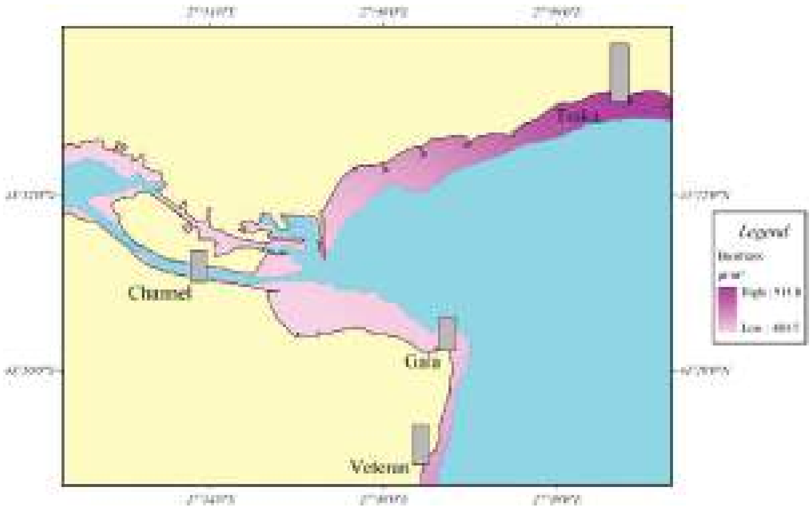

Fig. 7.7. Average multi-annual biomass values (g.m^{-2}) along the Bulgarian coastline during 1999-2002.

7.5. Turkish shelf area

A detailed account of the early algal records along the Turkish coast of the Black Sea (Fig. 7.8) is given by Aysel *et al.* (1996; 2000, 2004; 2005), Erdugan *et al.* (1996). 25 macroalgal taxa were reported in Trabzon coastal waters and 21 macroalgal taxa at Sinop and its vicinity (central zone), 55 taxa along the coast of Trabzon and 88 taxa between Rize and Sarp in the southeastern part of the Black Sea, 210 taxa at Bartin and 205 taxa at Zonguldak (western zone) belonging to four algal classes (Cyanophyceae, Rhodophyceae, Phaeophyceae and Chlorophyceae). In total, 258 taxa were identified in the Turkish Black Sea region, from five classes: Cyanophyceae with 13 species, Rhodophyceae with 140 species, Phaeophyceae with 53 species, Chlorophyceae with 50 species and Charophyceae with 2 species. With new additions of algal taxa, this number increased later to 297 by Aysel et al (2004). The list of algal taxa and macrophytes along the Turkish coast of the Black Sea is given in Table 7.10, and their relative dominancy is given in Table 7.11.

Conservation biology and threats: There have been dramatic changes in the southern Black Sea ecosystem as a result of eutrophication caused by increased nutrient input via major northwestern rivers and industrial and harbour activities in recent years. Abnormal changes due to altered nutrient balance were reflected in the qualitative and quantitative composition of phytoplankton, zooplankton and ichthyofauna (Bat et al., 2007). These changes also included the loss of extensive areas of seagrass meadows, a virtual collapse of the benthos over the shelf area and mass mortalities due to hypoxia. The dredging of sand from the sea has also been destroying the habitats along the Turkish Black Sea coast (Öztürk, 1998). In addition, the highway construction along the coastline harmed the macroalgae and macrophyte communities (Aysel *et al.,* 2005).

Fig. 7.8. Map for the coastal regions along the Turkish coast of the Black Sea.

Table 7.10. Benthic algae and macrophytes diversity from different areas in the Black Sea coast of Turkey (Aysel et al., 2005).

Regions	**Seaweeds**				**Macrophytes**	
	Cyano-phyta (CY)	Rhodo phyta (R)	Phaeo phyta (O)	Chloro phyta (C)	Magnolio phyta	Σ
Kirklareli	23	71	24	30	3	151
Kocaeli, Sakarya, Düzce	30	126	50	46	3	255
Zonguldak	20	100	42	43	3	208
Bartin	12	116	43	39	3	213
Kastamonu	22	133	56	48	3	262
Sinop	22	136	52	55	3	268
Samsun	20	106	27	22	3	178
Ordu	14	93	27	26	4	164
Giresun	18	109	33	30	3	193
Trabzon	1	23	8	23	3	58
Rize, Artvin	3	43	15	27	3	91
Total	30	142	57	58	4	297

Table 7. 11. Dominancy in division level among of Black Sea coast of Turkey (Aysel et al., 2005).

Regions	**Division**					
	R/O	R/C	R/CY	O/C	O/CY	C/CY
Kirklareli	3.00	3.70	3.10	0.80	1.00	1.30
Kocaeli,Sakarya, Düzce	2.52	2.73	4.20	1.08	1.66	1.53
Zonguldak	2.40	2.30	5.00	1.00	2.10	2.20
Bartin	2.70	3.00	9.70	1.10	3.60	3.30
Kastamonu	2.37	2.77	6.04	1.16	2.54	2.18
Sinop	2.60	2.50	6.50	0.96	2.50	2.59
Samsun	3.92	4.81	4.30	1.22	1.35	1.10
Ordu	3.44	3.58	6.64	1.04	1.93	1.86
Giresun	3.30	3.63	6.05	1.10	1.83	1.66
Trabzon	2.90	1.00	23.00	0.30	8.00	23.00
Rize, Artvin	2.90	1.60	14.3	0.60	5.00	9.00

Seagrasses (Magnoliphyta)

The seagrasses (Magnoliphyta) patchy distributed sandy and muddy substratums of the coast of Turkish coastal zone. According to Milchakova (1999), six species have been occured in the Black Sea. These are *Zostera marina* (eelgrass), *Z. noltii, Potamogeton pectinatus, Ruppia maritima, R. spiralis* and *Zannichellia major*. Among these, *Z. marina* (eelgrass), *Z. noltii, Potamogeton pectinatus* and as differently *Cymodocea nodosa* reported from Turkish Black Sea coast (Gönlügür-Demirci & Karakan, 2006). Generally the vertical distribution of *Zostera* beds in the Turkish self area is mainly between 0.7 m and 6 m but low-density patches can grow down to 17 m. *Zostera* meadows are an important source of food and shelter for the juvenile stages of many fish and crustacean species The network of roots and leaves in a *Zostera* bed provides ecological nichs for a wide range of associated with fauna and flora, so that the biotopes are important in maintaning coastal biodiversity. These beds exhibit high rates of primary productivity and are an important source of organic matter, fuelling detritusbased food chains within the biotope (Boström and Bonsdorff, 1997). The distribution of *Zostera* spp. meadows at the Turkish coastal zone was patchy, forming mosaic patterns with other phytobenthic and zoobenthic species (*Ceramium* spp., *Cladophora* spp., *Ulva* spp., *Polysiphonia* sp., *Potomageton pectinatus, Botryllus schlosseri,* and serpulid polychaets). (unpublished data). Seagrass constitute of an important part of the Black Sea coastal zone. They have still received much less attention than the other systems in terms of research and management. In Turkey, as in other Black Sea countries, the negative impact on the seagrass ecosystems is increasing due to a growing coastal population, pollution, and overexploitation of resources. Sinop region is an example of an area strongly influenced by overfishing, illegal bottom trawling, verified by local fisherman complaining on diminishing catch rates.

Consequently, to increase the present scientific knowledge on ecological interactions such as between fish and invertebrate assemblages, and seagrass environments of the region is important.

7.6. Northeastern (Russian) shelf area

Floristic composition: In the 1970s, the floristic richness of marine algoflora along the northeastern Black Sea coast comprised 146 macroalgae species: 33 Chlorophyta, 35 Phaeophyceae, 78 Rhodophyta (Kalugina-Gutnik, 1975). The studies performed during 1999-2007 identified 143 macroalgae species: 41 Chlorophyta, 29 Phaeophyceae, 73 Rhodophyta (Fig. 7.9). Only 39 of them (10 Chlorophyta, 7 Phaeophyceae, 22 Rhodophyta) had 100% frequency of occurrence, the others were registered only 1-3 times.

The important difference between the 1970s and the 2000s is the increase of Chlorophyta and simultaneous decrease of Phaeophyceae species, such as *Grateloupia dichotoma, Dasya baillouviana, Gracilaria verrucosa, Eupogodon apiculatus* (=*Dasyopsis apiculata*). It is noteworthy to point out that none of the widely spread species of Phaeophyceae has disappeared from the regional flora, though the majority of them belongs to oligosaprobic forms. Two brown algae, *Arthrocladia villosa* and *Halopteris scoparia,* were noted to be absent in 1999-2000. However, *Halopteris* was later found in the vicinity of Gelendzhik in 2001, and *Arthrocladia* at the Maria Magdalena Bank in 2002 (Maximova and Mitjaseva, 2003; Mitjaseva et al., 2003). In June 2003 *Gracilaria* appeared near Gelendzhik and in Inal Bay, and the real outbreak of this alga took place near Golubaja Bay at the depth of 7-9 m in July 2003. There were approximately 10 large thalli (up to 30 cm high) per square meter (A.A. Georgiev, M.I. Georgieva, pers.com).

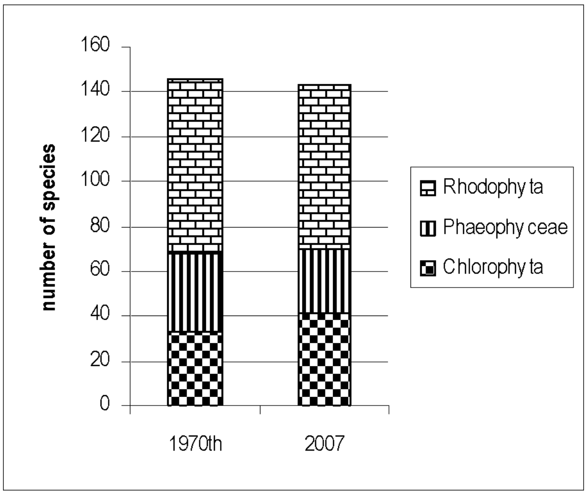

Fig. 7.9. Taxonomic composition of North Caucasian bottom algoflora in the 1970s (Kalugina-Gutnik, 1975) and the present decade.

In parallel to floristic depletion, a lot of new species have penetrated to the North Caucasian marine flora from the other regions of the basin: two *Ulothrix* species, *Ulvella lens, Pringsheimiella scutata, Entocladia* (= *Ectochaete*) *leptochaete, Cladophora siwaschensis* (Chlorophyta); *Pylaiella littoralis, Cladostephus spongiosus f. spongiosus, Myriotrichia clavaeformis* (= *M. repens*) (Phaeophyceae); *Goniotrichum elegans, Kylinia microscopica, Acrochaetium daviesii, A.savianum, Compsotamnion gracillimum, Polysiphonia fucoides (= P. nigrescens)* (Rhodophyta) and some others. Most of them are the endophytes, micro-epiphytes and filamentous forms.

Some species that have been considered to be rare in 1950-70s nowadays are widely spread along the North Caucasian coast. Among them are *Chaetomorpha gracilis, Cladophora vadorum, Cladophoropsis membranacea* (Chlorophyta), *Callithamnion granulatum, Rhodochorton purpureum, Ceramium siliquosum* var. *elegans* (Rhodophyta) and others. Thus, the changes took place not only in the floristic composition but also in the regional status of many species.

Bathymetric distribution and community structure of bottom vegetation: In the middle of 20th century, the most abundant member of bottom flora was Cystoseireta that stretched from 0.5 m to 20 m, in some places even to 35 m (the Bolshoi Utrish cape). The *Cystoseireta* formation survived under unfavorable conditions in the 1980s-1990s (Fig. 7.10). At present, its biomass at the upper phytal zone (0.25-1 m) reached 13-15 kg/m^2 in some places, and its average was about 3.5-5.0 kg/m^2. But, lower boundary of *Cystoseireta* still stay at the depth of 10-12 m (Fig. 7.10); only isolated oppressed thalli of *Cystoseira barbata* can be noticed as deep as 12-15 m. Its biomass at the localities deeper than 5-6 m usually is not higher than 150-300 g/m^2. Overall standing stock of both *Cystoseira* species was about 2 million tones and their annual primary production was up to 4.4 million tones. The *Cystoseira* communities included more than 120 species of other macroalgae. At the lower horizon of the phytal zone (18-28 m) the formation *Phyllophoreta* has been replacing the *Cystoseira* community, and formations *Polysiphonieta* (25-50 m) and *Antithamnieta* (45-70 m) have been usual and widespread along the northern shore of the Black Sea (Kalugina-Gutnik, 1975).

The northeastern Black Sea region produced nearly a half of the Black Sea *Cystoseira* stock in 1960-70s that was about 980 thousand tons (Kalugina-Gutnik, 1975). The contemporary *Cystoseira* stock in the region was, however, estimated to reduce to 100 thousand tons (Maximova and Moruchkova, 2005; Vilkova, 2005), but this value may be an overestimate due to very low biomass in deep phytal zone. The biomass of the leading species usually formed about 60% (from 30% up to 95%) of the total community biomass; hence the total stock of the regional macrophytobenthos would be no more than 160-170 thousand tons. Thus, it may be postulated that nearly ten-fold drop of the macrophyte biomass occurred along the North Caucasian coast during last 30 years. Needless to say, its commercial exploitation is not economically feasible any more.

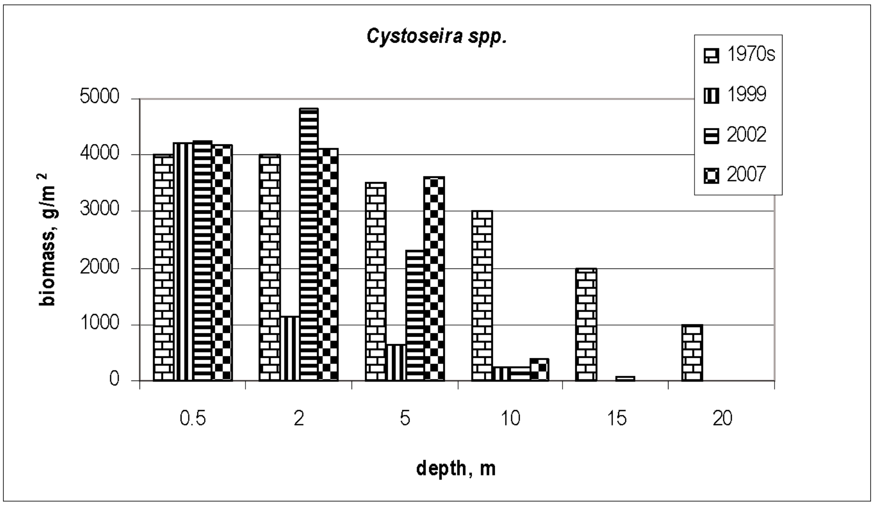

Fig. 7.10. Cystoseira biomass dynamics (1970s: Kalugina-Gutnik, 1975)

In the 1960s, the *Cystoseira* belt off the North Caucasian coast was as wide as 1.5 - 3 km (Kalugina-Gutnik, 1975). Now it is not wider than 300 m, usually about 100 m due to the structural (age, size, biodiversity, etc.) and functional (productivity, oxygen metabolism, bioconcentration) changes due to heavy eutrophication (Kalugina-Gutnik, 1975; Khailov et al., 1992; Maximova and Kucheruk, 1999; Gromov et al., 2001b; Gromov, 2004; and others). Their early life stages were very sensitive to the nutrient enrichment and its subsequent effects of low transparency, high sedimentation, epiphytes etc. (Berger et al., 2003; IsÆus et al., 2004; Bergström, 2005). Nitrate enrichment showed a significant negative effect on the attachment rate and germination of *Fucus vesiculosus* zygotes. Germling survival was reduced by over 20% in moderate nitrate enrichment, and by over 50% in high nitrate and phosphate enrichment during the first 10 days of experiment (Bergström et al., 2003). The intensive sedimentation reduced the survivorship for *Fucus serratus* embryos: under the 1 mm layer it dropped from 90% to 50%, and under 3 mm layer - to less than 10%. And what is especially significant: the ruinous effect of organically rich biodeposits was much higher than that of mineral sediment (Chapman and Fletcher, 2002); and the drop of water transparency after *Mnemiopsis* invasion was due to organic contamination, first of all.

Cystoseira germlings have not been observed deeper than 5 m from the late-1980s and to 2002. But, the annual appearance of numerous juvenile *Cystoseira* thalli was observed in intensively washed upper phytal zone during all these years. In 2000, the recruitment of juvenile *Cystoseira* was observed in some places. Maybe it was just the coincidence, but the year 2000 was the first year of suppressed *Mnemiopsis* activity and beginning of improvement of light and sedimentation conditions indicating an additional role of *Mnemiopsis* on *Cystoseira* beds.

The situation at lower phytal zone is even more dramatic. In the region between Gelendzhik and Novorossijsk, bottom vegetation was absent at depths greater than 20-25 m. Deep-sea formations of Polysiphonieta and *Antithamnieta* completely disappeared. As for *Phyllophoreta, Phyllophora nervosa* abundance dropped significantly at all levels of its bathymetric range. In the 1970s, the attached *Phyllophor*a had formed a wide belt with the coverage up to 50-80% with the mean biomass about 1.5 kg/m^2 and up to 4 kg/m^2 in the thick beds along the coastline from Anapa to Novorossijsk (Kalugina-Gutnik, 1975). In the 1980s - early 1990s the coverage was as high as 30-40% and mean biomass was 1.5 kg/m^2 (and up to 6 kg/m^2 at some locations) at depths from 12 to 28-30 m in the vicinity of Gelendzhik (Maximova and Rybnikov, 1993).

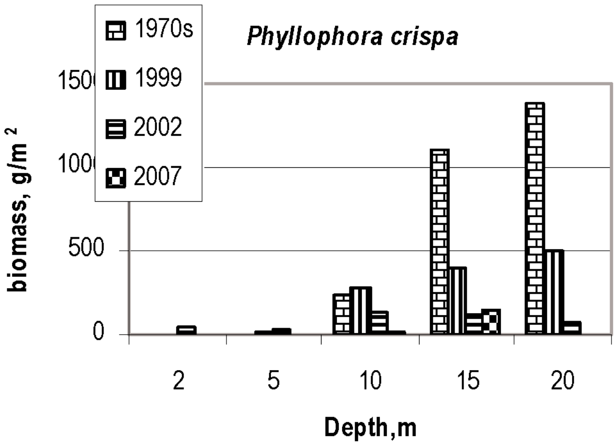

Fig. 7.11. *Phyllophora* biomass dynamics. Data source for 1970s: Kalugina-Gutnik (1975).

The investigations carried out in 1999-2007 in various points of the North Caucasian coast (Novorossijsk, Gelendzhik, Divnomorskoje, Inal Bay, Djubga, Arhipo-Osipovka, Tuapse) showed that the lower boundary of *Phyllophora* belt has shrunk by at least 10 m - to the depth of 15-20 m. One can now observe only rare small beds and single plants, the coverage is not higher than 15-20% and biomass rarely exceeds 0.3-0.5 kg/m^2, being usually about some tens of grams. In 2006-2007 we noticed only single thalli of *Phyllophora* at the depth of 20 m in Gelendzhik region (Fig. 7.11). Thus, not only the community of Zernov's Phyllophora Meadow showed the catastrophic changes (Milchakova, 2001; Zaitsev, 2006), but also the near-shore populations off the North Caucasian coast. The lower phytal zone associations suffered most from the reduced transparency of coastal waters. Even sciophile *Phyllophora* crispa could not adapt itself to the narrowing of the photic zone. The similar situation was also observed along the Crimean coast. The Crimean bottom vegetation degraded deeper than 3 m, while there is a marked signs of macrophytobenthic rehabilitation in the upper phytal zone (Milchakova, 2001; Zaika et al., 2004).

As the result of *Phyllophora* degradation, the dominant structure of deep-sea communities also changed. The biomass of green noncellular algae *Codium vermilara* reached 4 kg/m^2 with a density of 1500 sp/m^2 at the depths of 10-15 m in 2001-2002. A similar situation took place for the brown crust-forming algae *Zanardinia prototypus* in 2002-2007. Its coverage increased by 60-80% at depths between 4 and 10 m. These events are called as the macroalgal "blooms" as observed earlier for filamentous algae in intensively polluted areas, like *Cladophora* "blooms" in Anapa Bay (Vershinin and Kamnev, 2001). These blooms were highly dynamic events with significant year-to-year variations. For example, although a lot of juvenile thalli were observed at the depth of 15 m no *Codium* "bloom" was observed in 2003-2004 and the production of this alga returned its standard state and became one of the common but not a dominant species. The brown algae *Halopteris scoparia* has been rather abundant in 2001 in Gelendzhik region, but it has not been observed in following years, except a regular appearance in the vicinity of Tuapse. It may be quite likely that the periodic outbreaks of different species signify a gradual improvement of environmental conditions (e.g., illumination) after the invasion of *Beroe ovata*. Evidently, the temporarily deserted niches during the *Mnemiopsis* era started to be filled again but not necessarily by the same species.

In addition to the outbreaks of secondary species, the role of previous dominant species decreased simultaneously up to their disappearance. For example, the floristic composition belonged to the *Cystoseira-Phyllophora* association in the vicinity of Novorossijsk (Southern Ozereevka, depth 20 m) (Kalugina-Gutnik, 1975), but *Cystoseira barbata* was entirely absent indicating that the dominant algae group was removed from the association. The same association usually found in the depth range from 10-12 m to 15-18 m (e.g. *Phyllophora crispa, Apoglossum ruscifolium* and *Cladophora dalmatica*) also formed underwater bench at the depths of 2-5 m in sheltered regions in close proximity of deeper associations.

Maria Magdalena Bank: situation in clean waters: Macrophytobenthos transformation was also observed in Maria Magdalena Bank that was practically undisturbed and unpolluted region located in 5 km off Anapa coast. During the previous macroalgal investigations at the end of the 1950s, the bottom vegetation of the Bank was studied in the depth range from 2.8 m to 14.4 m, and 26 species of macroalgae were identified including 1 Chlorophyta, 13 Phaeophyceae, 12 Rhodophyta (Petrov, 1960, 1961a, b). After 45 years the algal samples collected at depths from 2 m to 30 m showed 41 species (11 Chlorophyta, 11 Phaeophyceae, 19 Rhodophyta) (Mitjaseva et al., 2003). The main difference in floristic lists was the pronounced increase in the number of Chlorophyta species. The high abundance of green algae was the evidence of brackish and/or eutrophicated waters. The equal quantity of green and brown species was the indication of mesosaprobient community (Kalugina-Gutnik, 1975).

The next difference was the change of dominants: *Cystoseira barbata* has been the main alga in the 1950s but it was replaced by *Cladostephus spongiosus* f. *verticillatus,* distributed from 2 to 15 m in 2003. *C. barbata* was registered only twice with small quantities at the very top of the Bank (2 m depth). On the other hand, *Cladostephus* was not mentioned at all in the 1950s. Likewise, two new associations observed recently *C.spongiosus* f. *verticillatus - Ceramium rubrum* at the depth 2-5 m, and *Arthrocladia villosa - Antithamnion plumula - Cladophoropsis membranacea - Bryopsis hypnoides* at the depth 25-30 m have not been described earlier (Maximova and Moruchkova, 2005). Instead, the attached form of *Phyllophora crispa* that mainly inhabited the depth range from 8.4 to 14.4 m was found only at 2 m, and only with a few thalli at 15 m in 2003. Thus, these long-term macrophytobenthos transformations observed even at undisturbed localities imply that anthropogenic changes affected the Black Sea macrophytobenthos as a whole even at the opposite end of the sea to the western coast.

Algae of living animal substrata: Recent observations also showed the macroalgae populations attached to the shells of live mollusks *Rapana venosa* (Gastropoda), *Chamelea gallina* and *Anadara inaequivalvis* (Bivalvia) on the soft bottom of the Anapa region and the Gelendzhik Bay at depths from 5 to 20 m. The dead shells were often inhabited by macroalgae, even though mollusks did not demonstrate any sign of illness or damage. The total density of *Chamelea* reached 300 sp./m^2, 10-30 of them bearing algae. The aspect of the association reminded the coloured clouds covering the bottom. The area of this association was wide enough to consider its primary production to be rather significant on the soft bottom.

Epiphytic sinusia and opportunistic species: The *Cladophora vagabunda* "bloom" mentioned above is a striking example of *r*-species development in the Black Sea with its standing crop of 7500 tons in the area of 15 km^2 in the Anapa Bay (Vershinin and Kamnev, 2000, 2001). Here the situation with the epiphytic sinusia will be discussed because of its noticeable changes during the last years. Its ecological role is high: about 80% of Black Sea benthic macroalgae are obligate or facultative epiphytes. At the beginning of the 1990s, epiphytic sinusia dominated in *Cystoseira* communities. In recent years, rich epiphytic flora, especially of red algae (*Laurencia obtusa, L. coronopus, Chondria capillaries, Ceramium rubrum, C. secundatum, C. diaphanum, C. siliquosum var. elegans, Polysiphonia subulifera, Antithamnion cruciatum, Seirospora interrupta, Compsothamnion gracillimum* etc) were observed but the quantitative characteristics of sinusia became much more spare. Even during their mass development at the end of summer the share of epiphytes in total community biomass did not exceed more than 30-35%. The epiphytic sinusia is more abundant (mainly owing to *Ceramium* species) at the upper phytal zone (1-2 m). The peak of its floristic diversity is marked at the depth of 2 m, but its contribution to the total community biomass is not high (3.5-5%). The species richness of epiphytes is lower (mainly *Laurencia obtusa* and *Polysiphonia subulifera*) at 5 m depth, but its biomass contribution rises up to 20-25%. At 10 m and deeper levels, the epiphytic sinusia is poor in both qualitative and quantitative aspects. For example, we have noticed 11 epiphytic species at the depths 0.5 m and 5 m, 17 - at the depth 2 m, and only 5 species at 10 m near Arhipo-Osipovka in 2001. In 2002 (the end of May - beginning of June), the real "bloom" of epiphytic *Chondrophycus paniculatus* (= *Laurencia paniculata*) was observed in the vicinity of Golubaja Bay. This species was the seasonal dominant of epiphytic sinusia; its brightly yellow thalli masked basiphytic *Cystoseira* plants. Such high abundance of this species was never reported before. In 2003 (the end of June) the unusually high brown epiphytic

Stilophora rhizodes (which had been rather rare in 2002 and earlier) and red *Chondria capillaries* were observed. They were so abundant (especially *S. rhizodes*) that nearly replaced the common dominants of epiphytic sinusia in *Cystoseira* associations - *Polysiphonia subulifera* and *Laurencia obtusa.* In 2003 *P.subulifera* was almost the rare component of sinusia, while *L. obtusa* was a slightly more abundant. These observations were held in Inal Bay, Golubaja Bay near Gelendzhik, in the vicinity of Divnomorskoje.

The changes in ecological and morphological properties of species: Under prolonged influence of eutrophication some algae have changed their properties. In particular, noticeable shifts occur in saprobic status of some algae populations. For example, oligosaprobic *Padina pavonia* and polysaprobic *Enteromorpha intestinalis* started growing in the mesosaprobic conditions; *Gracilaria verrucos*a and *Chara aculeolata*, inhabited the Gelendzhik Bay, one of the most polluted places along the shore (Maximova and Luchina, 2002). Apparently, high eutrophication became an environmental background which made the species to change their ecologic preferences. In the eutrophied environment, the morphology of the algae changed. *Cystoseira*, for example, lost the youngest branches (Khailov et al., 1992), and on the contrary *Gracilaria verrucosa*, *Gelidiella acerosa* intensified their branching (Rygalov et al., 1988; Mairh et al., 1990). Furthermore, two shallow-water ecological forms of *Phyllophora nervosa* appeared in the period of maximal eutrophication of coastal waters in early 1990s (Maximova and Rybnikov, 1993). During the present decade, the plants of the *crispa* morphotype were not noticed while the *pennata* form kept its abundance.

7.7. Conclusions

The major features of macrophytobenthos during the last several decades were decreasing species number, domination of small-size species with fast growth rate, decrease of community biomass, and reduction of *Cystoseireta* phytal zone to a narrow inshore strip shallower than 10 m which could only provide enough light for photosynthesis. As *Cystoseira* biomass decreased markedly, macroalgae blooms were dominated by opportunistic species (mainly epiphytic filamentous algae) in basiphytic and epiphytic sinusia.

Observations performed during the last 10 years indicated a restoration success of Cystoseira phytocoenoses in the coastal zone, weaker predominance of opportunistic species - mainly their epiphytic filamentous forms, with respect to 1980-90s, re-establishment of the *Phyllophora*-based community in the centre of the north-west shelf that has been formerly known to be Zernov's *Phyllophora* field. The main signature of restoration of Cystoseira and Phyllophora phytocoenoses was raising their species diversity with increasing moiety of large, perennial species and approximately two-fold decrease of the moiety of finely branched epiphyte species. However, no apparent recovery is yet evident at inshore locations close to the mouths of the Danube and Dniester. On the basis of 2004 observations, trophic status of the macrophytobethos along the western coast is classified as eutrophic, whereas the rest (the southern, Caucasian and Crimean) is mesotrophic. The Georgian coastal waters also fall into the eutrophic class.

Ongoing secondary eutrophication and human activities such as harbour constructions, industry, and tourism as well as anomalous climatic conditions led to establishment of different algal-dominated assemblages that adapted to the new conditions along coastal regions after the intense eutrophication state. At present, the macrophytes community structure is sensitive to the climatic changes and is dominated by either winter or summer species depending on the climatic conditions. The data tend to show a positive sign of recovery, but it is still difficult to mention a basin scale restoration of the macrophytobenthos community structure. Monitoring studies on the macroalgal flora should continue to follow likely ecological modifications of the macroalgal flora during its present transitional state.

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CHAPTER 8 THE STATE OF ZOOBENTHOS (N. Revkov et al.)

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8.1. Introduction

The state of zoobenthos community structure and functioning may be considered as one of the most conservative indicators for assessing the structural and functional changes and thus its ecological health. In the 1960s, the northwestern shelf was used to be represented by very rich fauna and nourishing place for economically valuable fish species. The anthropogenic disturbances made this biocoenosis less vulnerable to the environmental changes in the 1970-1980s, and diminished its benthic populations particularly in the discharge regions of Danube, Dnieper, and Dniester Rivers. As a result, the zoobenthos community structure shifted to the dominance of smaller size hypoxia tolerant groups and opportunistic species that resulted in an increase in total zoobenthos abundance but decrease in total biomass. Degradation of benthic communities has further been intensified by other forms of pollution, impacts of exotic invaders and their unsustainable exploitation. Regarding to exotic invasions, wide diversity of biotopes and low species diversity of the Black Sea has provided favourable conditions for exotic invaders, which find unoccupied ecological niches without competitors and/or predators. The rate of alien species introductions has been constantly increasing and degrading benthic community structures.

The main characteristic features of the northwestern benthic ecosystem during the intense eutrophication phase may be summarized as follows (Gomoiu, 1992; Zaitsev and Mamaev, 1997): drastic decrease of the specific diversity; simplified zoobenthic community structures; decreasing abundance and biomass of benthic populations; reduction of biofilter strength of the system due to the loss of filter-feeder populations;

qualitative and quantitative worsening of benthic biological resources, especially mollusks; flourishing of some opportunistic forms (especially worms causing sediment bioturbation); invasion by some exotic species (*Mya, Scapharca, Rapana* etc.); severe disturbances in all benthic populations. The present chapter evaluates the status and trends of the Black Sea zoobenthos macrofauna after the 1980s and assesses its present state by focusing mainly on the western and northwestern littoral zones.

8.2. Ukrainian shelf area

During 1973 - 2005, nearly 4500 benthic stations have been executed in the NWS and along the coast of Crimea mostly in the shallow coastal zone, with less frequent sampling at depths deeper than 40 m in the 2000s. The quantitative development and long-term changes of macrozoobenthos were studied using the database of the Benthos Ecology Department of IBSS (Sevastopol) and referenced published materials. The taxa role and species importance were evaluated by the 'Index of functional abundance' (IFA) and 'Density indices' (DI): $DI_i = IFA_i \times p_i$; $IFA_i = Ni^{0.25} \times Bi^{0.75}$, where B_i, N_i and p_i are wet biomass (g m^{-2}), abundance (ind. m^{-2}) and occurrence (0 - 1) of i taxon respectively. The approach to classification of bottom communities was based on the biomass determination of separate species dominating at stations (Vorobyov, 1949).

8.2.1. Taxonomic composition of macrozoobenthos and its long-term changes: Bottom macrozoobenthos community of the Black Sea northwestern shelf (NWS) and of the Crimean Peninsula coastal zone have experienced major population changes and morphological anomalies in the 1970s and 1980s. Most notable changes were encountered in the north-northwestern coastal area including the Karkinitskiy Bay (Povchun, 1992; Black Sea biological …, 1998; Shurova, 2003; Sinegub, 2006) and to a lesser extent along the western and southern coasts of the Crimean Peninsula (Zaika, 1990; Zaika et al., 1992; Petrov, Zaika, 1993; Kisseleva et al., 1997; Revkov et al., 1999; Zaika, Sergeeva, 2001; Makarov, Kostylev, 2002).

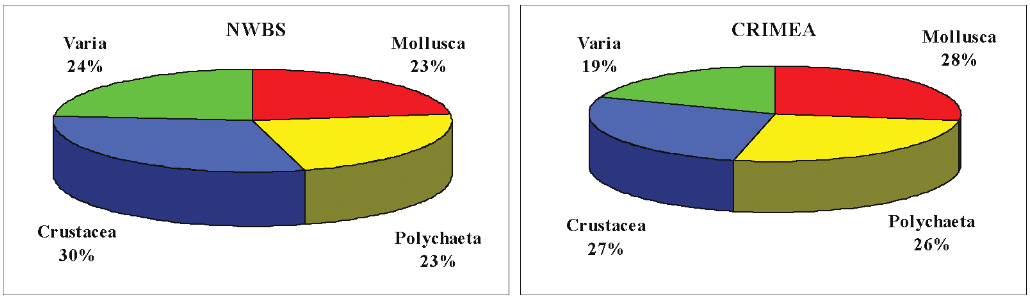

Fig. 8.1. Relative contribution of basic zoobenthos groups in the NWBS and at the Crimea coast during 1967 - 2005 (without taking into account Oligohaeta and Turbellaria).

Bottom zoobenthos fauna of the northern and northwestern coastal zone of the Black Sea has the Mediterranean-Atlantic origin (Mordukhay-Boltovskoy, 1972). It includes 419 species in the NWS (Sinegub, 2006) and nearly 600 species along the coast of Crimea (Revkov, 2003a). However, the recent studies did not focus in sufficient detail on the taxonomy of Porifera, Coelenterata, Nemertini, Turbellaria, and Oligochaeta groups. They have only shown an increase of Oligohaeta species number from 4 before 1967 up to 29 species (Shurova, 2006). For convenience, the Turbellaria, Oligohaeta and Insecta (larvae) groups are excluded from the taxonomical structure of the macrobenthos fauna listed in Table 8.1. The list comprised 363 species in the NWS for 1967 - 2005 as compared to 299 species before 1967 and 271 species during 1973 - 2003. The most numerous group in the NWS was Crustacea (30 %) followed by Mollusca (23 %), Polychaeta (23 %) and 'Varia' (24 %) (Fig. 8.1). The Crimean coastal zone has richer bottom fauna including 574 macrozoobenthos species (Table 8.1) that was formed by 28% Mollusca, 26% Polychaeta, 27% Crustacea and 19% Varia (Fig. 8.1).

Table 8.1. Basic taxa of macrozoobenthos along the NW and Crimean coastlines.

Taxon	The Black Sea, before 1975*	NWBS**			Crimean coastal zone***		
		before 1967	1973-2003	whole observation period	before 1975	1980-2005	whole observation period
PORIFERA	29 (29)	20	6	20	14	17	19
COELENTERATA	36 (32)	27	9	29	24	32	35
Hydrozoa	27 (24)	24	5	25	16	25	27
Scyphozoa	3 (3)	-	1	1	3	3	3
Anthozoa	6 (5)	3	3	3	5	4	5
NEMERTINI	31 (31)	11	3	11	20	3	20
POLYCHAETA	182 (149)	63	66	82	137	151	151
SIPUNCULIDA	1 (1)	1	-	1	-	-	-
PHORONIDEA	1 (1)	1	1	1	1	2	2
BRYOZOA	16 (16)	9	6	10	12	13	15
CRUSTACEA	230 (150)	83	102	111	134	151	157
Cirripedia	5 (5)	3	3	3	4	6	6
Decapoda	37 (35)	18	18	19	33	34	35
Mysidacea	19 (11)	8	8	9	5	8	8
Cumacea	23 (12)	9	10	11	9	15	15
Anisopoda	6 (4)	2	3	3	4	4	4
Isopoda	29 (22)	11	17	18	20	18	22
Amphipoda	111 (61)	32	43	48	59	66	67
PANTOPODA	7 (4)	2	1	2	4	4	5
MOLLUSCA	192 (132)	72	68	84	124	144	156
Loricata	3 (3)	1	1	1	2	2	2
Gastropoda	100 (76)	34	34	43	77	94	105
Bivalvia	89 (53)	37	33	40	45	48	49
ECHI NODERMATA	14 (5)	2	3	4	5	5	5
CHORDATA	9 (9)	8	6	8	9	9	9
Tunicata	8	7	6	7	8	8	8
Acrania	1	1	-	1	1	1	1
TOTAL	748 (559)	299	271	363	484	531	574

The number of species usual for waters with normal Black Sea salinity is specified in parentheses. * from Revkov 2003a, ** from Sinegub, 2006, *** from Revkov 2003a with additions.

These regionally-averaged values, however, differ considerably in the different parts of the NWS and Crimean Peninsula (Fig. 8.2). For example, 209 species were identified in the Dnepr-Bug estuary at 2061 stations, 161 on the shelf between Danube and Dnestr at 674 stations, 166 in Karkinitskiy Bay at 115 stations, and 107 in the Central part of the NWS at 46 stations (Sinegub, 2006). The southern Crimean coastal zone near Karadag comprised 367 macrozoobenthos species comparable to 358 species in the Sevastopol Bay (Revkov, 2005). In Dnepr-Bug and Danube-Dnestr estuary areas, Crustacea were the dominant group and constituted 39 - 40 % of the total species number (Fig.8.2). The "Varia" group had the largest share (24 %) in the Sevastopol Bay.

When the marine forms of main taxa (Porifera, Coelenterata, Bryozoa, Polychaeta, Mollusca, Crustacea, Echinodermata, Tunicata) are only considered in waters with average salinity of 18 ‰, the Crimean fauna is represented by 484 macrozoobenthos species before 1975 versus 531 species during 1980 - 2005 (Table 8.1). Therefore, the number of benthic species in the Crimean coastal zone has not decreased during the last decades. Instead, it was enriched due to 1) expansion of some species, 2) introduction of new forms, previously observed only in the pre-Bosporus region, 3) introduction and population outbreaks of alien species, 4) more detailed analyses of some systematic groups.

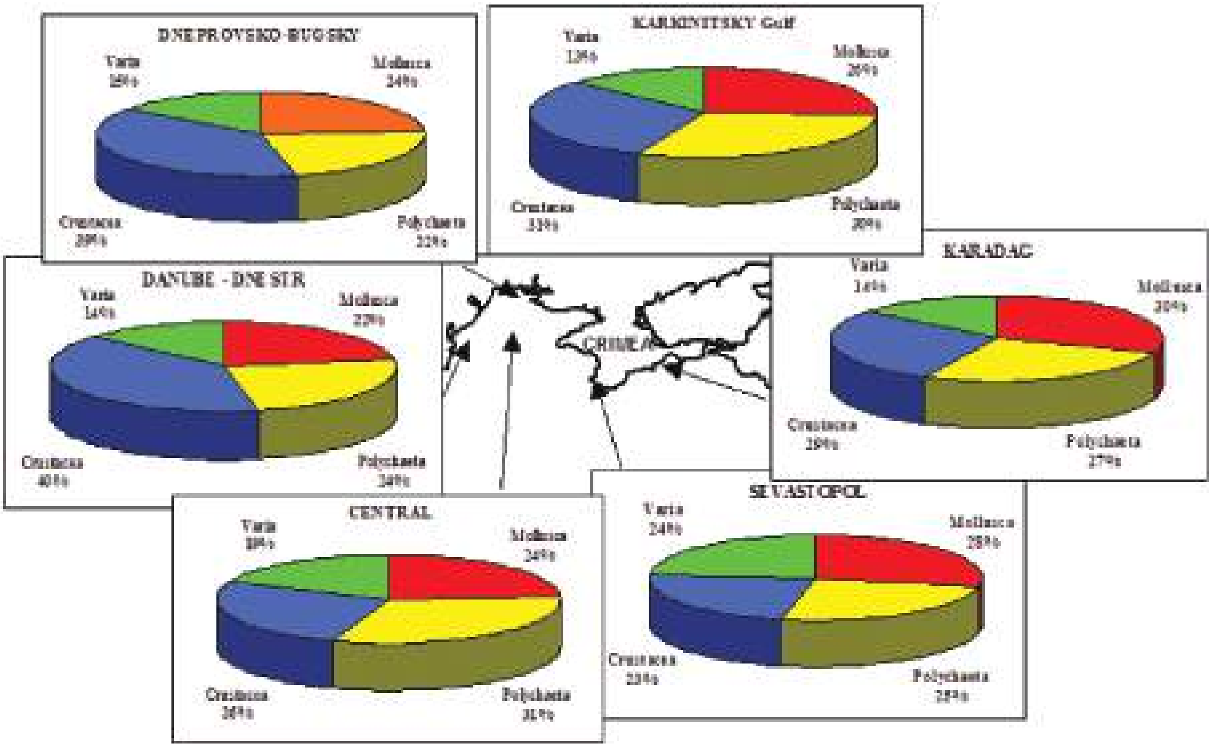

Fig. 8.2. Species numbers (in %) of basic zoobenthos groups in different regions of the Ukrainian sector of the Black Sea. The data used for the NWBS correspond to 1973 - 2003. For Sevastopol and Karadag, the measurement period covered observations prior to 1973.

So far, the group of Hydroids of Crimea was replenished by the species Coryne pusilla (Gaertner, 1774), *Eudendrium annulatum* Norman, 1864, *E. capillare* Alder, 1857, *Opercularella nana* Hartlaub, 1897 and *Stauridia producta* Wright, 1858; in the group of polychaetes new for the Crimean fauna in 1980 - 2005 became *Caulleriella caput-esocis* Saint-Joseph, 1894, *Euclymene palermitana* Grube, 1840, *Glycera gigantea* Quatrefages, 1865, *Hypania invalida* (Grube, 1860), *Nereis rava* Ehlers, 1868, *Notomastus latericeus* Sars, 1851, *Pectinaria belgica* (Pallas, 1766); new for the science species were described, such as - *Nerilla taurica* Skulyari, 1997 and *Vigtorniella zaikai* (Kisseleva, 1992); crustaceans group was replenished by *Chthamalus montagui* Southward, 1976, *Colomastix pusilla* Grube, 1861, *Cumopsis goodsiri* (Van Beneden, 1868), *Pseudocuma graciloides* G.O. Sars, 1894, *P. tenuicauda* (G.O. Sars, 1893), *Schizorhynchus scabriusculus* (G.O. Sars, 1894), *Orchestia platensis* (Kroyer, 1845), *Parhyale* sp., *Micropythia carinata* (Bate, 1862). Of Pantopoda this is *Anoplodactylus petiolatus* (Kroyer, 1844); of Bryozoa these are *Electra crustulenta* (Borg, 1931), *Schizoporella linearis* (Hassall, 1841) and *Victorella pavida* Kent, 1870. The most numerous additions appeared among mollusks: *Anadara inaequivalvis* (Bruguiere, 1789), *Clausinella fasciata* (Costa, 1778), *Mya arenaria* Linnaeus, 1758, *Doridella obscura* Verrill, 1870, *Hydrobia aciculina* (Bourguignat, 1876), *H. procerula* Paladilhe, 1869, *Melaraphe induta* (Westerlund, 1898), *Mutiturboella cornea* (Loven, 1846), *Pontiturboella rufostrigata* (Hesse, 1916), *Pseudopaludinella cygnea* Anistratenco, 1992, *P. leneumicra* (Bourguignat, 1876), *Pusillina obscura* (Philippi, 1844), *Thalassobia rausiana* (Radoman, 1974), *Th. coutagnei* (Bourguignat in Coutagne, 1881), *Tricolia pulchella* (Recluz, 1843), *T. tricolor* (Bucquoy, Dautzenberg et Dollfus, 1884), *Steromphala crimeana* Anistratenco et Starobogatov, 1991, *Bittium jadertinum* (Brusina, 1865), *B. scabrum* (Olivi, 1792), *Cerithium spinosum* Philippi, 1836, *C. gracilis* Philippi, 1836, *Truncatella desnoyersii* (Payraudeau, 1826) and *T. truncatula* (Draparnaud, 1805). The 'enrichment' of the gastropods took place mostly due to their taxonomical revision.

In parallel with the enrichment of the Crimean macrozoobenthos fauna, some traditionally rare species have not been observed since 1980s. This may be due to their small populations and inadequate sampling, as well as due to difficulties in identification of some specific groups (for example, Nemertini, Porifera, Turbellaria, Oligohaeta), and insufficient analysis of various biotopes. The species which were not observed along the coast of Crimea in 1980 - 2005 included for Anthozoa: *Synhalcampella ostroumowi* Wyragevitch, 1905; for Crustacea: *Palaemon serratus* (Pennant, 1777), *Chelura terebrans* Philippi, 1839, *Eurydice pontica* (Czerniavsky, 1868), *Jaera hopeana* Costa, 1853 and *Limnoria tuberculata* Sowinsky, 1884; for Pantopoda *Ammothea echinata* (Hodge, 1864); for Mollusca: *Cuthona amoena* (Alder et Hancock, 1842), *Doris ocelligera* (Bergh, 1881), *Embletonia pulchra* (Alder et Hancock, 1844), *Eulimella scillae* (Scachi, 1835), *Limapontia capitata* (Muller, 1773), *Parhedyle tyrtowii* (Kowalewski, 1900), *Pontohedyle milaschewitschi* (Kowalewski, 1901), *Pseudovermis paradoxus* Perejaslawtzeva, 1890, *Tergipes tergipes* (Forskal, 1775) and *Trinchesia foliata* (Forbes et Goodsir, 1839); for Bryozoa: *Aetea recta* Hincks, 1880 and *Bowerbankia caudata* (Hincks, 1877). Most of these species were marked earlier as rare.

During 1980 - 1990s along the coast of Crimea, the highest species diversity (242 species) was found at the coastal and relatively shallow depths of 11 - 20 m where mollusks were the most diverse group (81 species). Crustaceans and annelids (74 and 80 species, respectively) had the highest diversity at the depths of 0 - 10 m, and the fauna of miscellaneous species (35) - at the 21 - 30 m depth range. The presence of more various bottom fauna under the conditions of the rather shallow coastal zone was accompanied by a greater variety of habitats. For the whole observation period, in Crimean waters 55 macrozoobenthos species were found at depths of 100 m and deeper. These were 19 species of the group Annelida, 18 Mollusca, 7 Arthropoda, 4 Coelenterata, 3 Echinodermata, 2 Ascidiacea and by one species from Nemertini и Porifera. More than half of them are "occasional", and only 26 species can be attributed to "usual" for these depths (Revkov, 2003c). According to M.I. Kisseleva (2004) singular specimens of polychaetes *Aricidea claudiae, Nephtys* sp., *Melinna palmata, Heteromastus filiformis, Terebellides stroemi, Oriopsis armandi* were registered at the depth of 200 m off the southern coast of Crimea.

In deep waters (40 m and deeper) 3 - 5 fold 'visual' reduction in macrozoobenthos species diversity was found in the 1980s as compared to the 1960s (compare the curves 1 and 2 in Fig. 8.3, Zaika 1990). However, in 2003 new data for the period 1980 - 1990s were digested, essentially modifying the understanding of benthos communities development at depths 50 - 120 m. Undoubtedly, the new data showed no real reduction in the total number of benthic species in deep waters, but decrease in their occurrence on the Crimean shelf. In other words, the detection of missing rare species became possible only after analyses of considerably greater number of stations (Fig. 8.3, line 3). At approximately equal number of stations executed at the coast of Crimea both in 1960s and 1980s (nearly 100 stations) the decrease in species population density in 1980s lead to the effect of seeming reduction in diversity.

In a similar way, 3 - 4 fold seeming reduction of bottom fauna diversity was found on the northern Black Sea shelf during 1980 - 1990s (Black Sea biological …, 1998). In reality, decrease in population density of some species (rare chance to find them in the samples) occurred, but they had not disappeared from the local fauna completely.

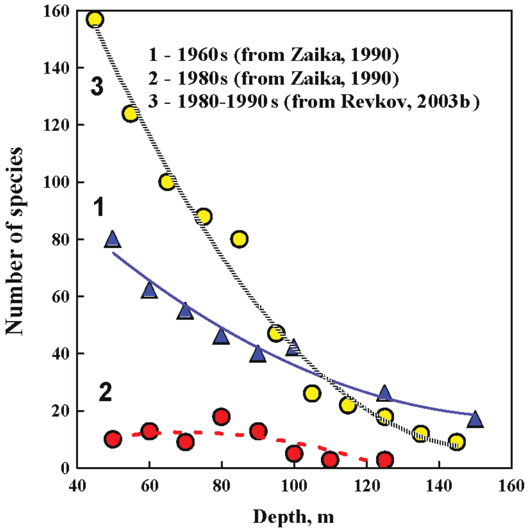

Fig. 8.3. Changes in macrozoobenthos species diversity on the soft bottoms along the coast of Crimea during different periods.

In 2005 - 2007, the total number of species in shallow NWS waters varied in the range of 30 - 60, the lowest values found in the Danube Delta and Odessa Bay regions, and twice higher diversity in Yagorlytskiy and Tendrovskiy Bays (Fig. 8.4). Crustacea and Polychaeta had almost equal and highest contributions, Bivalvia came the second, and the Gastropoda group was represented by lowest number of species at all sites of observations. However, in terms of biomass, the Bivalvia group dominated entirely with: ‹ 500 g m^{-2} in the Danube Delta and Odessa Bay and around 1000 g m^{-2} in Yagorlytskiy and Tendrovskiy Bays, reaching 2000 g m^{-2} in the Yagorlytskiy Bay during 2007 (Fig. 8.5).

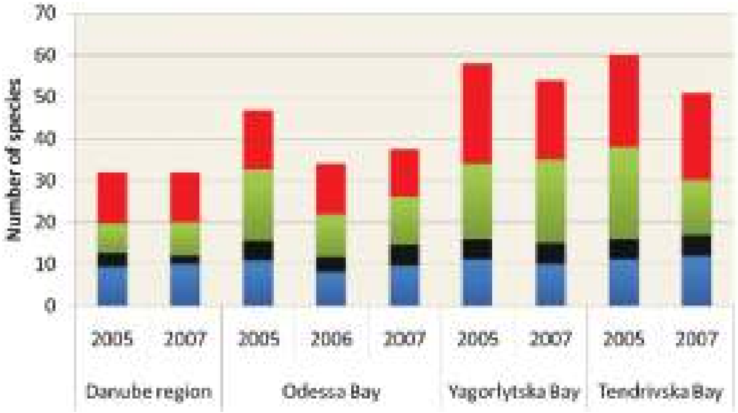

Fig. 8.4. Total number of macrozoobenthos species in different areas of the NW Black Sea: blue - Bivalvia, black - Gastropoda, green - Crustacea, red - Polychaeta (from Ukrainian National Report, 2007).

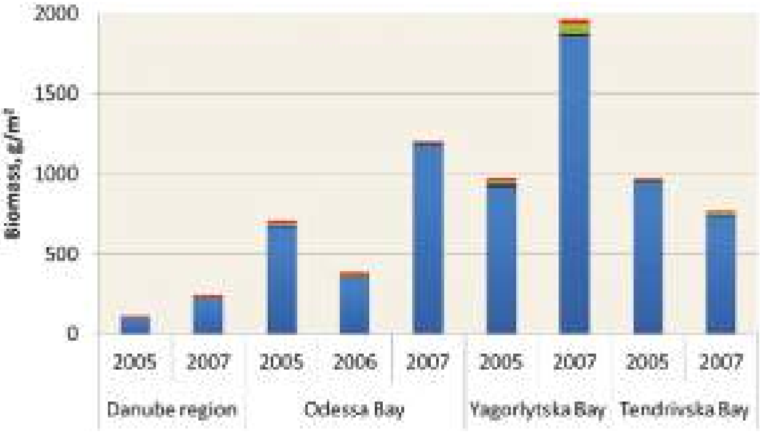

Fig. 8.5. Macrozoobenthos biomass (g m^{-2}) in different areas of the NW Black Sea: blue - Bivalvia, black - Gastropoda, green - Crustacea, red - Polychaeta (from Ukrainian National Report, 2007).

8.2.2. Biocenoses and quantitative development of bottom fauna: During 1983 - 2003, nearly 19 types of bottom biocenoses were described in the NWS (Table 8.2), most of which were autochthonous (Sinegub, 2006). *Heteromastus filiformis, Pontogammarus maeoticus, Paphia aurea, Orchestia cavimana, Anadara inaequivalvis, Irus irus* and *Donacilla cornea* were rather new biocenoses. The biocenoses of *Mya arenaria* and *Anadara inaequivalvis* were formed by introduced species, and the biocenoses of *Neanthes succinea* and *Heteromastus filiformis* were formed temporarily as a result of near-bottom suffocation (Sinegub, 2006).

Using the results of benthos surveys carried out in 1980 - 2004 along the coast of Crimea, about 50 bottom biocenoses can be described. According to the biocenotical classification suggested by Kiseleva and Slavina (1972), the biocenoses of *Mytilus galloprovincialis, Modiolula phaseolina* and *Chamelea gallina* were the most important and widespread ones presented on the maps as concentric zones along the coast. The other biocenoses were of more local origin occupying small areas in the region. The belt-community of *Modiolula phaseolina* extended from the mid-shelf (~50 m depth) to the shelf break (at 120 - 135 m depths) where mollusks were found in the form of fine spots (Zaika et al., 1992). *Modiolula phaseolina* at depths more than 100 m was represented mainly by juvenile forms and its presence was even extended to the sub-aerobic zone at ~180 m (Yakubova, 1948; Kisseleva, 1985; Zaika and Sergeeva, 2001).

The lower boundary of aerobic benthos along the Crimean coast, defined by the position of oxic/anoxic interface, forms the Periazoic belt (depths about 115 - 180 m). It is inhabited by a specific community of polychaete (*Vigtorniella zaikai,* Kiseleva, 1992), *Protodrilus* sp., specific hydroid and foraminiferan species, not studied in detail so far (Fig. 8.6) (Zaika, 1998). The periazoic belt was also found in the north-western part of the Black Sea (Bacesco et al., 1965). It is, however, not known whether the periazoic community forms ring-belt around the entire sea.

The belt of silt mussels *Mytilus galloprovincialis* was limited by the depth range from 30 - 40 m to 50 - 60. At depths less than 30 - 40 m the *Chamelea gallina* belt community is located. Here the benthic habitat becomes more heterogeneous and higher number of factors impact on the distribution of benthic animals. Communities of this zone become more and more patchy. Regional differences in species composition are here more pronounced and in this zone (less than 30 - 40 m) each benthic belt is a habitat of different local communities (Zaika, 1998).

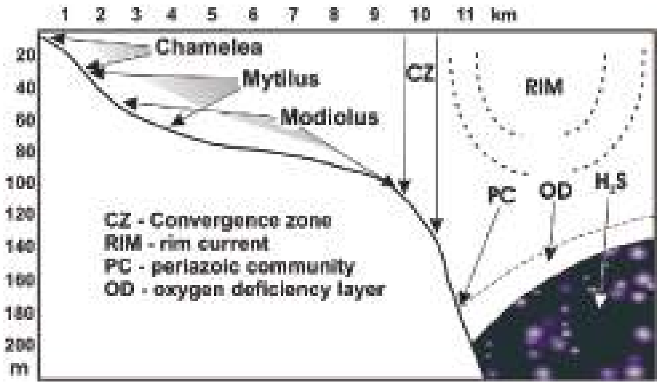

Fig. 8.6. Benthic belts of the Black Sea shelf (from Zaika, 1998, with additions).

The list of leading species on the NWBS shelf is headed by *Mytilus galloprovincialis, Mya arenaria and Neanthes succinea* (Table 8.2), on the Crimean shelf - by *Chamelea gallina, Mytilus galloprovincialis* and *Modiolula phaseolina* (Table 8.3). All three main biocenoses of the Crimean sea shelf are belts. In the biocenosis of *Mytilus galloprovincialis,* occupying large areas in the NWS, the greatest number of species (163) was registered. Significant part of the sampling stations in the Dnepr-Bug and the Danube-Dnestr marine areas (both belonging to the biocenosis of *Mytilus galloprovincialis*) was executed outside the suffocation zone in the depth range of 4 - 10 m (Sinegub, 2006). At this depth range of the Dnepr-Bug marine area, the abundance and biomass of benthos exceeded 10000 ind. m^{-2} and 10 kg m^{-2}, respectively. The lowest average values of abundance (1548 ind. m^{-2}) and biomass (462.2 g m^{-2}) were measured in the biocenosis of *Mytilus galloprovincialis* of the central NWS where the maximal length of mussels did not exceed 40 mm.

Table 8.2. Quantity indicators of development of bottom biocenoses on the NWS shelf during 1983 - 2003 (Sinegub, 2006).

Leading species of biocenoses	Time period	Number of stations	Depth, m	Number of species	Average biomass, ind. m^{-2}	Average biomass, g m-2	Share (%) of leading species biomass	Sites of NWBS*
Mytilus galloprovincialis Lamarck, 1819	1984 - 2003	526	4 - 45	163	2810	1486.7	95.3	NWBS
Mya arenaria Linnaeus, 1758	1984 - 1999	244	6 - 29	87	1630	217.1	82.1	DB, DD
Neanthes succinea (Frey et Leuckart, 1847)	1984 - 2003	132	7 - 29	46	1124	24.2	52.9	DB, DD
Heteromastus filiformis (Claparède, 1864)	1988 - 2000	57	7 - 25	25	352	2.8	65.7	DB, DD
Pontogammarus maeoticus (Sowinskyi, 1894)	1992 - 2001	39	0 - 1	9	8231	66.8	99.7	DB, DD
Cerastoderma glaucum Poiret, 1789	1988 - 2000	31	1 - 23	80	2025	86.7	60.4	DB
Mytilaster lineatus (Gmelin, 1791)	1988 - 2000	28	1 - 11	99	3774	415.1	42.0	DB, Kark.
Melinna palmata Grube, 1870 -	1990	25	25 - 35	10	114	2.7	85.2	Centr.
Paphia aurea (Gmelin, 1791)	1990	18	20 - 31	29	210	41.2	49.3	Kark.
Nephtys hombergii Savigny, 1818	1984 - 1990	16	2 - 35	31	220	5.7	20.3	DB, DD,
Orchestia cavimana Heller, 1865	1992 - 1994	12	0	4	2108	12.3	95.9	DB
Lentidium mediterraneum (Costa, 1829)	1983 - 1993	11	1 - 6	30	9035	78.0	63.9	DB, DD
Chamelea gallina (Linnaeus, 1758)	1985 - 2000	10	6 - 26	65	1203	532.3	72.5	Kark.
Modiolula phaseolina (Philippi, 1844)	1985 - 1986	6	49 - 54	30	762	93.	59.2	Centr.
Melinna palmata Grube, 1870	1994 - 1999	5	15 - 19	15	974	48.5	73.0	DB
Anadara inaequivalvis (Bruguiere, 1789)	1992 - 2003	5	6 - 11	8	2533	198.6	87.4	DD
Irus irus (Linnaeus, 1758)	1988	3	2 - 4	49	6567	1168.0	44.5	DB (T)
Balanus improvisus Darwin, 1854	1983	3	1 - 2	24	6251	213.7	73.6	DB
Donacilla cornea(Poli, 1795)	1992	2	0 - 0.5	7	17800	88.6	80.7	DB (T)

* - NWBS - all areas; DB - Dnepr-Bug sea water area; DD - Danube-Dnestr sea water area; Kark. - Karkinitsky gulf; Centr. - the Central area, DB (E) - Egorlytskii gulf; DB (T) - Tendrovskii gulf.

Table 8.3. Quantity indicators of development of bottom biocenoses at the Crimean shores during 1980 - 2004.

Leading species of biocenoses	Time period	Number of stations	Depth, m	Number of species	Average abundance, ind. m^{-2}	Average biomass, g m-2	Share (%) of leading species biomass	Site of Crimea*
Chamelea gallina (Linnaeus, 1758)	1981 - 2004	157	1 - 32	190	2547	494.9	75.8	Crimea
Mytilus galloprovincialis Lamarck, 1819	1980 - 2001	86	1.5 - 80	215	1767	670.6	77.6	Crimea
Modiolula phaseolina (Philippi, 1844)	1982 - 1999	38	45 - 110	68	596	31.2	63.4	Cr 2, 3, 4
Cerastoderma glaucum Poiret, 1789	1993 - 2004	27	0.5 - 17	106	3092	115.0	62.6	Cr 2
Terebellides stroemi Sars, 1835	1981 - 1999	25	15 - 136	49	338	5.4	64.7	Crimea
Pitar rudis (Poli, 1795)	1982 - 1999	21	4 - 70	111	1648	74.6	51.7	Crimea
Nassarius reticulatus (Linnaeus, 1758)	1982 - 2001	21	1 - 28	146	2218	60.7	47.8	Cr 1, 2, 4
Mytilaster lineatus (Gmelin, 1791)	1994 - 2004	19	1 - 16	127	5006	122.5	59.9	Cr 2, 4
Modiolus adriaticus (Lamarck, 1819)	1983 - 2000	18	3 - 40	104	2171	300.1	54.3	Crimea
Diogenes pugilator Roux, 1828	1983 - 1998	10	2 - 20	32	709	9.8	74.0	Cr 2 - 4
Paphia aurea (Gmelin, 1791)	1980 - 2000	8	4 - 26	60	742	116.8	52.5	Cr 1, 2
Amphiura stepanovi Djakonov, 1954	1983 - 1990	7	60 - 106	24	414	8.5	37.9	Cr 3, 4
Abra ovata (Philippi, 1836)	1993	6	1 - 12	40	2147	146.7	59.8	Cr 2
Nephtys hombergii Savigny, 1818	1987 - 2001	6	10 - 55	29	710	7.4	50.1	Cr 1-3
Parvicardium exiguum (Gmelin, 1791)	1989 - 2004	6	6 - 25	45	2113	81.9	49.2	Cr 2
Balanus improvisus Darwin, 1854	1994 - 2001	4	12 - 17	33	2385	17.9	43.5	Cr 2
Abra nitida milachewichi Nevesskaja,	1980 - 1989	3	8 - 35	30	276	47.1	61.1	Cr 1
Ascidiella aspersa (Muller, 1776)	1992 - 1994	3	32 - 52	29	636	266.3	54.4	Cr 2
Gouldia minima (Montagu, 1803)	1983 - 1990	2	11 - 30	17	570	212.2	60.4	Cr 3, 4
Loripes lacteus (Linnaeus, 1758)	2000 - 2004	2	3	28	1364	39.8	79.4	Cr 2

* Crimea - all areas, Cr 1 - northwest Crimea, Cr 2 - western Crimea, Cr 3 - southwest Crimea, Cr 4 - southeast Crimea.

The transformation of NWS mussel settlements during the 1980s and 1990s was caused by periodic suffocations of bottom fauna, destruction of bottom zoocenoses, and silting of substrata under the impact of large-scale trawling (Shurova, 2003). All of these led to the development of a more simplified population structure of mussel settlements (Shurova, Stadnichenko, 2002), which did not change considerably during the last decade. In summary, the present status of NWS bottom fauna exhibits radical changes in species composition, abundance and biomass both at the species and community level (Sinegub, 2006). The benthos trophic structure was simplified by a sharp reduction in carnivorous and phytophage abundances, domination of detritovorous species by abundance and of sestonophages by biomass in the brackish waters areas of the NWS shelf (river influenced), which experienced the strongest damage by suffocations.

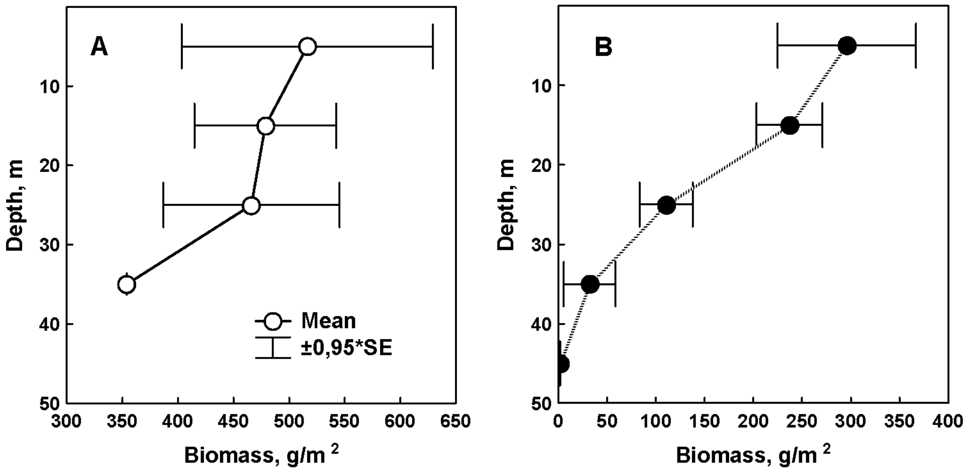

Fig. 8.7. Vertical profiles of the total zoobenthos biomass in the biocenosis *Chamelea gallina* (A) (according to 157 stations) and the biomass *Chamelea gallina* (B) (310 stations) at the coast of Crimea for the period 1980 - 1990s.

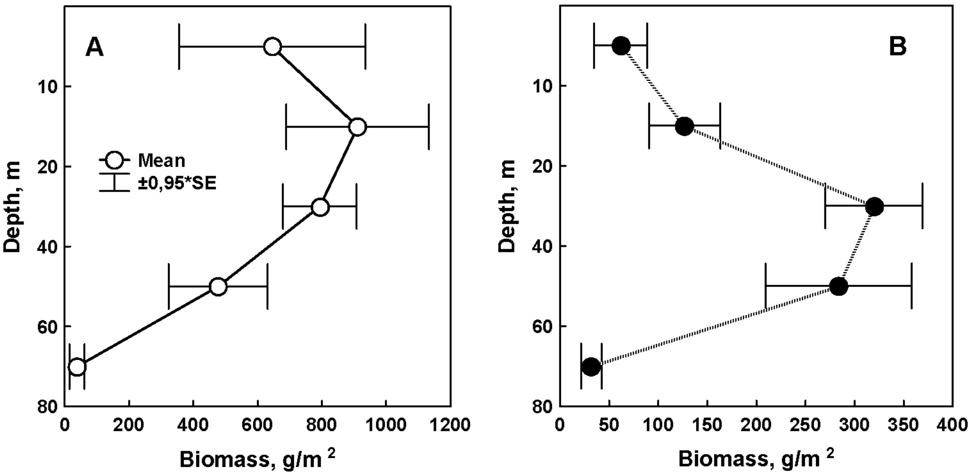

Fig. 8.8. Vertical profiles of the total zoobenthos biomass in biocenosis *Mytilus galloprovincialis* (A) (according to 86 stations) and the biomass *Mytilus galloprovincialis* (B) (370 stations) at the coast of Crimea for the period 1980 - 1990s.

In 1980 - 1990s along the Crimea coast, the maximal average macrozoobenthos biomass in the biocenoses of *Chamelea gallina* (~520 g m^{-2}) was registered within 0 -10 m depths (Fig. 8.7a) and of *Mytilus galloprovincialis* (~900 g m^{-2}) within 10 - 20 m depths (Fig. 8.8a). Previous locations of maximum macrozoobenthos biomasses in the biocenoses of *Chamelea gallina* and *Mytilus galloprovincialis* (1960 - 1970s) were, however, at 25 m and 40 - 45 m accordingly (Kiseleva, 1981). In 1980 - 1990s the maximal total macrozoobenthos biomass, allocated at depths of 10-20 m, did not coincide in space with the maximum of dominant species biomass observed in the biocenosis of *M. galloprovincialis* at 20-40 m depth (Fig. 8.8).

8.2.3. Long-term changes in quantitative development of the soft-bottom fauna: Analysis of long-term data for the period 1930s - 2000s, (Chigirin, 1938; Kisseleva, 1981; Zaika, 1990; Zaika et al., 1992; Kisseleva et al., 1997; Black Sea biological …, 1998; Revkov and Nikolaenko, 2002; Mironov et al., 2003; Mazlumyan et al., 2003; Sinegub, 2006; Revkov et al., 2008) evidences that the bottom fauna in the Ukrainian Black Sea has improved slightly (or, at least, has not worsened) during the last two decades in comparison with the 1970s. The areas below the 'offshore waters' and the 'Sevastopol Bay' of the western Crimea were used as examples to delineate the changes in the zoobenthos characteristics.

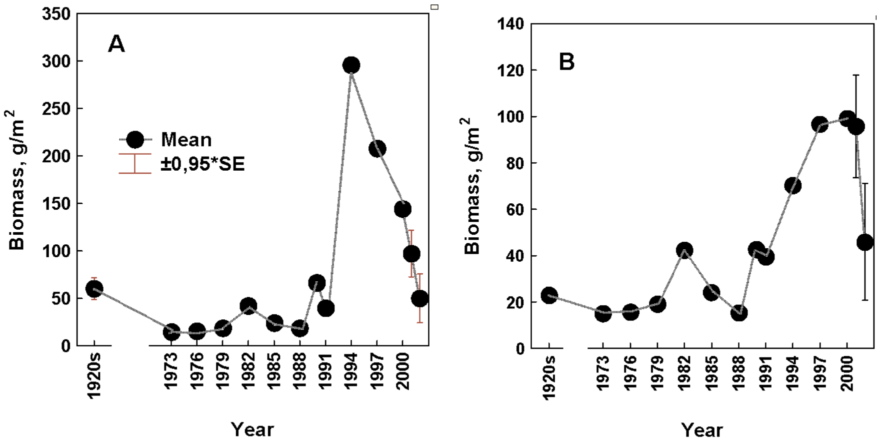

Fig. 8.9. Long-term dynamics of zoobenthos biomass in Sevastopol Bay - with consideration of all macrozoobenthos (A), and without *Mytilus galloprovincialis* which is not a typical soft bottom species of the Sevastopol Bay (B).

Sevastopol Bay: The data from 1920s and 2000s reveal pronounced changes in the development and occurrence of certain benthic forms (Revkov et al., 2008). For example, the most common forms of macrozoobenthos carnivorous *Nassarius reticulatus* and *Nephtys cirrosa* in 1920s with the occurrences of 92% and 89%, respectively, were replaced in 2001 by the detritus-feeders *Heteromastus filiformis* (91%) and *Cerastoderma glaucum* (85%), with *Nassarius reticulatus* remaining as a sub-dominant form observed only at several near-shore bottom sites. The alteration of dominant forms indicates qualitative changes in the flow of organic matter in the benthic ecosystem. Moreover, a pronounced increase in the share of seston-feeders was also found in the 1980s (Mironov et al., 2003).

As shown in Fig. 8.9a, the total zoobenthos biomass decreased by half during the eutrophication period of the 1970s and 1980s as compared to the pristine state, and remained below 50 g m^{-2} until the early 1990s, and then experienced a marked increase to 300 g m^{-2} in the mid-1990s. The latter was followed by a decrease towards the background values in 2000s (Mironov et al., 2003; Revkov et al., 2008). When *Mytilus galloprovincialis* biomass was excluded from the total biomass data, since it was not a typical species for the soft bottom fauna of the Sevastopol Bay, the zoobenthos biomass tended to have a more gradual increase from ~20 g m^{-2} in the 1980s to 100 g m^{-2} at the end of 1990s and then a marked decline in the 2000s (Fig. 8.9b).

Offshore waters of the western Crimea: Similar long-term structural changes in the zoobenthos biomass and abundance were also observed in the offshore waters of the western Crimea. Here, obvious excess of the average biomass was observed in the 1990s at the depths of 1 - 12 m (462±154 g m^{-2}), 13 - 25 m (476±97) and 26 - 50 m (353±180). For the time being the data of 2000s testify to decreasing of the total zoobenthos biomass towards the level of 1950 - 1980s (Fig. 8.10).

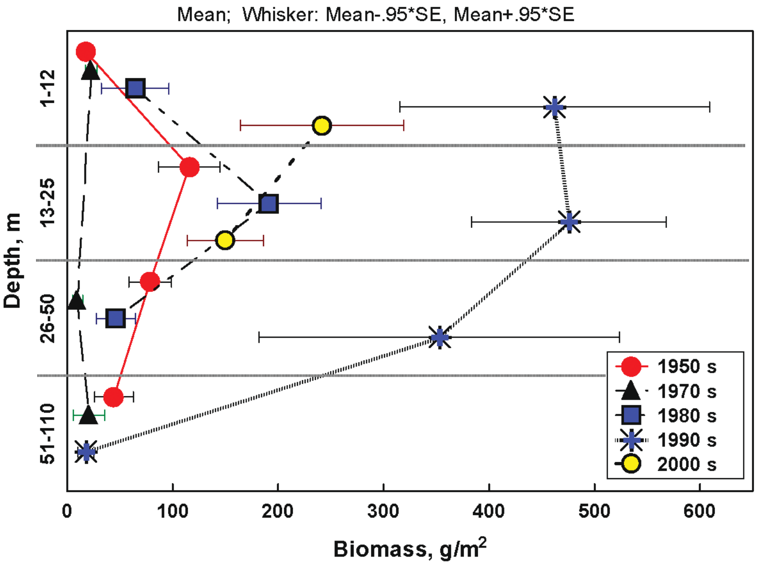

Fig. 8.10. Long-term changes of macrozoobenthos biomass at the western coast of Crimea.

The most significant macrozoobenthos species (by Density index) on the soft bottoms during various periods of study were *Chamelea gallina* (1 - 12 m depths), *Chamelea gallina* and *Gouldia minima* (13 - 25 m), *Mytilus galloprovincialis, Pitar rudis* and *Terebellides stroemi* (26-50 m), *Modiolula phaseolina* and *Terebellides stroemi* (51 - 103 m) (Fig. 8.11).

In terms of 'Density index', *Chamelea gallina* abundance at the 1 - 12 m depth range remained constant (about 25) up to 1980s and then experienced a sharp increase to 300 in the 1990s and decline afterwards to 137 in 2000s (Fig. 8.12). *Chamelea gallina* abundance, also dominating at the 13 - 25 m depth range, changed from 53 in 1980s to 176 in 1990s and dropped to 102 in 2000s. Similarly, *Mytilus galloprovincialis* density index rose abruptly from less than 5 to 153 during the same phase at the 26 - 50 m depth range, but its subsequent trend is not known due to the lack of data. Thus, *Chamelea gallina* and *Mytilus galloprovincialis* became the most optimal zoobethos forms in the 1990s. On the contrary, the density index of *Modiolula phaseolina,* which was the dominant species at the 51 - 103 m range in 1950s, decreased from 53 to less than 1 in 1970s and then remained at this level during 1970s - 1990s.

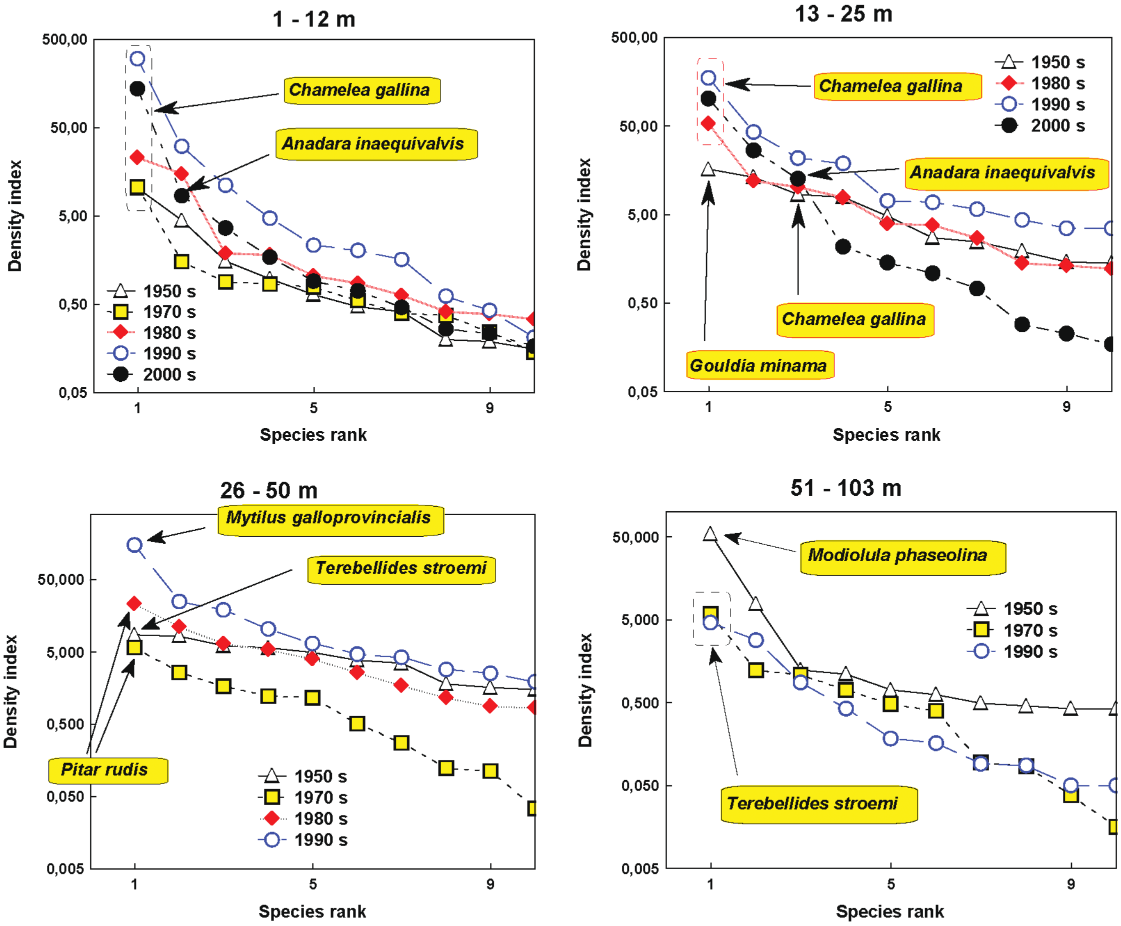

Fig. 8.11. Rank-'Density index' curves for the first 10 macrozoobenthos species at the western coast of Crimea.

We assume that one of the possible factors determining the modern state of benthos at the western Crimea, at depths more than 50 m, is the 'near-bottom' trawling. The areas of most intensive trawling at the coast of Crimea are its western and southern parts with depths 45 - 100 m where steady groupings of sprat are formed (Zuev, Melnikova, 2007). The underwater video observations executed in 2005 at the western Crimea (area off the river Kacha) have shown presence of essential anthropogenic pressure on the bottom seascapes, indicated by numerous traces of 'near-bottom' trawling (Boltachev, 2006).

During the period 1930s - 1990s similar changes took place in the benthos along the south-western coast of Crimea. Here, obvious excess of the average biomass was observed in the 1990s at depths of 13 - 25 m (800 g m^{-2}) and in the 1930s at depths of 26 - 50 m (667 g m^{-2}). In all other cases it is possible to conclude practically comparable levels of benthos development on the mentioned depths during all periods of observations (Fig. 8.13). Such filter-feeding mollusks as *Chamelea gallina, Spisula subtruncata, Paphia aurea, Mytilus galloprovincialis* and *Modiolula phaseolina* are the most pronounced "evolutioning" organisms, determining the revealed quantitative alterations in this region and the mode of functioning of benthic communities during all periods of observation.

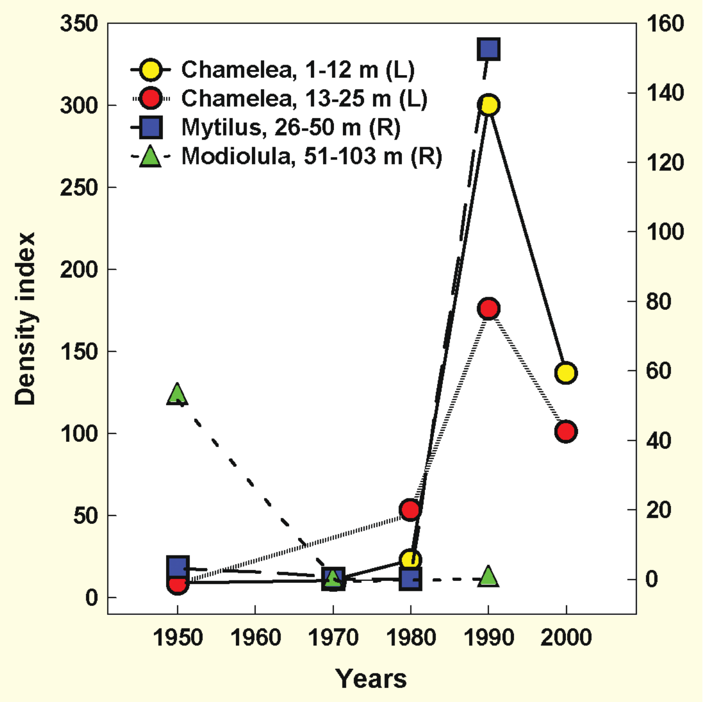

Fig. 8.12. Long-term changes of 'Density index' values with respect to populations of *Ch. gallina, M. galloprovincialis* and *M. phaseolina* at the western coast of Crimea. The 'Density index' axes on the left and right are marked by L and R, respectively, in the figure.

In the Lisya Bay, located about 3 km to the west of Karadag (southeastern coast of Crimea), the number of species of all dominant trophic groups increased in 1973 - 1998, and the total species number changed from 56 to 93. Consequently, the average benthos abundance increased from 395 to 7066 ind. m^{-2} and the biomass from 35.66 to 778.44 g m^{-2} (Mazlumyan et al., 2003). These changes were further accompanied by reduction in soft bottom areas and expansion of the macrophytes zone. The latter affected the qualitative structure of macrofauna by increasing crustaceans and phytophilous species number. The role of filter-feeders increased markedly due to the domination of *Chamelea gallina.* Based on the survey conducted in summer 2008, preliminary results suggested that the total biomass of the Lisya Bay benthic fauna is approaching to the values of 1970s.

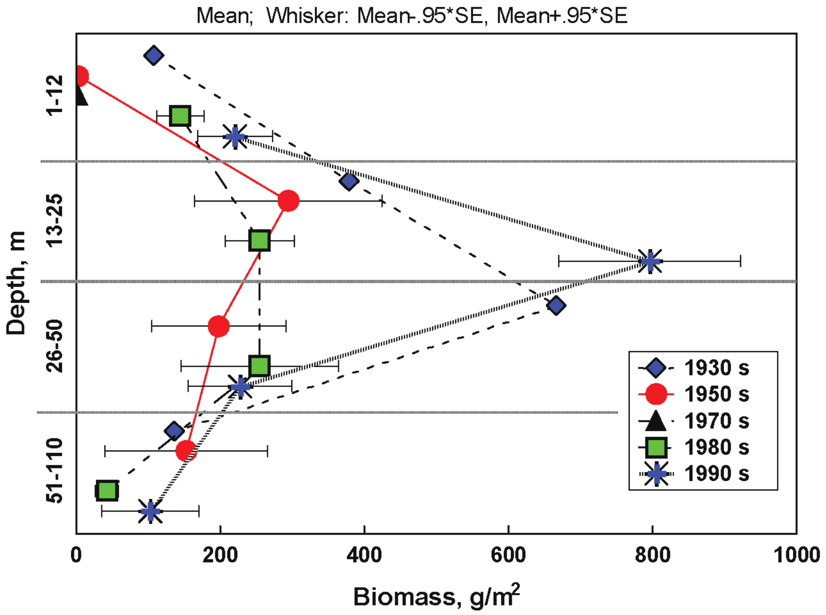

Fig. 8.13. Index of Biomass of benthic groupings per different years. Range of depths in groupings: a - (sandy zone) - 1 - 12 m, b - (silty-sand) - 13 - 25 m, c - (mussel silt) - 26 - 50 m, d - (phaseolina silt) - 51 - 110 m.

Thus, the tendency of sharp benthos biomass increase during the 1990s appears to be a common feature for many coastal waters of the northern Black Sea, related to the adaptation of the benthic ecosystem to increasing organic pollution. The filter-feeding molluscs *Chamelea gallina* and *Mytilys galloprovincialis* (in offshore waters) and *Cerastoderma glaucum* (in the internal part of the estuarine water areas) became the most abundant forms and altered the benthic assemblages structure along the Ukrainian coastal zone. Recent data from the 2000s testify to reduction in the total zoobenthos biomass towards the level of the 1970 - 1980s, possibly due to a reduction in abundance of pollution resistant species.

8.3. Romanian shelf area

8.3.1. Peculiarities of zoobenthos during the previous state of ecosystem

Almost 800 taxa of benthic invertebrates have been identified in Romanian coastal waters between 1960 and 1970 (Bacescu, *et al.,* 1965), a major portion of which belonged to meiobenthos. The lack of taxonomic studies after 1970, during the period of serious ecological disturbances in the region, however resulted in a gap in the zoobenthic diversity studies.

The most widespread biocoenosis *Lentidium (Corbula) mediterraneum* in the 1960s northern Romanian coastal zone was represented by very rich fauna (over 100 taxa, mostly molluscs and meiobenthic species), high abundance (> 100000 ind.m^{-2}) and biomass (> 50 g.m^{-2}) (Bacescu et al. 1957, 1965). Because of this richness, the biocenoses used to represent a nourishing place for economically valuable fish species. The anthropogenic disturbances however made this biocoenosis less tolerant to the environmental changes in the 1980s and 1990s, diminished its populations, and dropped the abundances from more than 20000 - 30000 ind.m^{-2} in the 1960's to 3000 ind.m^{-2} in the 1980s. Similarly, the density of *Spio decoratus,* an important polychaete of this biocenosis, decreased from 30000 - 50000 ind.m^{-2} to less than 1000 ind.m^{-2}. At the same time, some new opportunistic species (e.g. polychaetes *Neanthes succinea* and *Polydora limicola,* bivalves *Mya arenaria*-soft clam and *Scapharca cornea; syn. Anadara inaequivalvis*) have appeared and started dominating eutrophic areas (Gomoiu, 1976, 1985; Tiganus, 1988).

The development of soft-shell clam *Mya arenaria* in sandy infralittoral zones of Romanian shallow waters has been an important ecological event. Following its settlement, *Mya* has become a mass species with the average density of 1037 ind.m^{-2} and biomass of 1936 g.m^{-2} in 1970-1971. It dominated other molluscs and replaced the aboriginal mass species *Lentidium mediterraneum* community sensitive to ecological changes in the 1970-1980s (Petranu and Gomoiu, 1972). As an opportunistic species with a high capacity for regeneration, *Mya arenaria* was able to take advantage of consuming increasing quantities of organic matter available in the environment.

The biocoenoses of coarse sands in the mediolittoral of southern zone was characterized by the bivalve *Donacilla cornea* (syn. *Mesodesma corneum*) and sometimes associated with the polychaete *Ophelia bicornis* in the 1960s. Both of these species have not been recorded in the subsequent decades, but the bivalve *Donacilla cornea* was registered again in 2004 (Micu and Micu, 2006). In addition to pollution, coastal engineering constructions (dams, barrages) have also caused scarcity of *D. cornea* population and the polychaete *O. bicornis* disappearance from the shallow water bottoms. Invaders from the upper infralittoral *Idotea baltica, Gammarus subtypicus* and *G. olivii* occupied their niche and became mass species.

Rocky substrata forming only 0.3% of the total sea floor area of the Romanian shelf have included ecologically important benthic communities, the biocoenosis of the *Mytilus galloprovincialis* being the most important.

Hard substratum constituted the most complex environment in the benthic realm with the greatest diversity of fauna, including over 40% of the total identified species and 2.5% of the whole fauna stock of the Romanian littoral.

In the present decade, a survey in the benthos rocky zones indicated a slight decline in biodiversity, mostly in the crustacean community, which has been observed since the beginning of the 1980's. Twenty years ago, *Jassa ocia* and *Erichtonius difformis* accounted for 45% and 30% of the total abundance of amphipods, respectively. Research conducted between 1993 and 1998 revealed that *E. difformis* accounted for 12% while J. ocia 9% of the total amphipods abundance. Concerning the decapods, four crab species (*Pachygrapsus marmoratus, Pilumnus hirtellus, Xantho poressa* and *Rhitropanopeus harissi tridentatus*) were found in rocky zones. Both *Pachygrapsus* and *Rhitropanopeus* were still numerous, especially their juvenile individuals in the rocky zones in the southern littoral. *Xanto poressa* had a smaller distribution than in the 1980s. The large-size decapods species, such as *Crangon crangon,* the shrimps *Palaemon elegans* and *P. adspersus* constituted mass species in the past. Now, *P. adspersus* is considered as endangered and rare species.

Apart from eutrophication and pollution, the main cause of these changes was the reduction in macrophyte fields, mainly of the perennial alga *Cystoseira barbata* habitat.

The range of vagile fauna had shrunk and there had been severe reductions in populations of phytofile species (Tiganus & Dumitrache, 1995). Another negative ecological impact was the penetration of the predator gastropod *Rapana venosa,* originating from the Sea of Japan known to be a predacious enemy for the littoral malacofauna. It firstly appeared in the Danube estuaries and rapidly spread southward and became a common element in shallow waters both on sandy and rocky bottoms (Gomoiu, 1972). This gastropod species was found most abundantly and frequently on rocky bottoms between 4 m and 10 m isobaths with a maximum density (up to 10 - 12 ind.m^{-2}) at 8 m depth. Because of its high consumption of bivalves, especially *Mytilus* and *Mya,* it played a key role as natural biofilters.

The *benthic communities of muddy bottoms* have been influenced by numerous factors, including increased water turbulence and sedimentation. High load of alluvial deposits carried by the Danube River continually modified the substrata and induced instability.

Two subcoenoses in front of the Danube mouths at depths between 15 and 50 m included sandy-muddy type bottom (15-30m) and muddy type bottom (30 - 50m depth) with mussels *Mytilus galloprovincialis.* Hypoxia events associated with frequent and intense phytoplankton blooms caused mass mortality and impoverishment of many species of these subcoenoses (Gomoiu, 1981, 1983). Out of 32 species existed at 10-30 m depth range in 1975-1977, 22 remained in 1979, and only 14 in 1980 (Tiganus, 1982).

The muddy biocoenosis was considered to be the richest biocoenosis in the entire sector containing 50 different types of organisms among which *Mytilus* was the most dominant between 1960 and 1965. The presence of *Phyllophora* field in front of the Danube mouths at depths of 40 m played a significant role on the enrichment of the benthic fauna. When *Phyllophora* populations had declined to the point of extinction, the biodiversity started degrading during the 1976-1980; the most affected species became molluscs and crustaceans. Crustaceans reduced from 15 in 1977 to 2 in 1980 and molluscs declined from 20 to 4 over the same period. On the other hand, the populations of some opportunistic species have proliferated and become dominant in some communities such as: *Mya arenaria, Neanthes succinea, Polydora limicola and Melinna palmata.* For example, the polychaete worm *M. palmata* formed abundant populations and has become characteristic of communities at 15 - 30 m depths (Gomoiu, 1981, 1985; Tiganus, 1982, 1988). The benthic communities on the sedimentary substratum have become more homogenous and large areas have been dominated by these opportunistic species.

Along the Romanian littoral, the *Modiolus phaseolinus* biocoenoses was the most characteristic species on the bottoms from 55-60 m to 120 m. It covered an area of 10,000 km^2, which roughly corresponded to 40% of the total Romanian continental shelf (Bacescu *et al.,* 1971). Its maximum development took place between the Sulina-Sf.Gheorghe (pre-Danubian area) and Mangalia (southern) sectors. Research conducted in 1970 indicated high density and biomass and a good trophic base for benthifagous fish. Measurements performed between 1970 and 1980 did not show any appreciable changes in the *Modiolus phaseolinus* muddy bottom, and it was the only stable biocoenoses as compared with shallow waters biocoenoses. The *Modiolus* biocoenosis was however degraded after 1990 that was identified by the reduction of macrozoobenthic organisms, particularly those less tolerant to pollution, from 36 in 1981-1982 to 33 between 1991 and 1995 and 23 in 2000-2001. As a result, opportunistic species were able to spread even in this community that have already dominated coastal communities and reduced total species number (Fig. 8.14). In general, the mean abundance and biomass of the deep benthic communities reduced from 7800 ind.m^{-2} and 233 g m^{-2} in 1981-1982 approximately five times in 2000-2001. This implies that the decline has begun in the early 1980s as a consequence of hypoxia (Gomoiu and Tiganus, 1990; Dumitrache, 1996/1997) even though this biocoenosis has not been further monitored after 2001.

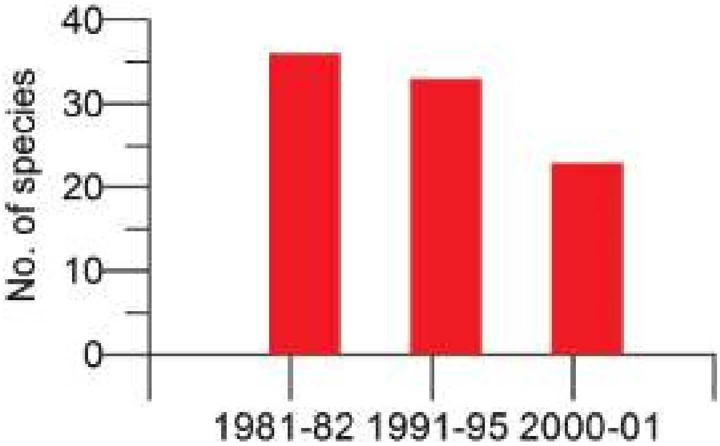

Fig. 8.14. Change in species diversity in the muddy bottom biocoenosis of *Modiolus phaseolinus* during 1981-2001 that was the most characteristic biocoenosis along the Romanian coast from 55m to 120 m.

8.3.2. Peculiarities of zoobenthos during the present state of ecosystem

The pre-Danubian sector: The results of recent researches (Dumitrache and Abaza, 2004; Abaza et al., 2006a, 2006b) emphasized an improvement of the qualitative structure of the zoobenthic communities due to reduction in phytoplankton bloom frequencies and intensities. Taking into account the whole area from Sulina to Portitza (the northern sector of Romanian shelf), relatively high *species diversity* at depths between 15 to 50 m was registered. As compared with 20-to-24 species in the 1990s the macro-benthic fauna was represented by 26-to-44 species during 2000-2003, 49 species in 2005. The increase can be even higher since the samplings in 2004 and 2005 only covered the northern Romanian sector between 5 m and 20 m depths (Fig. 8.15).

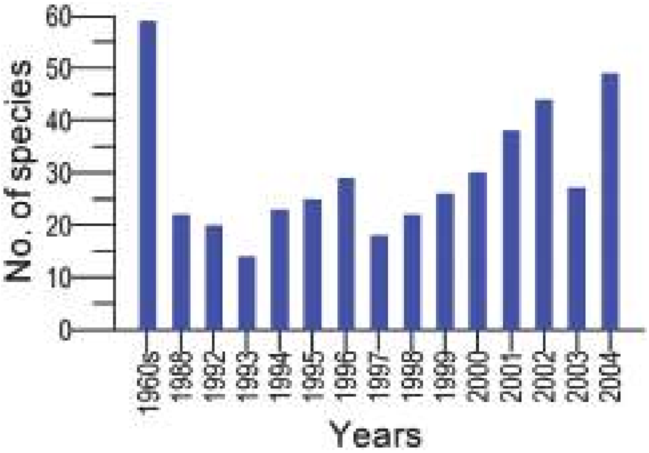

Fig. 8.15. The change in species diversity of the macrobenthic fauna in the pre-Danubian sector of Romanian coastline during 1993-2005.

Regarding the quantitative structure, a slight recovery was noted in abundances of both shallow and medium depth species in 2004 and 2005 with respect to the 1990s: their abundances increased from 2591 ind.m^{-2} to 3140 ind.m^{-2} at 15-30 m depths and from 2128 ind.m^{-2} to 4453 ind.m^{-2} at 30-50 m depths. Worms constituting 95% of the total density dominated quantitative structure. Among polychaetes, most dominant species were *Melinna palmata* (55%), *Neanthes succinea* (52%), and *Polydora ciliata* (50%). The average total abundance at 5-20 m depth range increased to 12186 ind.m^{-2} in 2005 due to the improvement of the bivalve *Lentidium mediterraneum* populations (Fig. 8.16). The high percentage of young specimens (with 1-3 mm length), which settled on the substratum at 5 m depths, suggests process of recovery in response to the improvement in environmental conditions.

Regarding to the biomass, it is difficult to compare the data collected at different months and different depths. The data for 2000-2003 showed a lower biomass value (144.0 g m^{-2}) compared with 1990-1999 (450.0 g m^{-2}) at depths between 10 and 30 m (Fig. 8.17). In this particular case, the soft clam (*Mya arenaria*) populations flourishing at the beginning of the 1970s diminished during the recent years and represented only 25% of total biomass. The decrease can be related to mortalities caused by adverse effects of hypoxia or bottom trawling on benthic organisms. In 5-20 m depth range, the average biomass increased from 289.0 g m^{-2} in 2004 to 796.0 g m^{-2} in 2005. Highest biomass belonged to the mollusks due to their well-developed populations. Among the mollusks, *Lentidium mediterraneum, Cardium sp.* and *Anadara inaequivalvis* were dominant in weight; the last one is an opportunistic, self-acclimatized species, appeared and spread extensively through the highly eutrophicated marine environment. Biomass of mussels (*Mytilus galloprovincialis*) communities on the muddy bottoms between 30 m and 50 m depth increased two-folds as well, because of the well-developed mollusc populations. In this area the mussels were present in large numbers dominated by small and medium size populations.

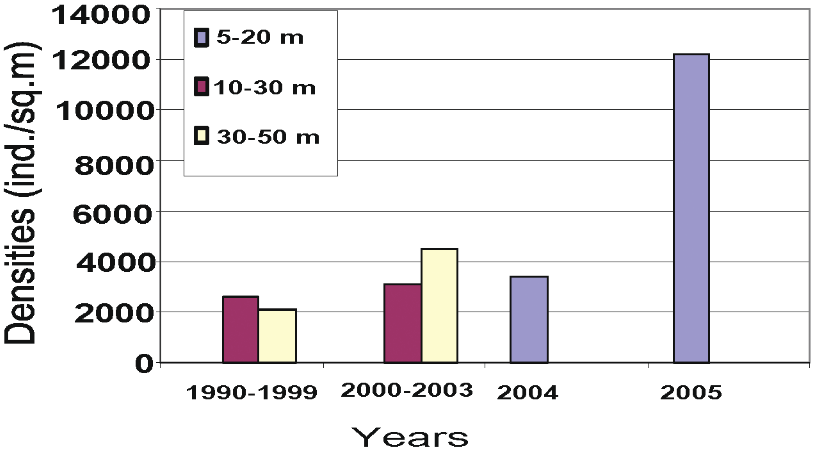

Fig. 8.16. Changes in the average abundances of macrozoobenthos at different depths in the pre-Danubian sector.

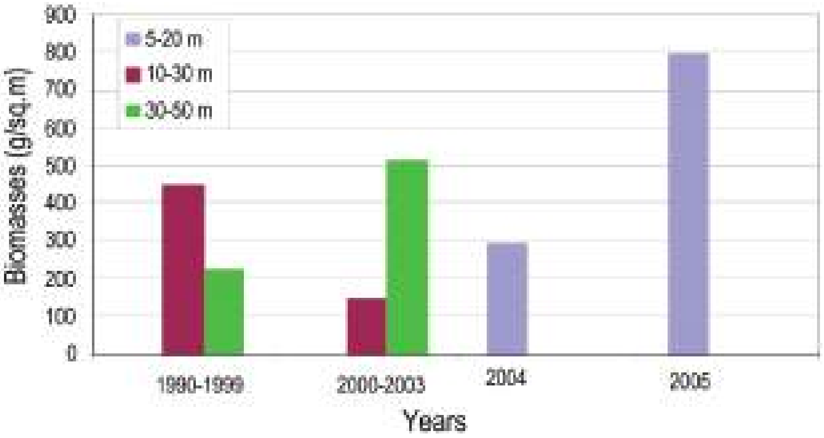

Fig. 8.17 - Changes in zoobenthic average biomass at different depths in the pre-Danubian sector.

The Constanta sector: Long-term investigations in the Constanta sector showed a recovery in terms of species diversity (Tiganus and Dumitrache, 1995). The species number reduced below 10 in 1995-1996 due to negative effects of intense and repeated phytoplankton blooms in spring-summer 1995. Beginning with 1997, weakening of intense algal blooms caused fast recovery and the biodiversity increased from 18 to 53 species in 2002 (Fig. 8.18).

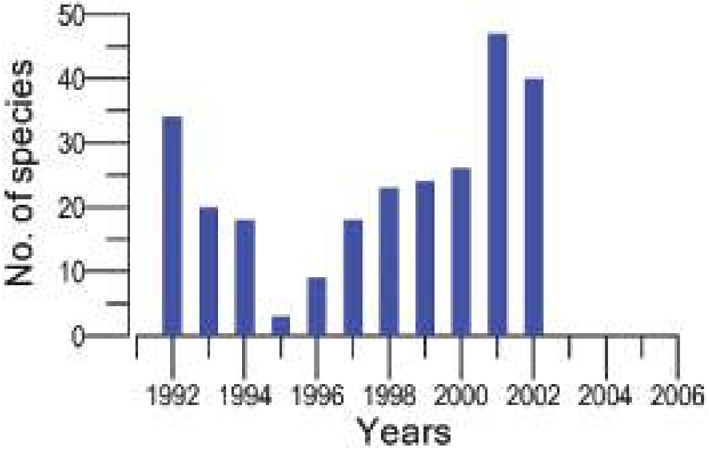

Fig. 8.18. Change of species diversity in the Constanta marine sector between 1993 and 2002.

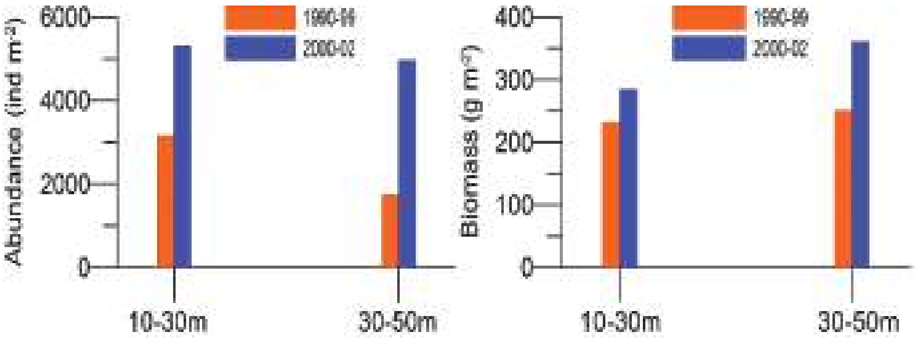

Fig. 8.19. Average zoobenthos abundance (ind. m^{-2}, left) and biomass (g m^{-2}, right) at 10-30m and 30-50m depth ranges in the Constanta sector of the Romanian shelf waters during 1990-99 and 2000-02.

From the quantitative point of view, the abundance increased 2-3 times in 2000-2002 with respect to the 1990s both at 10-30m and 30-50m depth ranges (Fig. 8.19, left). The revigoration tendency of the mollusk and crustacean populations was observed, even if the worms dominated density variation of entire macrozoobenthic population in this area. Similarly, in regards to the biomass the range of values between 286 g m^{-2} at 10-30 m depths and 361 g m^{-2} at 30-50 m depths obtained in 2000-2002 were slightly better than those registered in the 1990s (Fig. 8.19, right). In the *Mytilus galloprovincialis* mud community at 30-50m depths a slight recovery process of biomasses was observed; there are some zones where the mussel populations expanded under more favourable conditions.

The results of benthic ecological research in shallow bottoms (5-20 m) performed between 2003 and 2005 showed a slight reduction in the macro invertebrates fauna from 26 species in 2003 to 21 species in 2005. Similarly, the average abundance (13257 ind.m^{-2}) was higher in 2003 than 2004 (6410 ind.m^{-2}) and 2005 (9710 ind.m^{-2}) (Fig. 8.20) that mostly dominated by *Spio filicornis* and *Lentidium mediterraneum.* The average biomass ranged between 327 g.m^{-2} in 2004 and 800-850 g m^{-2} in 2003-2005 (Fig. 8.22) that was due to a well-defined mollusks community dominated by *Mya arenaria* and *Scapharca inaequivalvis* (Abaza *et al.,* 2006a, 2006b).

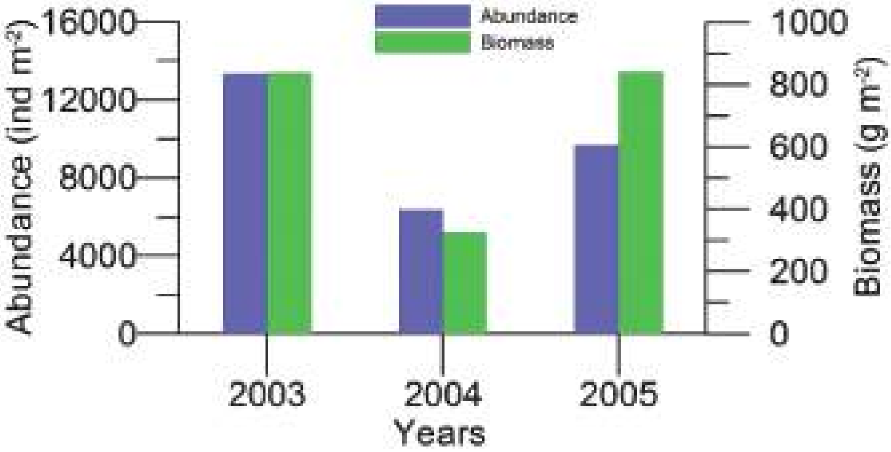

Fig. 8.20. Changes in the average abundance (ind m^{-2}) and biomass (g m^{-2}) of macrozoobenthic populations in the central (Constanta) sector at 5-20 m depth range.

The southern littoral zone: Species diversity in the southern sector of Romanian littoral zone between 15 to 50 m increased steadily in the present decade, and became almost double with respect to the 1990s (Fig. 8.21). The 2005-2007 period maintained relatively stable species number between 50 and 60. In particular, samplings from Tuzla to Vama Veche at depths to 20 m between 2003 and 2005 have revealed 73 different types organisms (Abaza et al., 2006a; 2006b). In the mud mussels' community at 30 m to 50 m depths, maximum 36 macrobenthic species have been identified in 2000-2002 that comprised the members of muddy bottoms biocoenoses as well as iliophylic and opportunistic species. In the subsequent three years, only areas down to 20 m depths have been monitored. The most representative species were the polychaetes *Terebellides stroemi, Prionospio cirrifera, Nephthys hombergi, Exogone gemmifera and Phyllodoce maculata, the bivalves Mytilus galloprovincialis,* and *Modiolus phaseolinus* and the amphipods, *Corophium runcicorne, Microdeutopus damnoniensis, Iphinoe elisae* and *Phtisica marina.* The frequency of these common species ranged between 66% and 100 %. Other two species recorded with 83% frequency were polychaetes *Polydora limicola* and *Melinna palmata.* The new environmental conditions promoted abundant populations of the opportunistic polychaete species *M. palmata.*

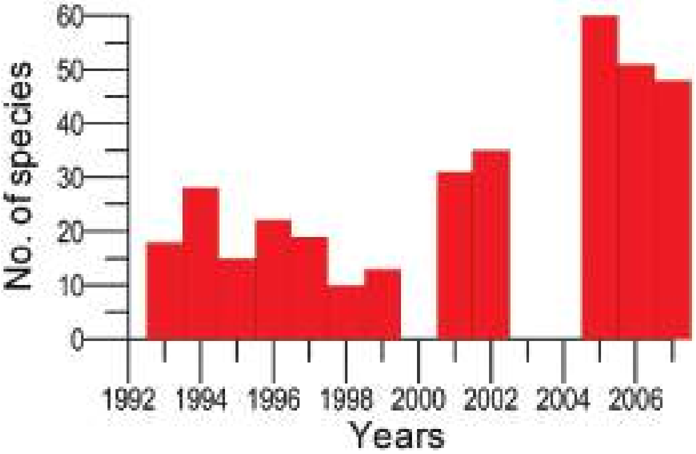

Fig. 8.21. Change of species diversity in the Southern (Mangalia) marine sector between 1993 and 2007.

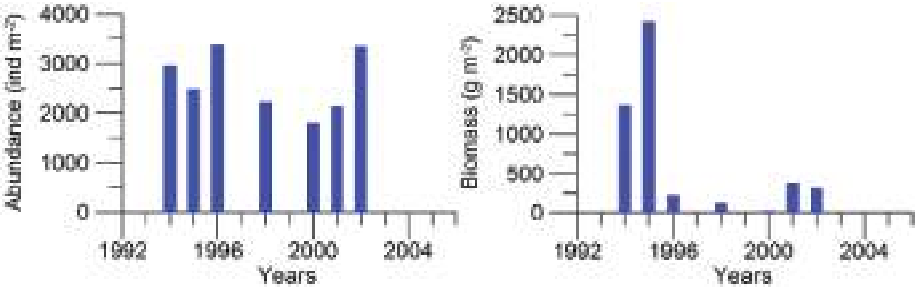

Fig. 8.22. Average zoobenthos abundance (ind. m^{-2}, left) and biomass (g m^{-2}, right) at 30-50m depth range in the Mangalia sector of the Romanian shelf waters during 1994-2002.

From the quantitative point of view, the benthic populations in the mud mussels' community at 30 m to 50 m depths has been subject to moderate interannual variations changing between 2000-3000 ind.m^{-2} since the early 1990s (Fig. 8.22, left). These populations were dominated primarily by worms and secondarily by mollusks and crustaceans. The mollusks however dominated the biomass after the mid-1990s although their biomass remained appreciably low, less than 200 g m^{-2} (Fig. 8.22, right). The abundance at 0-20 m depth range increased from 12377 ind.m^{-2} in 2003 to 14113ind.m^{-2} in 2005. The biomass increased from 1000 g m^{-2} in 2003 to a maximum of 5596 g m^{-2} in 2004 and then reduced slightly to ~4500 g m^{-2} in 2005 (Fig. 8.23). Relatively high abundance in this littoral zone indicates a better capacity of rehabilitation as compared to further offshore.

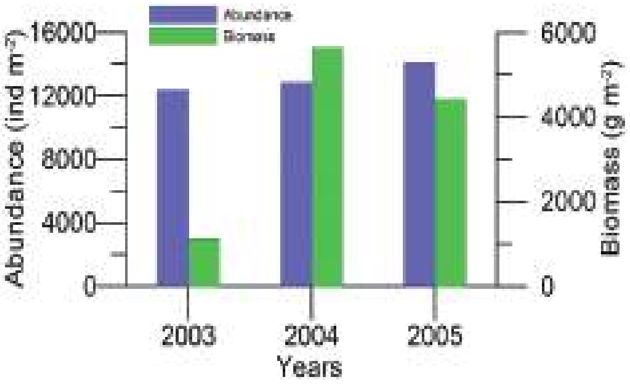

Fig. 8.23. Average abundance (ind. m^{-2}) and biomass (g m^{-2}) of macrozoobenthic populations in the southern sector at 0-20 m depth range.

Comparison of three regions: In terms of average biomass for the 2002-2006 period, the southern sector was three-to-four times superior to the others while the mean abundance is almost comparable to the central but twice better than the northern sector (Fig. 8.24a). The Shannon diversity index varied between 1.5 and 3.5 for all regions during 2002-2006, and implied moderate biodiversity for the central and northern sectors and slightly good biodiversity for the southern sector (Dumitrache et al., 2008). All three regions indicated better macrozoobethos characteristics when compared with the northwestern Ukrainian coastal waters (Fig. 8.7, 8.8). The organisms living in/on the sea bottom also suggested a rehabilitation tendency in terms of their diversity. The species number had a gradual increase in the Danube delta region up to 50 in 2004, comparable number in the central littoral zone and even better in the southern littoral zone (Fig. 24b). The eurioic forms (characterized by large ecological valence) however occurred with high frequencies in all three zones (*Neanthes succinea, Polydora limicola, Melinna palmata, Ampelisca diadema and Mya arenaria*). On the other hand, some species qualified as rare in the Black Sea Red Book, such as *Apseudopsis ostroumovi, Caprella acanthifera and Xantho poressa* were again identified in 2003.

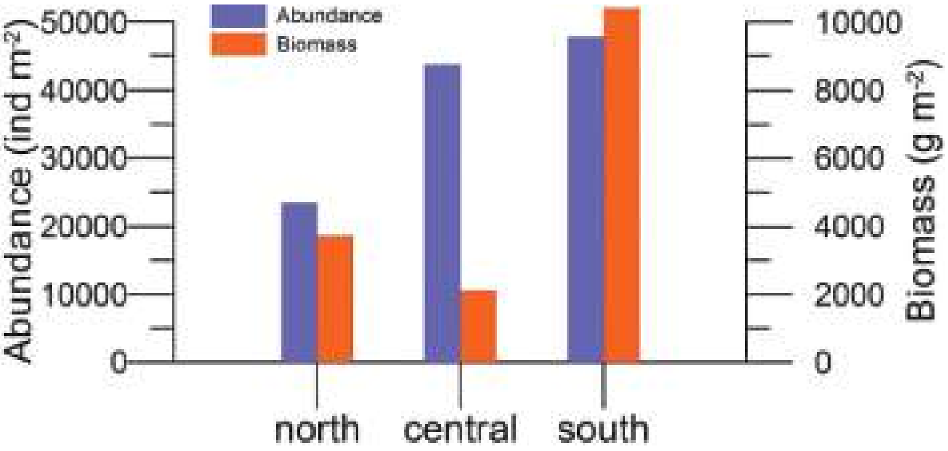

Fig. 8.24a. Average abundance (ind. m^{-2}) and biomass (g m^{-2}) of macrozoobenthic populations during 2002-2006 at 0-20 m depth range of the northern, central, southern sectors of Romanian litteral zone.

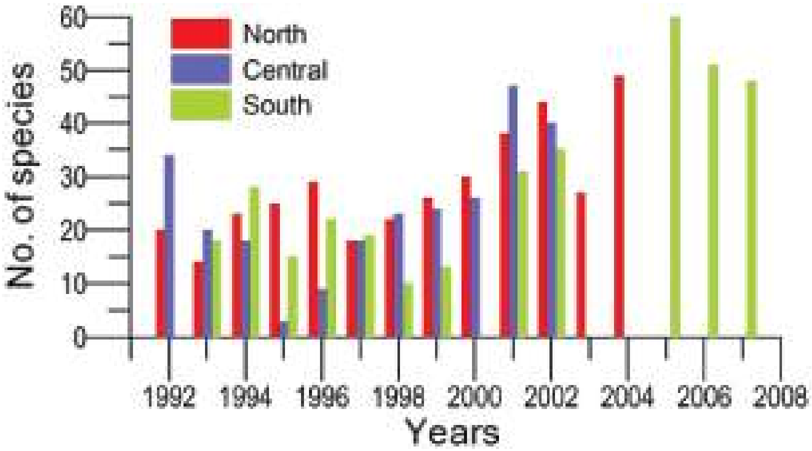

Fig. 8.24b. Change in number of macrozoobenthic species during 1992-2007 in the northern, central, southern sectors of Romanian litteral zone.

8.4. Bulgarian shelf area

The long-term changes in macrozoobenthic communities were examined by comparing recent data obtained along the standard monitoring network of the Institute of Oceanology, BAS (Fig. 8.25) during the summers of 1998-2002 (Stefanova et al. 2005, Todorova and Konsulova 2000) with the reference data from the "pristine" period 1954-1957 of the Black Sea ecosystem (Kaneva-Abadjieva and Marinov, 1960) and the period of the most intensive anthropogenic eutrophication 1982-1985 (Marinov and Stojkov 1990).

8.4.1. Characteristics of major zoobenthic communities

The pool of samples collected during summers of 1998-2002 yielded 134 species and 5 taxa: Polychaeta (41 species), Crustacea (41 species) and Mollusca (38 species), Varia (3 anthozoans, 3 echinoderms, 4 ascidians, 2 pantopods, 1 phoronid, 1 cephalochordate), and the higher taxa included Turbellaria, Nemertini, Oligochaeta, Acarina, and Insecta. The hierarchical cluster analysis (Todorova and Konsuolova, 2000; 2006) differentiated five zoobenthic communities distributed on the Bulgarian shelf as given on the map shown in Fig. 8.26. Bathymetry and sediment type (Table 8.4) were identified as the important determinands of community structure and pattern.

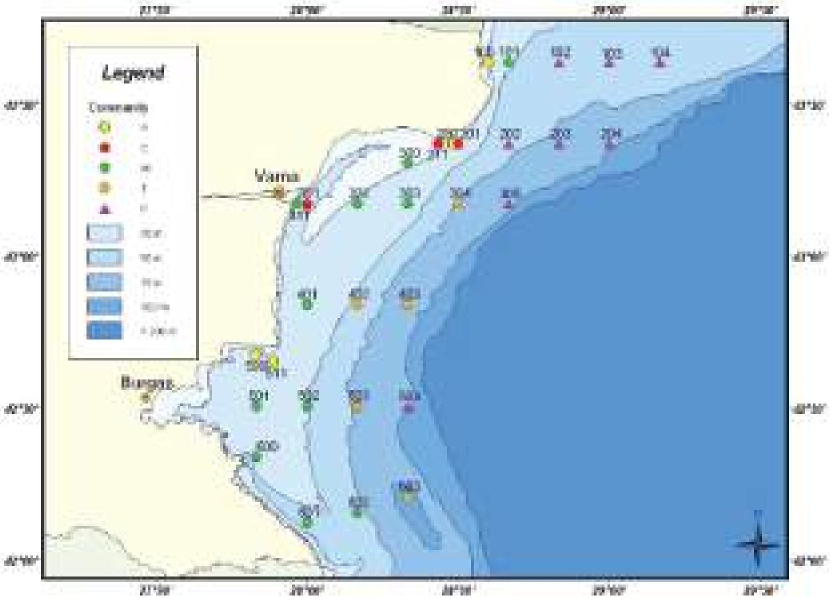

Fig. 8.25. Map of the studied area with sampling locations and communities as differentiated according to the cluster analysis: S - infralittoral sand community, C - infralittoral silt community, M - upper circalittoral silt community with *Melinna palmata,* T - impoverished circalittoral silt community, P - lower circalittoral clay community with *Modiolula phaseolina.*

The "infralittoral sand community" (S) is distinguished by the typical psamophylic polychaetes *Prionospio cirrifera* Wiren, 1883 and *Protodorvillea kefersteini* McIntosh, 1869 and the clam *Chamelea gallina* Linne, 1758 that contribute mostly to between-groups dissimilarity. The community is dominated in the abundance by *Prionospio cirrifera* - second order opportunist, tolerant to disturbance (Borja et al., 2000), *Polydora ciliata* Johnston, 1838 and oligochaetes - first order opportunists tolerant to hypoxia, colonizers of organically enriched sediments (Pearson, Rosenberg, 1978, Gray et al., 2002). The community is the most abundant and diverse assemblage on soft bottom habitats of the Bulgarian shelf (see Table 8.4). This fact stresses the importance of sandy bottom habitats for marine biodiversity conservation as the sandy bank "Cocketrice" (st. 511, Fig. 8.24) was declared as a protected area in 2001 by the Bulgarian Ministry of Environment and Waters. The bank was included into the network of European Marine Biodiversity Research sites established in order to address the climate change effects on species level (Warwick et al. 2003).

The "infralittoral silt community" (C) is dominated in the abundance by *Heteromastus filiformis* Claparede, 1864; *Neanthes succinea* Frey & Leuckart, 1847; *Hydrobia acuta* Draparnaud 1805. These have major contribution to within-group similarity and discriminate the assemblage against other soft bottom communities. *Heteromastus filiformis* is first order opportunist, pioneer colonizer of organically enriched sediments (Pearson, Rosenberg 1978), *Neanthes succinea* is tolerant to disturbance by organic enrichment (Borja et al. 2000, Simbura & Zenetos 2002) and *Hydrobia acuta* is common in organically enriched fine sediments in the Black Sea and Azov Sea, tolerant to episodes of hypoxia and presence of H2S (Tatishvili et al., 1968).

Table 8.4. Habitat features, average conf. lev. 95 % of the number of species (S), abundance, biomass, and Shannon-Wiener community diversity H' index of soft bottom macrozoobenthic communities on the Bulgarian Black Sea shelf, summer 1998-2002.

Habitat/ Community	Depth range (m)	Sediment type	S	Abundance (ind.m-2)	Biomass (g.m-2)	H' (log2)
Infralittoral sand (S)	16-23	sand	37 ± 4	13500 ± 6291	2576 ± 2343	3.55 ± 0.29
Infralittoral silt (C)	12-26	silt	22 ± 6	6404 ± 2793	866 ± 1230	2.69 ± 0.36
Upper Circalittoral silt (M)	17-65	clastic silt, silt	28 ± 2	9923 ± 2206	420 ± 315	2.74 ± 0.15
Impoverished circalittoral silt (T)	64-93	clay silt	19 ± 3	1579 ± 381	21 ± 16	3.08 ± 0.39
Lower circalittoral clay (P)	60-103	Calcareous (shellson clay matrix)	25 ± 4	4581 ± 3316	84 ± 40	2.87 ± 0.49

The "upper circalittoral silt community with *Melinna palmata"* (M) is named after the terebellid worm *Melinna palmata* Grube, 1870 that ranks second in the abundance but has highest contribution to within-group similarity and is a key structural species. Its dense vertical tubes consolidate the sediment and determine the specific character of the habitat. The most abundant is *Aricidea claudiae* Laubier, 1967 considered as a species sensitive to anthropogenic disturbances (Borja et al. 2000, Simbura & Zenetos 2002). "*Melinna palmata* silt" is one of the communities with widest spatial distribution on the Bulgarian shelf (Fig. 8.26).

In terms of species composition, the "impoverished circalittoral silt community" (T) is transition between "*Melinna* silt" and "*phaseolina* clay" communities. The assemblage is dominated by *Melinna palmata*, but its average abundance is 4.5 times lower than "*Melinna* silt community". Increased occurrence of some species typical of deeper habitats such as *Amphiura stepanovi* D'yakonov, 1954 and *Modiolula phaseolina* Philippi, 1844 was observed in this community. Community impoverishment is manifested both in significant abundance/biomass decrease and species richness decline (Table 8.4).

The "lower circalittoral clay community with *Modiolula phaseolina*" (P) is discriminated from the rest of the assemblages by the mussel *Modiolula phaseolina* with highest contribution to within-group similarity and dominant in the abundance. The habitat is characterized by bulk of dead shells and shelly detritus of the same species, hypoxia and increased salinity in comparison to coastal habitats. Other discriminating species are *Amphiura stepanovi* and *Notomastus profundus* Eisig, 1887.

Mussel beds typical of the Bulgarian shelf are not differentiated by the multivariate analysis of similarity as a distinct community assemblage. This is due to the continuous species composition alteration of mussel bed associations in correlation with bathymetry and sediment type.

8.4.2. Spatial patterns of diversity, abundance and biomass distribution

The species richness decreased from shallow coastal sites to deeper offshore sites (Fig. 8.27). Species richness of benthic macrofauna had the second strongest negative correlation with silt-clay percentage in sediments after the strongest positive correlation with oxygen saturation in bottom water Todorova (2005). On the other hand, benthic diversity was weakly correlated with trophic supply. The observed spatial pattern of diversity is therefore basically driven by the depth gradient of decreasing oxygen concentration and hypoxia that are determined by regional hydrochemical characteristics, and further modified by sediment heterogeneity especially at the shallow habitats. The infralittoral sand habitat supported the most diverse zoobenthic community as evident by the highest average number of species and highest Shannon-Wiener index (Table 8.4). Silty and clay habitats were less diverse compared to sand. "Upper circalittoral silt community with *Melinna palmata*" (M) was the richest in species among fine sediment habitats; however increased dominance of few polychaetes yields somewhat lower Shannon-Wiener index (Table 8.4). Minima of Shannon-Wiener index at coastal sites (st. 211, 301, 501) are due to the dominance of *Melinna palmata* and/or *Heteromastus filiformis,* while in the offshore area (st. 102, 204, 504) the observed minima are due to the dominance of *Modiolula phaseolina* (Fig. 8.26).

The abundance and biomass decrease from shallow coastal to deeper offshore area and from north to south (Fig. 8.27 and Fig. 8.28). The decrease along the depth gradient is related to the reduction in trophic supply offshore and significant hypoxia at benthic habitats deeper than 90 m, while the decrease from north to south along shallower coastal zone correlates with reduced primary productivity at increasing distance from the Danube discharge zone.

The abundance structure (Fig. 8.27) is commonly dominated by the polychaetes, except for the "lower circalittoral clay community with *Modiolus phaseolina*" where the predominance of *M. phaseolina* increases the molluscs share. Most of the observed abundance maxima occur in the "upper circalittoral silt community with *Melinna palmata*" due to M. palmata and *Aricidea claudiae* and in the "infralittoral sand community" due to *Prionospio cirrifera* and *Polydora ciliata*. Extensive literature data showed that organic enrichment of sediments due to pollution and eutrophication resulted in an increase in abundance of opportunistic polychaetes largely due to their ability to continuously colonise the newly available sediment and thus overcome smothering and hypoxia episodes (Gray *et al.* 2002; Pearson & Rosenberg, 1978). Excessive abundance of polychaetes along the Bulgarian Black Sea coast suggests over-stimulation of benthic biota due to increased productivity of the marine ecosystem and organic enrichment of the sediments.

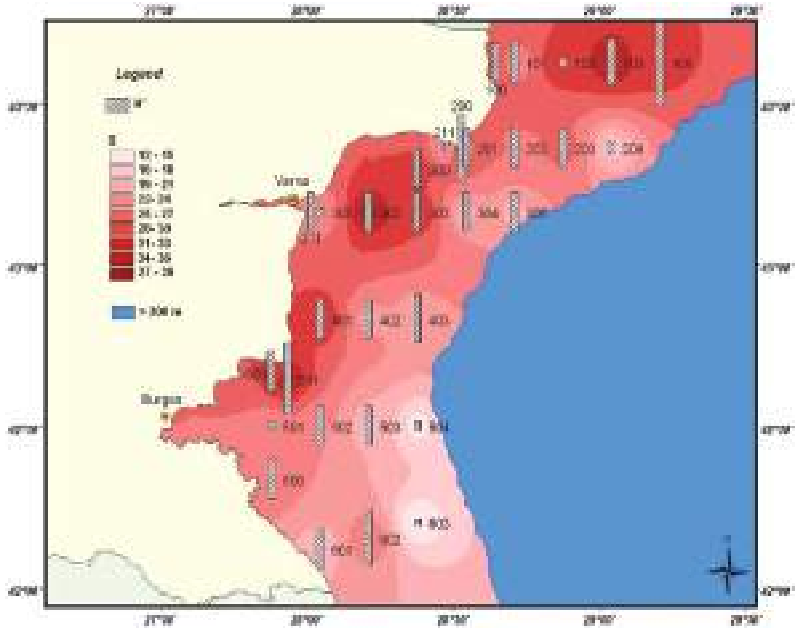

Fig. 8.26. Distribution of the average number of macrozoobenthos species (S) on the Bulgarian shelf and average Shannon-Wiener community diversity (H') index at sampling stations, summer 1998-2002.

Considerable spatial variability of biomass that was caused by patchy distribution of the dominant species (*Mytilus galloprovincialis*) makes difficult determination of its average value within statistically acceptable limits (Table 8.4). The biomass structure (Fig. 8.28) is typically dominated by the bivalve mollusks, except for the "impoverished circalittoral silt community", which is dominated by the polychaetes due to almost complete absence of mollusks in the community composition.

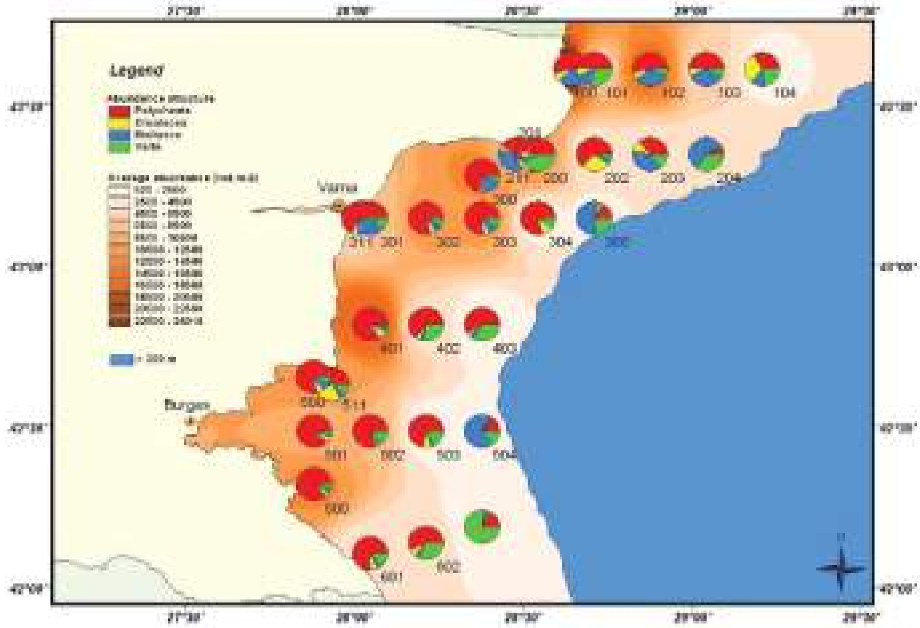

Fig. 8.27. Distribution of average macrozoobenthos abundance on the Bulgarian Black Sea shelf and abundance structure at sampling stations, summer 1998-2002.

8.4.3. Assessment of recent ecological state

The ecological state of benthic macrofauna on the Bulgarian shelf is assessed according to the AZTI Marine Biotic Index (AMBI) (Borja *et al.* 2000) that provides an "ecological state classification" in the range from 0 to 6 in terms of the percentages of abundance of the five ecological species groups according to their sensitivity to stress/pollution. The species are classified as very sensitive to organic enrichment and present under unstressed conditions (the group I), insensitive to enrichment and always present in low densities with non-significant variations with time (the group II), tolerant to excess organic matter enrichment with densities stimulated under organic enrichment (the group III), the second-order opportunistic species (the group IV), the first order opportunistic species (the group V). Opportunistic species are those that can take advantage of adverse conditions and thrive in locations where more sensitive species will not survive; they are capable of rapid colonisation and recovery. First order opportunists are species which first colonise the habitat after mass mortality episodes, while second order opportunists come next.

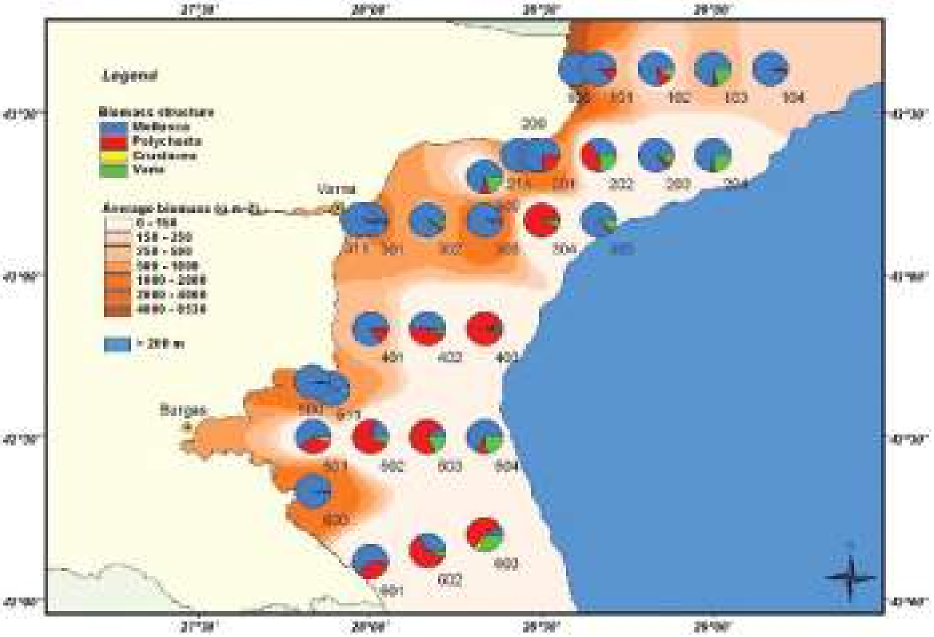

Fig. 8.28. Distribution of average macrozoobenthos biomas on the Bulgarian Black Sea shelf and biomass structure at sampling stations, summer 1998-2002.

The following threshold values are set to distinguish between five categories of benthic disturbance in consistent with the ecological state (ES) classification scheme established by the European Water Framework Directive (WFD): AMBI ≤1.2 Undisturbed community (High ES), 1.2 >AMBI ≤3.3 Slightly disturbed (Good ES), 3.3 >AMBI ≤4.3 Moderately disturbed (Moderate ES), 4.3 >AMBI ≤5.5 - Heavily disturbed (Poor ES), 5.5>AMBI ≤6 Extremely disturbed and azoic (Bad ES).

At few coastal stations in the northern part of the shelf (st. 101, st. 200, st. 202) the ecological state is moderate (Fig. 8.29). Increased community disturbance probably reflects higher level of the eutrophication impact as the distance to the Danube nutrient source decreases. Offshore sites (except st. 603) manifest better ecological state (high at most of the stations, e.g. st. 204, 305, 504) compared to coastal sites. The pattern of improved ecological state offshore evidently reflects decreasing organic enrichment in the open Black Sea area. Despite the natural hypoxia, the environment at deeper offshore habitats is more stable and predictable and less exposed to anthropogenic impact compared to coastal sites, therefore the community is undisturbed or only slightly disturbed as implied by AMBI. The predominance of ecologically conservative bivalve *M. phaseolina* in the abundance/biomass also indicates low level of environmental impact. AMBI, in contrast to diversity indices, is independent of the habitat type, therefore more sensitive in reflecting the anthropogenic impact. On the contrary, the diversity indices may be used for ecological state assessment only if their deviation from reference values, expected under non-degraded conditions in similar habitat types, are known.

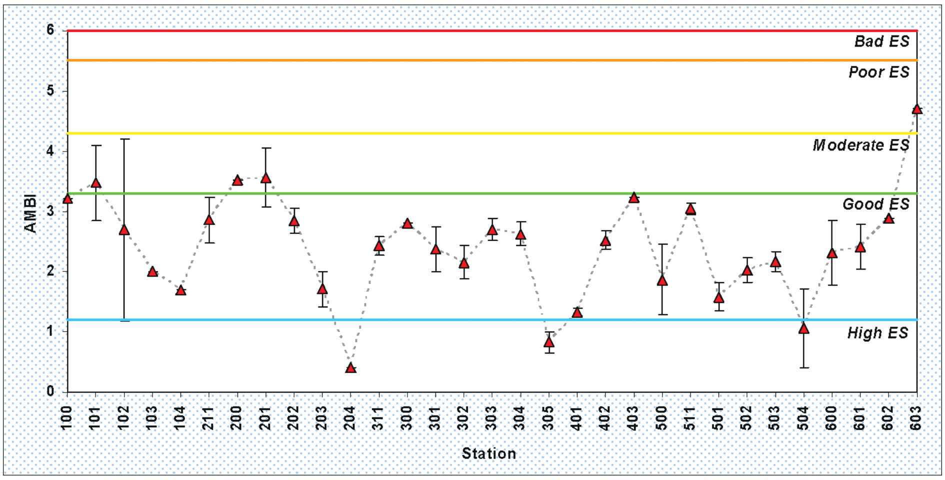

Fig. 8.29. AMBI values (mean±st. error) at sampling stations (according to Fig. 8.26) on the Bulgarian Black Sea shelf, summer 1998-2002 and thresholds for five ecological state categories.

The ecological state classification provided by AMBI manifests lack of undesirable disturbance of benthic communities in the Bulgarian Black Sea area and gives an encouraging sign of ecosystem recovery after a period of severe decline during the 1980s.

8.4.4. Long-term trends in species diversity, abundance and biomass

Species composition: Total 57 taxa of macrozoobenthos organisms were found in 2001-2003 in the Bulgarian Black Sea. The number of species varied from 54 in 2001 to 47 in 2002 and 57 in 2003. These changes were related most probably to over-fishing of Mollusca and Crustacea species and the negative effect of bottom trawling activities on the bottom communities during the commercial harvesting of *Rapana thomasiana*.

The species composition comprised mainly Polychaeta, Mollusca, Crustacea and "Diversa" groups. The majority of species (about 20) belonged to Polychaeta which included some dominant species (*Melinna palmata, Nephthys homergii, Nephthys cirrosa*) which were resistant to strong changes in environmental conditions. The second dominant group Mollusca was presented by 17 species, like *Mytilus* *galloprovincialisand, Mactra subtruncata.* Crustacea was mainly represented by their dominant species *Ampelisca diadema.* Polychaeta had more dominant share (43 %) during the first half of the years and slightly decreased towards the second half (35%). Crustacea (18 %-26%) showed increasing tendency from winter to autumn whereas Mollusca (30-31%) and Diversa (8-9%) species numbers remained steady throughout the year.

Comparison of the recent and historical data sets reveals decreased diversity of benthic macrofauna during the period of anthropogenic eutrophication (1982-85) in all key taxonomic groups (Fig. 8.30a). The polychaetes regained their species richness during the recent period (1998-2002); however, the recovery of the crustaceans, despite significant increase, was incomplete. The current mollusks' richness also exceeded the level of the "pristine" period. Partly this is due to the immigration and naturalisation of several new settlers in the Black Sea such as the predatory gastropod *Rapana venosa,* and the bivalves *Anadara inequivalvis* (Bruguiere, 1789) and *Mya arenaria* Linne, 1758. Their expansion was determined by the rich trophic resources available to the predators and suspension-feeders and by hypoxia tolerance of both alien bivalves (Zaitsev & Öztürk 2001).

As the total number of species analysed depended on the sampling effort, the taxonomic structure is more objective indicator of community composition alterations. The observed changes are characterised by continuous increase of the mollusks' share over the three compared periods, increase of the polychaetes share during the eutrophication period and recovery in the recent period, decrease of the crustaceans share during the eutrophication period and incomplete recovery during the recent period (Fig. 8.30b).

The temporal trends in the taxonomic structure and species richness can be interpreted in the context of tolerance of crustaceans, polychaetes and mollusks to oxygen deficiency. The crustaceans are the most sensitive group to oxygen deficiency, the polychaetes are less sensitive and the bivalves are the most tolerant (Nilsson & Rosenberg 2000, Rosenberg *et al.* 1991). Recurrent hypoxia/anoxia, associated with extensive phytoplankton blooms during the period of anthropogenic eutrophication, probably caused the observed sharp decline of crustacean richness, whereas the mollusks and pollychaetes increased their relative share. The recovery of the crustaceans and polychaetes comparable to the "pristine" state therefore suggests an improvement in hypoxia conditions during the recent period. However, the increase of mollusks share was probably caused by ample organic load to the bottom that caused episodes of oxygen deficiency that reduced other oxygen sensitive species (Moncheva *et al.* 2001).

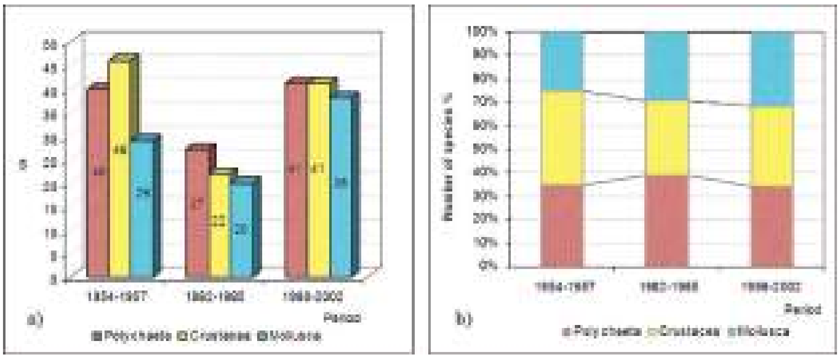

Fig. 8.30. Alterations in (a) total number of species (S) and (b) taxonomic structure of benthic macrofauna over the "pristine" period 1954-1957, the intensive anthropogenic eutrophication period 1982-1985, and the recent period 1998-2002.

Density and biomass: The average multi-annual abundance of macrozoobenthos during 2001-2003 was 1518 ind.m^{-2} that dropped to minimal values 50 ind.m^{-2} in 2002 at 20 miles offshore Cape Emine, and attained its maximal value 5520 ind.m^{-2} in front of Cape Emine in November 2001. The multi-annual average density in front of the Capes Galata and Emine was 1130 ind.m^{-2} for 1992-2000 and became 1037 ind.m^{-2} in 2001-2003. According to the average data for 2001-2003, the main share belonged to Polychaeta (65%) because of their successive outbursts, followed by Mollusca (15%) and then "Diversa" and Crustacea (10%) (Fig. 8.31b).

When compared with the historical data (1954-57), the total average abundance did not rise during the eutrophication period 1982-85, whereas more than 10-fold increase was evident for the recent period (Fig. 8.31a). The overwhelming portion of this abundance increase belonged to Polychaeta. The change in abundance structure comprised the shift from predominant Mollusca species (60%) during the pre-eutrophication period to the current state of opportunistic polychaetes species (65%) (Fig. 8.31b). Thus, Mollusca share decreased by four times and Polychaeta share increased two-folds. High abundance of opportunistic deposit-feeding polychaetes during 1998-2002 indicates excessive organic load to sediments.

The average multi-annual macrozoobenthos biomass in 2001-2003 along the Bulgarian Black Sea coast was 452.253 g.m^{-2} and encompassed the range 0.31-9803.1g.m^{-2}. The extremely high biomass was mainly due to high Mollusca *Mytilus galloprovincialis* abundance is some samples collected at some of its patchy sources along the Bulgarian coast. Furthermore, this mean biomass was almost identical to its 1992-2000 average value of 434 g.m^{-2}. Mollusca biomass was slightly higher than the previous period which may be considered as a positive sign in the evolution of benthic community along the Bulgarian waters, and likely connected to the decreasing tendency of hypoxic conditions, decrease in the *Rapana* abundance due to its commercial harvesting, and diminishing density of *Mnemiopsis*.

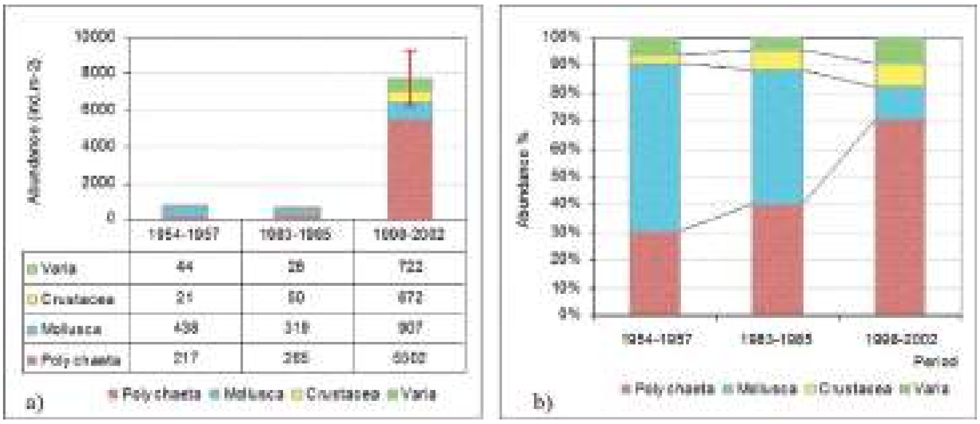

Fig. 8.31. Alterations in (a) total abundance and (b) percent abundance structure for the "pristine" period 1954-1957, the intensive anthropogenic eutrophication period 1982-1985, and the recent period 1998-2002.

According to Pearson and Rosenberg (1978) benthic succession model in response to organic enrichment, the total species number and biomass increase faster than the total abundance as organic load increases above background levels. For further increase in organic load, species diversity starts decreasing, biomass levels off, and abundance raises more rapidly. Additional organic load first causes a sharp peak in abundance with some corresponding increase in biomass and then a rapid drop in both abundance and biomass to background levels due to deteriorated oxygen conditions. Assuming that this model applies to the Bulgarian shelf benthic structure, the present state corresponds to the phase "increase in abundance and level off biomass" prior to the collapse.

8.5. Turkish Shelf waters

Macrozoobenthic populations of the Turkish littoral and sublittoral zones have been investigated only partially so far. For the last 45 years, the studies of zoobenthic organisms carried out mostly within the Bosphorus-Black Sea junction region (Demir, 1952; Dumitresco, 1960, 1962; Rullier, 1963; Caspers, 1968; Kiseleva, 1981; Uysal et al., 2002). These studies were then extended more recently to the rest of the southern coastal waters (Kocataş and Katağan, 1980; Ateş, 1997; Mutlu et al., 1992; 1993; Sezgin et al., 2001; Gönlügür, 2003; Çulha, 2004; Öztürk et al., 2004; Çınar & Gönlügür-Demirci, 2005; Kırkım et al., 2007; Sezgin& Katağan, 2007; Bilgin et al., 2007; Sezgin et al., 2007). On the basis these studies, macrozoobethos species richness along the Turkish coast and the indicator species list are given in Table 8.5 and Table 8.6, respectively.

According to the Table 8.5, out of 10 different groups, Polychaeta, Mollusca and Amphipoda accounted for 76% of the total abundance, followed by Decapoda, Isopoda, Echinodermata, Cumacea, Porifera, and others. 385 macrobenthos species were registered during 1980-2000, and this number increased to 419 in 2000-2007 (Table 8.5). Therefore, no evidence exists for the reduction of species richness in the Turkish Black Sea coastal zone during the last 25 years. Moreover, bottom fauna was enriched in 2000-2007 due to (1) introduction of some species that were previously recorded only in the Bosphorus region, (2) introduction of alien species, (3) Mediterranization (climate change effects), (4) more detailed studies to cover neglected geographical locations or habitats, (5) recovery of ecosystem health. However, contrary to the steady character of species richness, abundance and biomass of some species were dramatically changed. The decline in populations of many benthic invertebrates (Crustacea, Mollusca, Polychaeta), which play a significant role in the food chain of the benthos consuming fish, has been clearly noted in the last two decades. The first visible changes in the structure of coastal benthic communities in southern coast of Black Sea were the incresae in density of some Mollusca species (such as *Patella* spp., *Rapana*, *Chamelea*) during the last 10 years. Moreover, the replenishment of juvenile bivalve populations was found to depend on the strength of *Mnemiopsis-Bero*e interactions in the pelagic zone and therefore subject to considerable interannual variations. Better resistance of *Anadara ineaquivalvis* to environmental stresses than the native species permitted its population to become a dominant group at the 10-30 m depth range.

A comprehensive zoobenthos survey conducted on soft bottoms along the Turkish coast in May-July 1999 (Kirkim et al., in pres) revealed that the depth range 10-25 m, mostly consisting of fine-to-medium sandy bottom sediment, was dominated by polychaete (M. palmata) and molluscs (*C. gallina, L. mediterraneum, L. divaricata*). The total average abundance of zoobenthos was 1524 ind.m^{-2} and their biomass 109 g m^{-2} (Kırkım et al., unpublished data). At the 25-50 m depth range, the composition of bottom sediments slightly changed to sand-mud composition. The number of recorded zoobenthic species decreased to 74. and their total average abundance and biomass was 2134 ind.m^{-2} and 62.4 g m^{-2}, respectively. Within 50-80 m depths, the bottom sediments consisted of the combination of mud, clay and dead shells. The species diversity was the poorest; a total of 52 species recorded among which polychaetes and some echinoderms the most abundant. The total average abundance and biomass of zoobenthos was 1171 ind.m^{-2} and 41 g m^{-2}, respectively (Kırkım et al., unpublished data). In this study, Low dissolved oxygen values of lower layer and soft substratum of sediment resulted in wide distribution of the opportunistic polychaet *M. palmata* (the mean abundance of 450 ind. m^{-2}) that were adapted to such conditions. Molluscs were among the second abundant taxa, accounting for 32% of the total number of macrofaunal species. The most common bivalve, *C. gallina* (69%) had a highest frequency value of the 39 stations, followed by the bivalve *P. rudis* (64%), the gastropod *Cyclope neritea* (Linne, 1758) (59%) (Kirkim et al., unpublished data).

Table 8.5. Species richness of zoobenthos over the Black Sea and along the Anatolian coast (Sezgin et al., unpublished data)

Taxon	The Black Sea	Turkish Black Sea coastal zone		
		1980-1990s	2000-2007	For all time observations
Polychaeta	308	112	120	120
Mollusca	177	103	115	115
Amphipoda	104	75	86	86
Decapoda	59	29	31	31
Isopoda	34	13	14	14
Echinodermata	27	13	14	14
Cumacea	26	12	13	13
Porifera	33	12	11	12
Tanaidacea	6	6	6	6
Anthozoa	6	4	3	4
Ascidacea	10	3	3	3
Cirripedia	7	2	2	2
Sipuncula	1	1	1	1
Total	798	385	419	421

Harvesting of the bivalve *Rudipates decussatus* by dredging the mediolittoral zone damaged the benthic community and destroyed fish habitats, particularly *Solea* and *Scophthalmus*. Some important molluscs (e.g *Donax* sp., *Turitella* sp., *Mactra* sp.) were under the threat due to coastal degragation and destruction. The dredging of sand from the sea also destroyed the benthic habitats along the Turkish coast (Öztürk, 1998). Illegal bottom trawling for *Rapana venosa* harvesting has raised ecological concerns with respect to the benthic communities and especially the mussel beds. The population decline of the habitat-structuring species *Mytilus galloprovincialis* in the impacted areas was accompanied by degradation of the associated benthic community from "mussel bed" type to "silt bottom" type dominated by opportunistic polychaetes and oligochaetes. The mollusc species *M. arenaria* replaced the dominant species *Lentidium mediterraneum* in the coastal sandy strips and thus affected negatively biodiversity of the

Black Sea ecosystem. On the other hand, the high biomass of *M. arenaria* provided food for the benthic fish and coastal birds.

Table 8.6. Some indicator zoobenthic species in the southern Black Sea.

Species	**Description**
CRUSTACEA	
Corophium acutum	higher abundance under increased pollution
Corophium acherisicum	
Ericthonius brasiliensis	
Jassa marmorata	
Hyale crassipes	
Hyale pontica	
Leptochelia savignyi	
Idotea baltica basteri	
Shaeroma serratum	
	sensitive species to hypoxia; indicators of clean waters
Elasmopus spp.	
Crangon crangon	
POLYCHAETA	
Capitella capitata	an indicator of organic pollution
Malacoceros fuliginosus	
Neanthes caudate	
Neanthes succinea	
Ophiodromus pallidus	
Prionospio (Minuspio)	
Schistomeringos rudolphi	
Hydroides elegans	
Syllis prolifera	an indicator of clean waters
MOLLUSCA	
Lentidium mediterraneaum	higher abundance in organic rich environments
Mytilus galloprovincialis	
Mytilus edulis	Species resistant to severe hypoxia
ALGAE	
Ulva lactuca	higher biomass in organic rich environments
Enteremorpha linza	
Cystoreira spp.	an indicator of clean waters
SEAGRASS	an indicator of clean waters
Zostera marina	
Zostera noltii	

Decapod cructaceans *Crangon* crangon and *Paleamon* spp. biomass and denstiy also decreased in last 10 years. An exception is *Mercierella enigmatica* (= *Ficopomatus enigmaticus*) (Polychaeta), whose density has increased; however, this species grows on coastal substrates and is inaccessible for the benthos consuming fish. Presently, domestic and chemical pollution is the main factor controlling the state of macrophytobenthos along the southern Black Sea coastal waters.

Available observations appear to indicate that eutrophication and different survival ability of benthic species in hypoxic conditions played an important role in the development and formation of macrobenthic communities. It appears that the invasion of *Beroe ovata* in 1999 did not play any major role for either the recovery of benthic communities or the development of a new stable structure. On the contrary, disturbing quasi-stability of the system, the community started experiencing more pronounced fluctuations in both abundance, biomass and species structure. On the other hand, the Mediterranization process or invasion of of the system by new species continued.

8.6. Georgian shelf area

Marine Ecology and Fisheries Research Institute (MEFRI) and Georgian Fisheries Trust data focused on monitoring the distribution of invasive species starting by 1949. These data sets suggested that *Rapana* invasion caused sharp decline in the oyster *Ostrea edulis* stock due to the presence of roughly 30 *Rapanas* per 1 live oysters. The data in 1950 further showed considerable spreading of *Rapana* along the entire Georgian coastal waters. This was followed by the reduction of other commercial mollusks as the abundance of *Rapana* continued increasing.

In 1978-1979, the new opportunistic species filtrating mussel *Cunearca cornea* was found initially with sizes 1.0-2.5 cm, and 6-8 cm individuals in the vicinity of the Chorokhi River mouth. This bivalve was especially abundant on the Anaklia bank where mussel collectors were installed in 1978-80. Presently, *Cunearca cornea* is widely distributed in Georgian waters (Gogmachadze & Mickashavidze, 2005).

The last study of benthic communities was conducted in 2003-2004 on a seasonal basis by monitoring 16 stations along the Georgian coast (Table 8.7). In these studies, new exotic species *Anadara inaequivalvis* and *Mnemiopsis leidyi* were found together with significant changes in zoobenthos biodiversity in comparison with previous data (Gogmachadze & Mickashavidze, 2005; Mickashavidze, 2005). Out of 65 macrozoobenthos species recorded, 27 were Molluscs (41%), 18 Crustacean (28%), 20 Polychaeta (31%). Both the zoobenthos species diversity and total abundance were highly variable regionally and seasonally (Fig. 8.32). The species diversity increased as compared to 1990 for all these groups (Fig. 8.33).

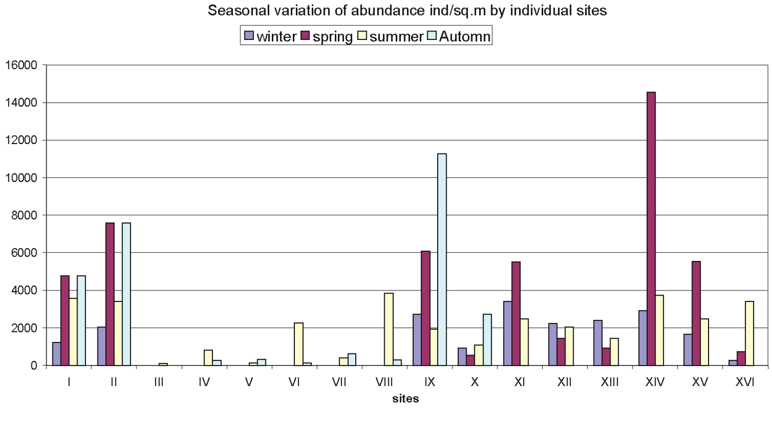

Fig. 8.32. Seasonal changes of macrozoobenthos abundance (ind.m^{-2}) at 16 coastal stations along the Georgian shelf waters in 2003-2004.

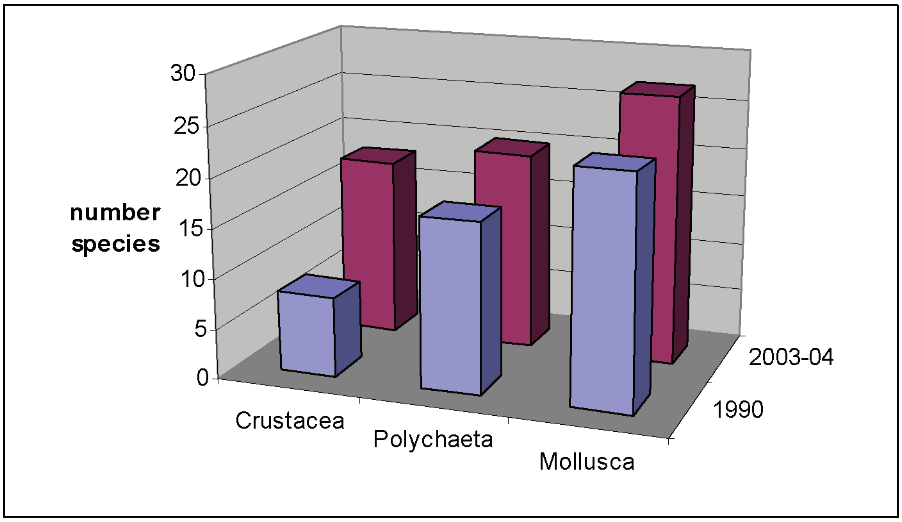

Fig. 8.33. Species number of main macrozoobentic group registered in 1990 and 2003-04 observations along the Georgian coast.

Table 8.7. Quantitative characteristics of the benthic communities in Georgian Black Sea waters in 2003-05.

Area	Substrate	Abundance (min-max) ind.m-2	Biomass (min-max) g.m-2	Species Index (min-max)	Dominant species
	Sand	100-14960	16.9-123.5	0.8-1.8	Chamelea gallina, Lentidium mediterraneum, Mytilaster lineatus,
	Sand (6-10m)	280-14540	8.1-169.9	0.2-2.0	Nephtys longicornis, Chamelea gallina, Rapana thomasiana, Diogenes
Kvariati-Gonio	Sand (6-10m)	2040-11140	60.3-126.0	0.4-2.0	Nephthys longicornis, Chamelea gallina, Lentidium
Between the mouths of river Chorokhi and river Khorolistskhali	gray clay[1]	110	1.1	0	Heteromastus filirormis,
	yellow sand	260-820	3.45-87.1	0.8	Rapana thomasiana ,Callianassa truncate
	yellow sand	134-320	0.74-9.0	0.3	Melinna palmate; Chamelea gallina
	gray sand	2720-11280	6.73-139.1	0.4-1.6	Lentidium mediteraneum
	gray sand	540-2720	10.9-70.6	0.4-1.2	Lentidium mediteraneum
	Sand	2480-5500	2.6-83.0	0.7-1.3	Lentidium mediteraneum
Near to		920-2380	3.09-124.5	0.8-1.5	Nephthys longicornis, Melinna palmate; Chamelea gallina, Ciclope
Batumi Port	Sand	140-2260	9.8-46.4	0	Chamelea gallina
	Black silt with smell	300-3840	0.2-5.4	0.1-0.2	Ceritidium pusillum, Melinna palmate

In autumn 2003 strong underwater current was registered, the benthic samples were absolutely void of any species.

[2] The main part of biomass is formed by molluscs Rapana thomasiana and Crustacea Callianassa truncate, 50.6 and 34.4 g/m^2 respectively.

8.7. Russian Shelf Waters

The data presented for the Russian coastal waters of the Black Sea are based on the materials collected during seasonal surveys of the R/V "Akvanavt" in 2001-2007 (Table 8.8). During every survey 22-54 stations were visited and five grab samplings were collected at each station at depth range from 10 to 45 m (Fig. 8.34). The previous studies (Chikina and Kucheruk, 2004; 2005) indicated that the northeast Black Sea coastal waters were classified in two different regions according to the state of benthic communities: the first one extends from Kerch Strait to Anapa in the northern sector, and the second one from Gelendjik to Adler in the southern sector that encompasses almost 90% of the Caucasian coastal ecosystem (Fig. 8.34). Most of the changes in zoobenthic communities during the last 10 years took place noted in the southern (Gelendjik-Adler) region, whereas the Anapa-Kerch Strait region remained fairly stable.

Table 8.8. Number of stations made during surveys on R/V "Akvanavt"

Year	Month	Number of stations
2001	August, September	53
2002	April, June	54
2003	December	40
2004	May	39
2005	May	31
2006	May	22
2007	May	38

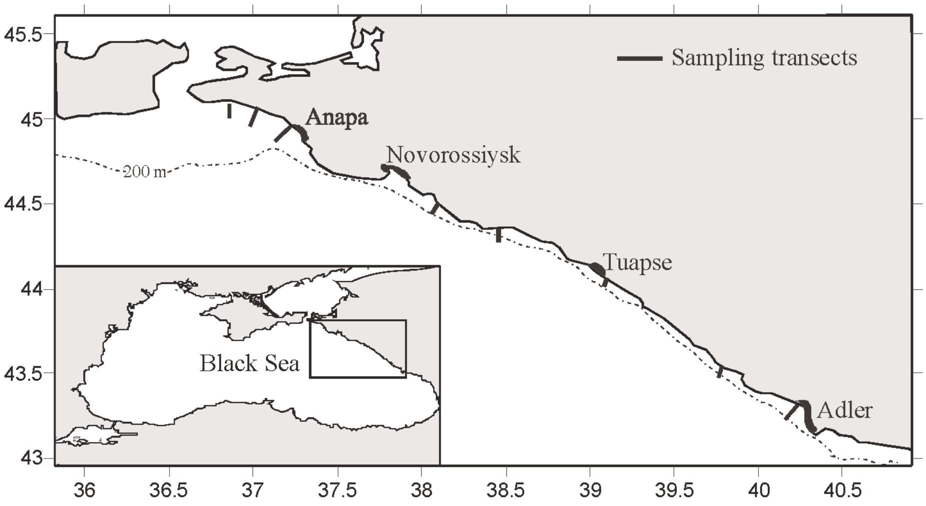

Fig. 8.34. Location of sampling transects in 2001-2007.

According to the studies in 1957, 1963, 1968 (Kiseleva, 1967, 1981; Kiseleva and Slavina, 1965, 1966) and in 1980 (Nikolaenko and Povchun, 1993), the species composition and quantitative characteristics of macrozoobenthos possessed a stable structure until the 1950s. Shallow waters with sandy bottom (< 30 m) were inhabited predominantly by bivalve *Chamelea gallina*. This community was taken over by *Mytilus galloprovincialis* community at depths of 35-40 m, and *Modiolus phaseolinus* community at depths deeper than 60 m. This benthic community structure has then been altered when the carnivorous gastropod *Rapana venosa* invaded the region in 1947. Its first impact was to eliminate oyster banks, bivalves *Ostrea edulis, Chlamys glabra* and *Mytilus galloprovincialis.* The niche has then been filled by small bivalves *Gouldia minima* at intermediate depths. This bivalvia having better reproduction and growth capabilities provided sufficient food resource and thus provided *Rapana* to settle into the regional biocoenosis permanently and to expand into shallower depths where *Chamelea gallina* inhabited (Kiseleva, 1967, 1981; Kiseleva & Slavina, 1965, 1966). Later on, a new alien opportunistic bivalve species *Anadara inaequivalvis* invaded the system. But, neither *Rapana* nor *Anadara* imposed critical predation pressures on the regional benthic ecosystem structure. In the mean time, the *Chamelea gallina* biocenosis was able to promote higher production in response to moderate level eutrophication and its biomass increased from ~80 g m^{-2} in the 1950s to ~250 g m^{-2} in the 1980s prior to the population outburst of *Mnemiopsis* (Fig. 8.35). The bivalves *Pitar rudis* and *Anadara inaequivalvis* constituted subpopulations of this biocenosis with lower biomass and abundances. The predator *Rapana* also revealed low biomass less than 50 g m^{-2} at 10-30 m depth range.

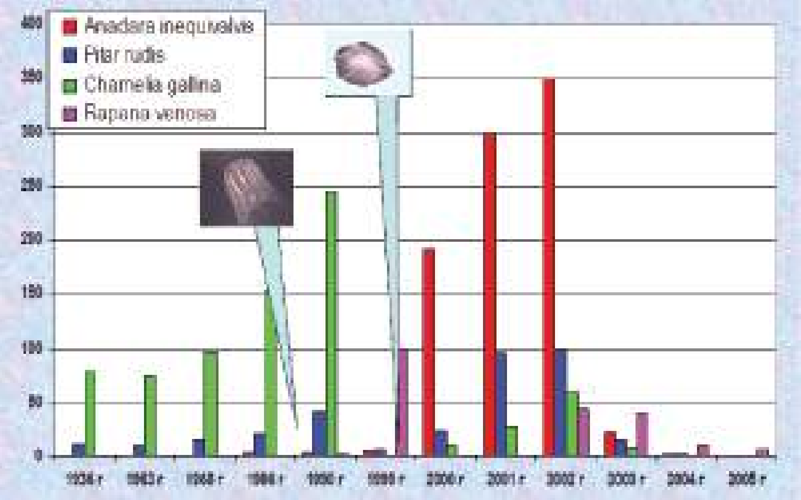

Fig. 8.35. Long-term changes in biomass of dominant macrozoobenthic species at 10-30 m depth range in the southern Caucasian coastal zone.

The outburst of *Mnemiopsis* after 1988 affected the food web structure by reducing thickness of the euphotic zone and increasing organic material sedimentation rate and reinforcing oxygen deficiency of subsurface levels and thus bringing the lower boundary of phytal zone to shallower depths (Alekseev & Sinegub, 1992). The belt of *Cystoseri*a associations was shifted simultaneously to 10-12 m depths, *Chamelea gallina* and its successor *Gouldia minima* at the depth range of 20-30 m and *Mytilus galloprovincialis* at the depth range of 30-50m completely disappeared. *Chamelea gallina* dominance was then confined to the narrow coastal belt shallower than 11m. Heavy *Mnemiopsis* predation on bivalve larvae limited settlement of young bivalves whereas adult bivalves were consumed by the predator gastropod species *Rapana*. Consequently, macrozoobethic communities within 5-30 m coastal zone have been degraded seriously during the 1990s. In 1999, the mean *Rapana* biomass and abundance reached at 100 g m^{-2} and 50 ind. m^{-2}, respectively. But its population was aggregated at shallower sandy bottoms (5-15 m) and no *Rapana* settlement was observed at depths deeper than 15m.

The collapse of *Mnemiopsis* in 1998-1999 triggered substantial changes in the macrozoobethic community structure. Reduction of its predation strength on bivalve larvae in 1999 allowed for mass settlements (on the order of thousands) of *Chamelea gallina* larvae and juvenile at 10-18m depth range and of *Anadara inaequivalvis* at 20-25 m in 2000, whereas such settlements was less than 100 ind.m^{-2} prior to the *Mnemiopsis* collapse. A consequence of such highly dense young bivalve community was their very slow growth rate. They attained 5 mm length at most in two years instead of 8-15 mm under normal conditions. Therefore, the sudden jump in bivalve biomass to 200 g m^{-2} in 2000 was followed by their slower biomass increase in the subsequent two years up to 350 g m^{-2} for *Anadara*, 100 g m^{-2} for *Pitar rudis* and 60 g m^{-2} for *Chamelea* in 2003. Higher *Anadara* biomass was due to their opportunistic character for space and food consumption (Van Hoey et al., 2007). As expected, such slowly growing abundant bivalve population was attack by the opportunistic predator *Rapana*. As 1 ind. per 10 m2 was a typically observed *Rapana* population, the population density of young *Rapana* increased to 8 ind.m^{-2} in 2001 and 100 ind. m^{-2} in 2002. Their massive grazing pressure on bivalve (*Chamelea, Anadara, Pitar rudis*) populations caused an abrupt decrease in bivalve biomass and abundance from 470 g m^{-2} and 1292 ind.m^{-2} in 2002 to 35-45 g m^{-2} and 29-61 ind.m^{-2} in 2003-2004 (Fig. 8.36). This was accompanied by biomass increase of *Rapana* from 3 g m^{-2} in 2001 to ~35-45 g m^{-2} in 2002-2003 as well.

The abrupt loss of bivalves further shifted the macrozoobethos community structure to a Polychaeta-dominated system with an increase of Polychaeta species from 10 to 16, abundance from 300 ind.m^{-2} to 1494 ind.m^{-2} and biomass from 2.5 to 7.5 g m^{-2} in 2003-2004. At the same time, the lack of sufficient food for high *Rapana* population caused decline of their population to a background level (< 5 g m^{-2}) in 2004-2005. Thus, the Beroe invasion in 1999 introduced interesting prey-predator interactions with strong year-to-year fluctuations in the macrozoobethic community structure during 2000-2004.

8.8. Conclusions

Following significant changes in the qualitative and quantitative characteristics of zoobenthos community along the entire Black Sea in the 1970-1980s in response to intensifying eutrophication and other complementary factors, some increase in benthic species diversity and relative recovery of hypoxia sensitive groups during the post-eutrophication period suggested an adjustment process of benthic communities towards a new quasi-stable balance. On the basis of autumn 2003 observations, the Bulgarian shelf benthic macrofauna was identified as in "good" ecological state except some hotspots subject to local anthropogenic impacts. The northern sector of Romanian shelf (from Sulina to Constanta) had "moderate" state of zoobenthic community structure that however improved towards the south with increasing distance from the Danube discharge zone. Coastal zone between the Danube-Dniester River outflows was in the "poor-to-moderate" state, but the zoobenthos community structure in Odessa coastal area was heavily disturbed. The recovery of shallow (15-30 m) and medium (30-50 m) depth benthic communities is encouraging and signals for a rehabilitation trend. Albeit to such slow recovery, the general state of zoobenthos community structure over large areas of the Ukrainian and Romanian shelves is still fragile and suffers from active role of opportunistic and invasive species that continue to exert undesirable disturbances into the system. High capacity for regeneration and food consumption of these opportunistic species (e.g. bivalves Mya arenaria, Anadara inequivalvis, Rapana venosa) still allow them to expand and destroy benthic food web. The conditions appear to gradually progress to the south and east away from the source region of the pollution and eutrophication.

Resuspension and redistribution of fine sediments and silting of large coastal areas due to bottom trawling remains to be an ecological concern that alter sediment type, destroy mussel beds, degrade the associated benthic community from "mussel bed" type to "silt bottom" type dominated by opportunistic polychaetes and oligochaetes. But the link between bottom trawling and its effects on macrozoobenthos has not been studied in sufficient detail yet. Determining the cumulative direct and indirect effects and ecological consequences of hypoxia, high organic load, invasive and opportunistic species, trawling is often complicated and largely unknown. Their quantification is necessary in order to improve our understanding the recovery process.

The present assessment study demonstrated many information gaps in our present state of knowledge of zoobenthos structure of the Black Sea due to lack of systematic observations. The observations are mostly based on scientific cruises, designed for some other purposes interests, which may not very be compatible with monitoring strategy. The present level of knowledge does not allow for a more solid assessment beyond making rather trivial statements such as "recovery but still fragile structure", "prone to undesirable disturbances", etc. Answering questions like "where the present benthic system stand in terms of its stability", "how it is close to its former background state", "whether it is approaching to it or going to be stabilized at an alternative state" require implementation of a comprehensive and systematic monitoring strategy that should resolve regional heterogeneities in benthic structure and their pronounced interannual changes.

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CHAPTER 9 THE STATE OF MARINE LIVING RESOURCES (V. Shlyakhov & G. Daskalov)

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9.1. Introduction

In the context of this chapter, "Marine living resources" (hereinafter it is referred to as MLR) comprise the populations (exploited, being exploited or being able to be exploited by humans) of finfishes (hereinafter - fishes), mollusks, crustaceans, water plants and other living organisms inhabiting the Black Sea, excluding waterfowl and mammals. About 200 fish species, more than 500 mollusks species and water plants-macrophytes (red and brown algae as well as marine floral plants) inhabit the Black Sea. Among the whole specific diversity, the greatest economic value, however, is not more than two dozens of species that produce about 98% of catch in 1996 - 2005 (Fig. 9.1). The rest 2% included commercially less important fishes, mollusks, crustaceans and other aquatic organisms. The main portion of catches falls into three groups - anadromous, pelagic, and demersal fishes. In each of these groups, more than 90% of capture volume fall on several leading species. As a whole, the total mean annual catch of MLR in 1996 - 2005 was at the level of 410 thousand tons varying annually between 330 thousand tons and 500 thousand tons, that is more than 30 thousand tons higher than the mean catch in 1989 - 1995 (Fig. 9.2).

This chapter summarizes the state of marine living resources in the Black Sea during the last 10 years with respect to the previous decades. In particular, the state of MLR will be assessed for 1996 - 2005 as compared with the earlier period to explain the changes occurred. The chapter was benefited from the data used for the TDA (Technical Task Team National Experts on Fisheries) Reports (2006), kindly submitted to the BSERP - PIU by the authors. Information on MLR catches of the Black Sea countries in 1989 - 2005 was taken from the FAO statistical data base with some corrections made on the basis of TDA reports (2006) and the Black Sea Commission Information System data base.

9.2. The state of key anadromous fishes

The anadromous species of the Black Sea include the pontic shad (*Alosa pontica*) and three sturgeon species *Acipenser gueldenstaedtii, Acipenser stellatus, Huso huso.* Among fishes by the capture volume, anadromous fishes take the last place (Fig. 9.1), but their high consuming and economical value determines their specific role in the structure of the MLR. Their life cycle consists of marine period (wintering and fattening) and river period (spawning and migration of newly born juveniles into the sea). Stocks of anadromous fishes are formed mainly by the Danube populations. The catch data of anadromous fishes (Fig. 9.3) suggest decline of their commercial value in 1996 - 2005 as compared with the previous period. Following the minimal catch occurred in 1999, nevertheless an increasing trend of annual catches was observed due particularly to the recovery of Pontic shad.

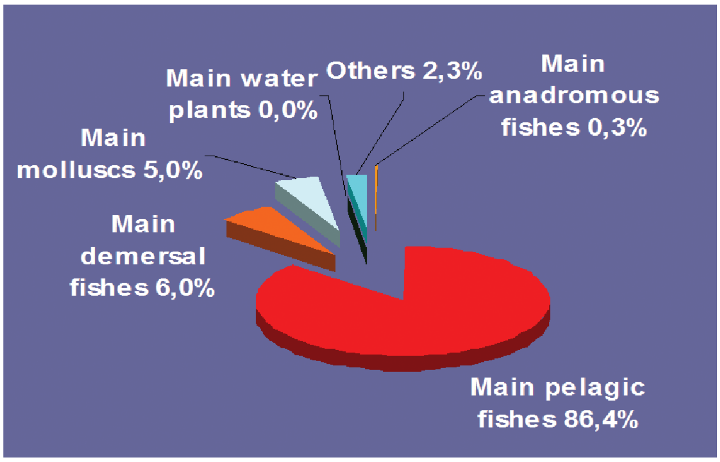

Fig. 9.1. Commercial exploitation of Marine Living Resources in the Black Sea in 1996 - 2005.

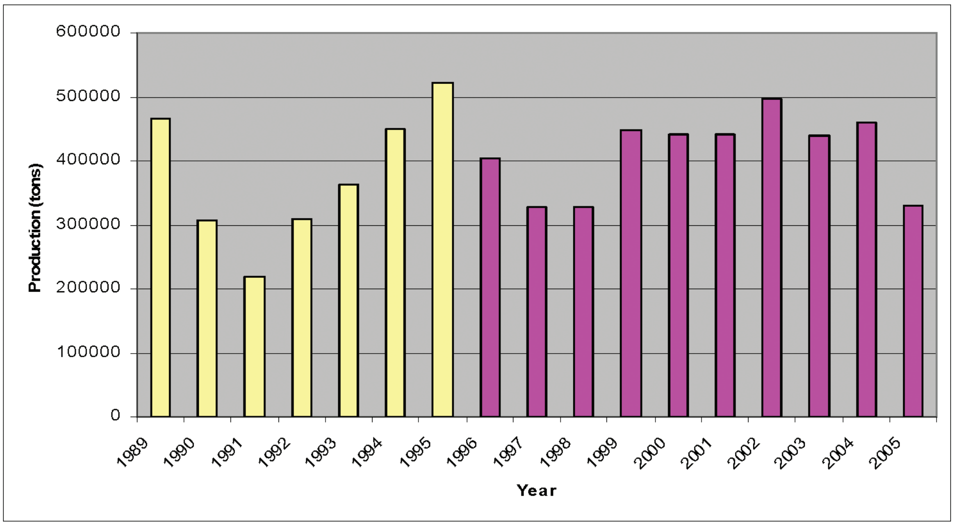

Fig. 9.2. Total capture production of Marine Living Resources in the Black Sea in 1989 - 2005.

9.2.1. Sturgeons

Out of six sturgeon species of family *Acipenseridae* inhabited the Black Sea and inflowing rivers, three species called the Russian sturgeon (*A. gueldenstaedtii*), starred sturgeon (*A. stellatus*) and beluga (*Huso huso*) are most common. They are large-sized fishes with long life cycle: beluga lives up to 100 years and reaches the weight more than 1 ton with length of 490 cm; for Russian sturgeon maximum recorded age is 37 years, the length is 236 cm and weight is 115 kg; starred sturgeon reaches the length of 218 cm, weight 54 kg and age 23 years old (Pirogovskii et al., 1989; Popova *et al*., 1989; Vlasenko *et al.,* 1989). Russian sturgeon and starred sturgeon feed mainly on benthic organisms, namely mollusks and *Polychaetae*. Beluga is a typical predator, feeding on fish exclusively. Anadromous sturgeons make extended migrations during their life from the sea into the rivers; larvae drift after hatching and juveniles in rivers; and back into the sea after completion of spawning.

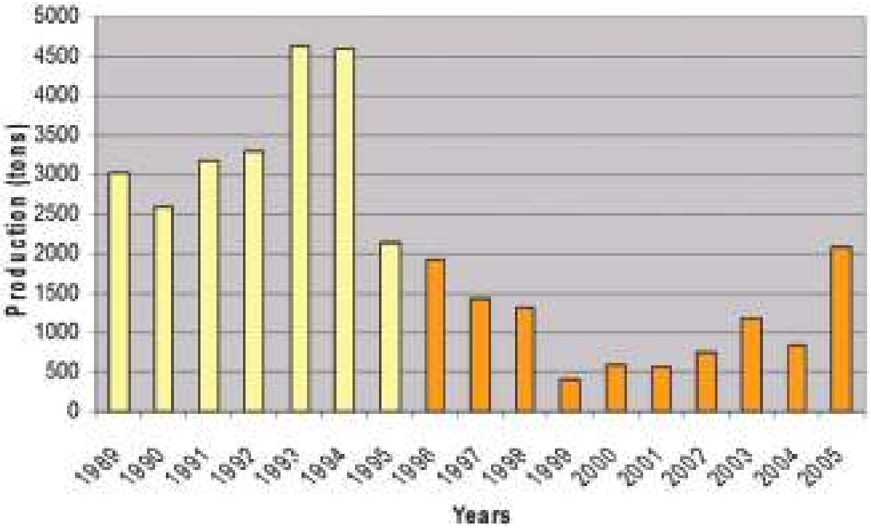

Fig. 9.3. Total capture production of main anadromous fishes in the Black Sea during 1989 - 2005.

The main fattening and wintering grounds of the Danube and Dnieper populations of the Russian sturgeon and starred sturgeon as well as juveniles of beluga are the coastal waters of Ukraine. The Danube, the Dnieper and the Rioni Rivers offer most important habitats for their reproduction. Major part of the adult sturgeon populations in the sea comes from the Danube and Dnieper populations. The Danube populations of Russian sturgeon, starred sturgeon and beluga are all abundant. Among Dnieper populations, the Russian sturgeon is the most abundant, artificial reproduction (restocking) play an important role for keeping its abundance above a certain level. In Ukraine, restocking of sturgeons and releasing their fingerling into the wild is carried out in the Dnieper Sturgeons' Rearing Plant. From 1985 till 1995 this farm has released into the sea 1 - 2.5 million juveniles per year (generally, Russian sturgeon) (Prodanov *et al.,* 1997; Shlyakhov, 2003). The scale of sturgeons' restocking is the largest in the River Dnieper; however, it has the tendency to decrease up to 0.354 million individuals in 2005 and 0.118 million individuals in 2006 (Table 9.1).

According to the methodology described by Shlyakhov and Akselev (1993) and Shlyakhov (1994) and the results of bottom trawl surveys (1981, 1984, 1987, 1991, 1992, 1993, 1994, 1998, and 2002) that were undertaken on the wintering grounds in the Karkinitsky Bay in February-March, the Russian sturgeons' abundance acquired a continuous growth in 1981 - 1993, but started decreasing in subsequent years (Fig. 9.4). On the contrary, the abundance of starred sturgeon remained more or less stable around 1.5 millions of individuals until 1994 and reduced gradually afterwards to less than 0.5 millions of individuals at the end of the 1990s and the early 2000s. The abundance of beluga juveniles decreased from 0.4 to around 0.1 million individuals, and then remained steady around 0.1 - 0.15 million individuals up to 2002 that was about one third of the level in 1981. Thus, the total sturgeon abundance increased from 0.2 millions of individuals in 1966 - 1974 (Ambroz, Kirilluk, 1979) to 5.3 - 6.2 millions of individuals in 1992-93. This increase was due to population growth of Russian sturgeon under highly efficient protection measures and restocking. Starting by 1994, their total abundance however decreased gradually up to 2 millions individuals in 1998 and 1.5 millions of individuals in 2002.

Table 9.1. The total and individual populations of the Russian and Starred sturgeon and Beluga in the Rivers Dnieper and Danube in 1996 - 2006, in million individuals per year. Data sources: for RO - R. Reinartz (2002), for BG and UA - BSIS (2007).

Year	Country	River	Russian sturgeon	Starred sturgeon	Beluga	Total
1996	RO	Danube	0.010	-	-	0.010
	UA	Dnieper	…	…	-	4.018
1998	BG	Danube	0.001	-	…	0.001
1999	BG	Danube	0.027	-	0.003	0.030
2000	BG	Danube	0.020	-	0.001	0.021
	RO	Danube	-	0.068	-	0.068
2001	BG	Danube	0.028	-	-	0.028
	UA	Dnieper	2.370	-	-	2.370
2002	BG	Danube	0.022	-	-	0.022
	UA	Dnieper	2.366	0.142	-	2.508
2003	BG	Danube	0.161	-	0.005	0.161
2004	BG	Danube	0.127	-	-	0.127
	UA	Dnieper	1.071	-	-	1.071
2005	UA	Dnieper	0.354	-	-	0.354
2006	UA	Dnieper	0.112	0.006	-	0.118

The rejuvenation of sturgeon schools after 2000 was reflected in their smaller length-weight characteristics in the Ukrainian sector of the Danube. 82% of all analyzed fish samples corresponded to the range of 96 - 105 cm and 4.96 kg in weight. The male:female ratio for both starred and Russian sturgeon schools was 82%:18%. At present starred sturgeon population corresponding to 60% of the total population at 7 years of age made the basis of sturgeons' catches in the Danube delta; other age groups as well as Russian sturgeon are found in smaller amounts in catches (Table 9.2).

The changes in Russian and starred sturgeon abundances in the Danube school (Fig. 9.4) imply larger amount of fishing of Russian sturgeon than starred sturgeon after 1993 - 1994 that made the starred sturgeon progressively more predominant species forming almost 75% of the total population.

The fact that all acipenseriform species were included in the Convention of International Trade of Endangered Species (CITES Appendix II /Notification to the Parties No. 1998/13 *Conservation of Sturgeons*) since 1998 evidences an unfavorable state of sturgeon populations during the present decade although the data shown in Fig. 9.4 did not extend beyond 2002. In the opinion of the IUCN experts, stocks of migratory sturgeons in the Lower Danube River have been overexploited and a collapse of stocks was inevitable with the same rate of exploitation.

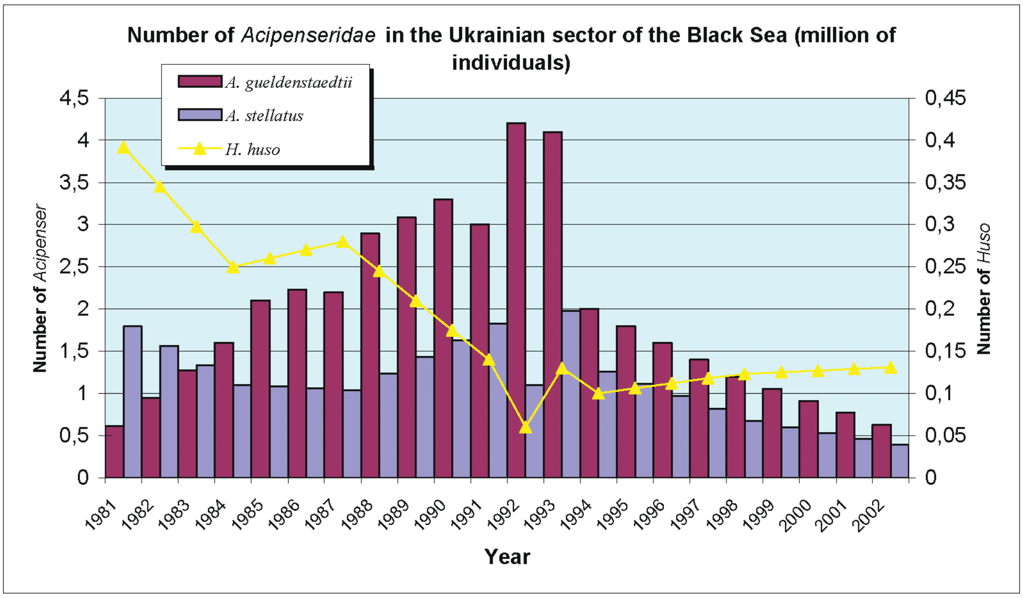

Fig. 9.4. The total abundance (in million of individuals) of three anadromous sturgeon species in the north-western Black Sea according to the data of YugNIRO trawl surveys and mathematical modeling (taken from Shlyakhov, 2003). Red bars: Russian sturgeon; blue bars: Starred sturgeon; yellow line: Beluga.

Table 9.2. Length-weight and age characteristics of mature Russian and starred sturgeons in the Ukrainian Danube in 2003

Age	6	7	8	9	10	11	12	13	14	15
Starred sturgeon										
L (cm)	101.0	100.8	102.8	104.5	110.5	-	-	-	103.0	-
Weight(kg)	4.6	5.42	5.66	6.25	7.50	-	-	-	5.0	-
%	10.0	60.0	22.0	4.0	3.0	-	-	-	1.0	-
Russian sturgeon										
L (cm)	-	-	110.0	112.7	113.5	114.8	115.9	116.5	117.0	126.0
Weight(kg)	-	-	8.50	9.93	10.43	10.68	11.57	14.00	14.00	16.50
%	-	-	4.0	12.0	16.0	20.0	28.0	8.0	4.0	8.0

Statistics on targeted and non-targeted fisheries comprise only officially documented catch or by-catch. "Unreported" catch due to its hidden part during legal fisheries and from poachers' catch as well as dead fish which is not landed by some reasons (fish died in nets, discarded illegal catch, etc.) were not usually included in statistics, but their proportion may be much higher than the officially reported catch size. Therefore, any reliable assessment for the state of sturgeons need to include the contribution of unreported catch as published earlier by Prodanov *et al.* (1997); Navodaru *et al.* (1999); Shlyakhov *et al.* (2005).

Immediately after the USSR disintegration, the unreported catches increased up to 280 tons (in 1994) due to the illegal fishing of sturgeons' wintering aggregations in the Karkinitsky Bay (Zolotarev *et al.,* 1996). 60 - 70% of these poaching catches consisted of Russian sturgeon. The unreported catch of anadromous sturgeons was estimated as ~600 tons for 1995 that was 12 times more than the officially reported catch by all the Black Sea countries. This number is expected to be even higher since the calculations did not cover all areas of the sturgeons' fishery and no correction was made for fish death at sea. In the Sea of Azov, mean annual unreported catch of the Russian sturgeon was estimated as 2.0 - 4.8 thousand tons for 1988 - 1997 (Table 9.3). As depicted in Table 9.3, overfishing led to the collapse of the Azov Sea sturgeon stock and its fisheries within less than 10 years. It can't be overcome till now in spite of the complete banning of commercial fisheries of Azov sturgeons after 2000 by the Russian Federation and Ukrainian authorities.

Table 9.3. Mean annual and unreported catches and total abundance of Russian sturgeon according to the data of trawl surveys in 1988 - 2005 in the Sea of Azov (assessments of unreported catch were taken from Shlyakhov et al., 2005).

Years	**Total abundance (thousand individuals)**	**Catch, tons**	
		Official	Unreported
1988-90	12606	772*	4814
1992-94	8264	1143*	3213
1995-97	4357	427	2040
1998-00	2785	156	984
2001-03	1757	6	109
2004-05	745	1	54

* - Russian sturgeon and starred sturgeon

According to the official statistics, the total catch of all three species of anadromous sturgeons in the Black Sea basin increased from 19 tons in 1994 to 211 tons in 2003 and then sharply declined to 42 - 43 tons in 2004 - 2005. This abrupt decline may be interpreted as an evidence of the stock collapse due to the recruitment failure.

Besides over-exploitation during the last 10 years, anadromous sturgeon populations were also adversely affected by habitat loss and habitat degradation as a consequence of loss of shelters, feeding and reproduction habitats; alteration of the hydrological regime of surface and ground waters (loss of regular soil aeration and moistening), changes in the sediment regime (balance of erosion and sedimentation processes), loss of typical and rare habitats and species diversity especially in flood plains, reduced flood retention capacity resulting in increased flood hazards downstream of dams, reduced self-purification capacity resulting in increased need for expensive water purification, reduced productivity (regular free nutrient input) for forestry, agriculture and fisheries, reduction of recreational value.

In accordance with the assessments of national experts, the three main threats for anadromous fishes are as follows.

Illegal fishing and use of destructive harvest techniques: Illegal fishing since 1993 was the major reason of overfishing of sturgeons, and perhaps the collapse of their stocks. Control of poaching in the former Soviet Union countries had no effect at all; responsible authorities were often engaged in illegal fishery (Toje and Knudsen, 2006). In the opinion of IUCN experts, control of poaching and illegal caviar trade should be carried out via development and implementation of regional trade and law enforcement agreements; improvement of social and economic conditions of people; improvement enforcement of existing laws.

Loss of valuable spawning and nursery habitats in rivers and lagoons: Recovery of spawning and nursery habitat in rivers and lagoons in the nearest future is not realistic.

Key habitats in the Danube, Dnieper, Rioni Rivers and in the Black Sea from catches or by-catches should be protected.

Modification in river flow regimes (including building of dams and drain of meadow): Reduction and loss of anadromous sturgeons may also be connected with dam constructions. Prior to the dam construction, the Dnepr sturgeons were used to travel up to Mogilev (Belarus) and the major spawning area was extended from Kherson all over the lower Dnepr, including the Dnepr rapids. After construction of Kakhovka dam in 1956, the spawning area reduced to 75 km. Even in the vicinity of New Kakhovka and village Lvovo, conditions for spawning of sturgeons became unsuitable. Similarly, important spawning sites in the Middle Danube River were reduced after the construction of the Iron Gate Dam I in 1972. The Iron Gate Dam II in 1980 further reduced the migration potential of sturgeons. The dams in the Turkish Rivers Sakarya, Yesilirmak and Kizilirmak were the reason of complete loss of their significance for spawning of anadromous sturgeons.

Banning of commercial sturgeon fisheries by Turkey more than 15 years ago, Ukraine since 2000 and Romania since 2006 was an important step towards conservation of sturgeon stocks. However, such measures as well as insufficiently developed restocking and inefficient control of poaching cannot solve this transboundary problem. Concerted actions of all Black Sea countries are necessary.

9.2.2. Pontic shad

Pontic shad (*Alosa pontica*) is an anadromous pelagic fish reaching the length of 45 cm, maturing at the age of 3-4 years. It is not found in the catches at the age older than 6-8 years. Mature Pontic shad feeds mainly on fish (anchovy, sprat), and to a lesser extent, crustaceans. It is considered that two populations of Pontic shad - Don and Danube ones - inhabit in the Azov and Black Seas. The Don populations winter in the eastern part of the sea from the Crimean coasts to Batumi and the Danube populations in the western part of the sea (Svetovidov, 1964). More recent studies suggested a possibility of wintering along the Turkish coasts (Prodanov *et al.,* 1997). The Danube population migrates into the Danube, Dnieper and Dnestr Rivers for spawning in spring. Its fisheries are conducted both at sea during spring migration period in Bulgaria and Romania and during wintering phase in Turkey and in the western rivers by Bulgaria, Romania and Ukraine. Its fishery is almost absent in the territorial waters of Georgia and Russian Federation.

According to assessments by Ivanov and Beverton (1985) on the basis of analysis of age cohorts in the catches of Bulgaria, Romania and the former USSR for 1963 - 1979, the Danube population of Pontic shad varied from 17 million individuals in 1968 to 114 million individuals in 1974. The corresponding stock was 3 and 20 thousand tons. In subsequent studies (Prodanov *et al.,* 1997) high abundance of the Pontic shad in 1974 was estimated as 122 million individuals without including the Turkish catches and considering only the catches in the eastern part of the sea which possibly did not include the Danube school.

After the peak in 1974 - 1975 till the early 1990s, the stock and catches of Pontic shad tended to reduced even excluding the Turkish catch. After 1989, the catch statistics also included the Turkish catches that accounted for 2 - 4 thousand tons from 1989 to 1995 (Fig. 9.5). Intensification of catch in the Turkish waters was most likely due to the yearning of fishermen to compensate their losses as a result of collapses in anchovy and horse mackerel fisheries. The extensive harvesting then caused sharp drop in shad catches after 1994 to less than 500 tons in 1999 - 2001. The Turkish catch increased again in 2005, exceeding 1 thousand tons. The catches of Bulgaria, Romania and Ukraine in 1989 - 1998 were approximately at the same level of 1 thousand tons. It declined sharply in 1999 and acquired a slight recovery afterwards.

The Turkish Pontic shad fishery appears to introduce an important contribution to the sharp decline of the stock after 1995. The Danube population generally winters along both western and eastern coastal waters of Turkey. The Don population of Pontic shad also winters along the eastern Turkish coastal waters. Younger year classes of these Pontic shad populations were therefore harvested in the Turkish waters during their overwintering phase, as their older age classes were caught along the coasts of Bulgaria, Romania and Ukraine during spawning migrations into the rivers, mainly the Danube. If that was the case, intensification of the Turkish fisheries on the Pontic shad caused depletion of the stock of potential breeders in 1990 - 1995 that then became an important cause of stock and catch decline after 1995.

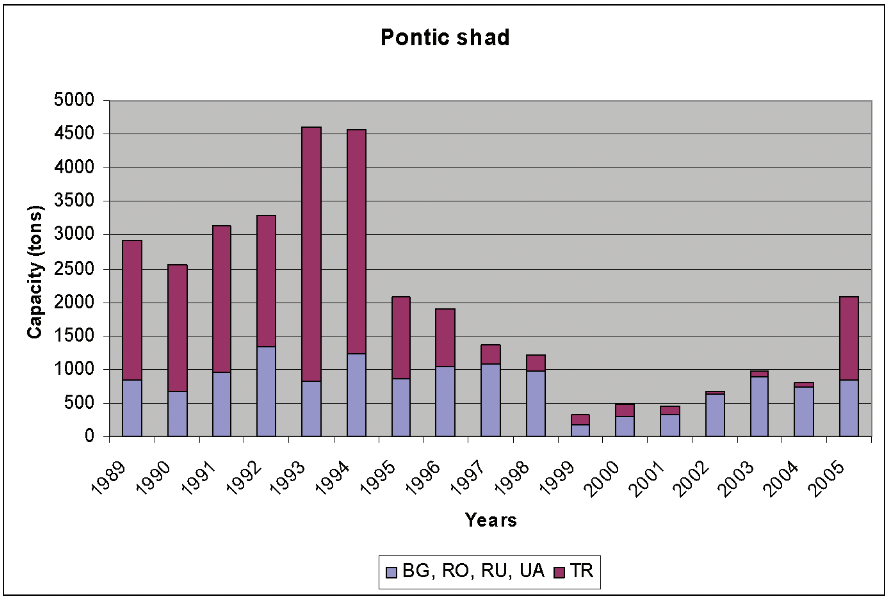

Fig. 9.5. Changes in Pontic shad catches in the Black Sea basin in 1989 - 2005.

The stock assessment of the Danube shad at the level of 4 - 6 thousand tons during 1989-1992 (Prodanov et al., 1997) might be an underestimation, since the analysis did not include the Turkish catch which in fact exceeded the total catch of Bulgaria, Romania and Ukraine in those years. The other source of underestimation was the correction for poaching in the Danube and adjacent coastal waters. Assessment for the abundance and biomass of the Danube population of shad in 1996 - 2005 was not available. By analyzing of the composition and values of annual catches of Pontic shad by Odessa YugNIRO Centre, the shad biomass was assessed as ~1000 tons in 1998 - 2004 except a temporary drop to ~500 tons in 2001in the Ukrainian sector of the Danube (Fig. 9.6). An implication of such rather uniform stock assessment is the importance of including the Turkish catch data into the stock estimation analysis without which it wouldn't be possible to explain reliably the stock changes of Pontic shad over the basin.

The present state of the Danube population of Pontic shad should be regarded as unfavorable. Even taking into account unfortunate ecological changes due to the environmental factors such as lower water level, water temperature and pollution that could actually affect the success of the Danube shad reproduction, the most important cause of the stock decrease appears to be the overfishing mainly in the Danube Delta area (Radu, 2006). Indeed, poaching fishery for shad in the lower Danube for recent 10 years has become wide-scale, although it has not been assessed properly so far. Perhaps, marine fisheries of Turkey make a comparable contribution to the overexploitation of the Danube stock of shad.

The main threats for anadromous Pontic shad are almost the same as for sturgeons. The only additional point which might be added is the slightly better state of shad stock as compared with sturgeon due to their natural abilities for rapid recovery. Therefore, the regional level of fishery regulation should be sufficient to improve the Danube population of Pontic shad.

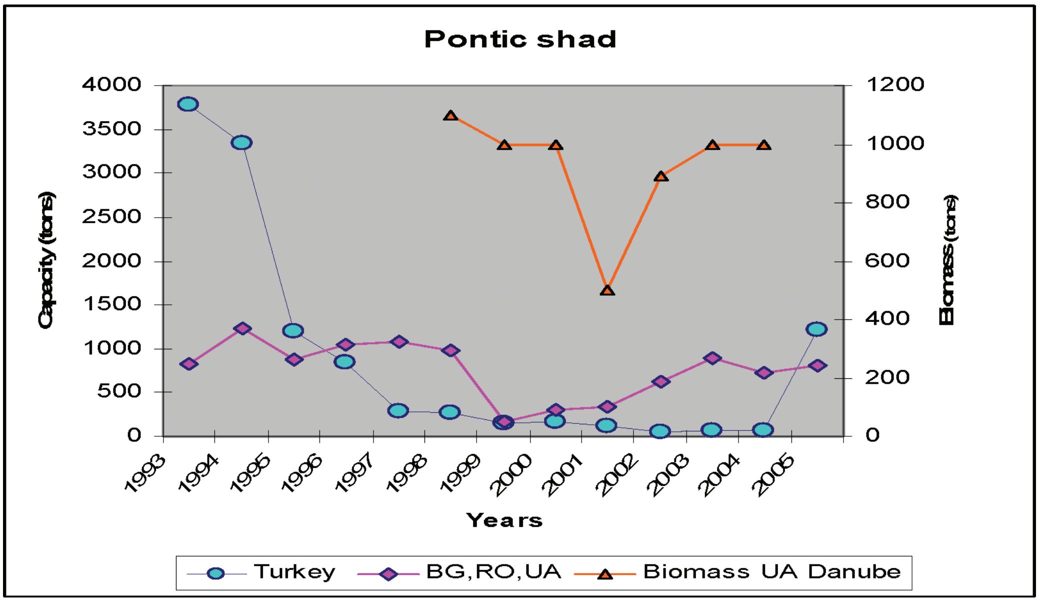

Fig. 9.6. Turkish and the sum of Bulgarian, Romanian and Ukranian catch variations of Pontic shad in the Black Sea as well as its biomass estimation in the Ukrainian Danube region.

9.3. The state of key pelagic fishes

Pelagic fishes, particularly their small-sized plankton-eating types are the most abundant in the Black Sea ichthyocenosis. This factor defines their leading role in fisheries. The main target species of fisheries is European anchovy (*Engraulis encrasicolus*), whose catch has varied from 31% in 1991 to 75% in 1995 of the total MLR harvest during the last 15 years. Mediterranean horse mackerel (*Trachurus mediterraneus*), European sprat (*Sprattus sprattus*), Atlantic bonito (*Sarda sarda*) and bluefish (*Pomatomus saltatrix*) are the major pelagics in terms of fishing value. The latter of these three species are large-sized predators which enter the Black Sea from the Marmara and Aegean Seas for feeding and spawning in spring and turn back for wintering in late autumn. The catch data suggest partial recovery of major pelagic species after the fishery collapse at 1991 (Fig. 9.7).

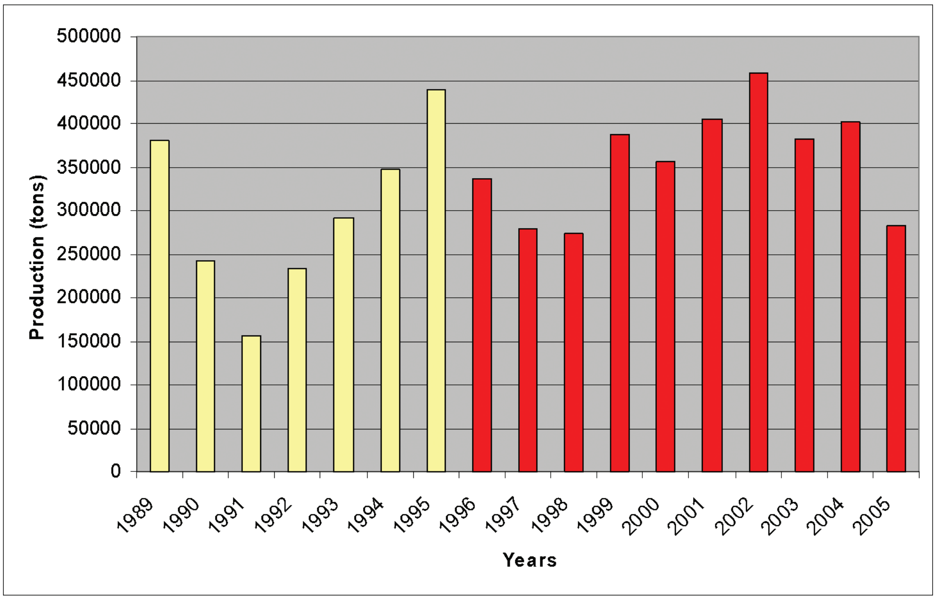

Fig. 9.7. Total catch of main pelagic fishes in the Black Sea during 1989 - 2005.

9.3.1. Sprat

Sprat is a self sustaining, one of the most abundant and commercially important pelagic fish species in the Black Sea, and it serves an important food source for larger fishes (Ivanov and Beverton, 1985; Daskalov *et al.,* 1996; Daskalov, 2002). It is distributed over the whole Black Sea, but its maximum abundance takes place in the northwestern region and shelf waters (Ivanov and Beverton, 1985; Fashchuk *et al.,* 1995). In spring, schools migrate to coastal waters for feeding. In the summer, sprat stays under the seasonal thermocline forming dense aggregations near the bottom during the day and in the upper mixed layer during the night (Ivanov and Beverton, 1985).

Sprat reaches maturity at 1 year and reproduces during the whole year, but its peak spawning takes place between November and March. The spawning size is strongly controlled by winter hydroclimatic conditions and plankton blooms (Simonov *et al.,* 1992; Daskalov, 1999). Its reproductive niche is therefore situated to ensure optimal concentration and retention for eggs and larvae. Eggs and larvae are mostly concentrated near the shelf edge and within the central cyclonic gyres with relatively stable subsurface layer (20 - 50 m) (Arkhipov, 1993; Fashchuk *et al.,* 1995).

Its recruitment population was found to be weakly dependent on the parental stock biomass and correlated negatively with SST and river discharge but correlated positively with the wind stress (Daskalov, 1999). Its spawning during the winter and spring in deeper layers was also relatively unaffected by *M. leidyi* because of its low biomass and therefore weak food competition and predation impacts on sprat eggs and larvae. In summer, the juvenile and adult sprat populations leave the upper warmed layer and thus avoid severe competition for food with other plankton-consumers including *M. leidyi.* During this period their preferred food consists mainly of the cold-water *Calanus* and *Pseudocalanus* copepod species living below the cold intermediate layer of the water column. It should be noted that this prey is also available to *M. leidyi* feeding as they migrate to the thermocline at night for their daily feeding where they can be consumed by the ctenophore. This can partly explain the reduction of the sprat stock in the early 1990s of the *Mnemiopsis* population outburst. As with the other commercial stocks, heavy overfishing took place before and during the *M. leidyi* outbreak as well, which should aggravated the stock depletion (Prodanov *et al.,* 1997; Daskalov, 1998). In addition to *M. leidyi,* the jellyfish *Aurelia aurita* distributed in deeper waters has a strong trophic interference with sprat. This may explain the coincidence between the declining phase of sprat recruitment and biomass and the peak abundance of *A. aurita* during the 1980s (Daskalov, 2003; Shulman et al., 1994).

Sprat has always been subject to both artisanal and commercial mid-water trawl fisheries. The regular pre-recruit surveys were performed by the former USSR in collaboration with Bulgaria and Romania from the early 1960's to 1993 (Tkacheva and Benko, 1979; Ivanov and Beverton, 1985; Arkhipov, 1993; Prodanov *et al.,* 1997). The long-term monitoring of sprat fat content for at least 30 years has been performed by Shul'man *et al.* (1994). Data on catches (often monthly) have been collected by the countries since the early 20th century. Size and age compositions have been regularly assessed (weekly and monthly) based on samples from the commercial landings or research survey. CPUE has been monitored for different vessel type, fleets, and gear since the 1980s (Daskalov *et al.,* 1996). Research surveys however have been limited in recent years because of financial constraints in many research institutes in the region.

Time-series of the main stock parameters based on catch-at-age stock assessment models (Daskalov *et al.,* 1996; Daskalov 1998; Daskalov *et al.,* 2007) are shown in Fig. 9.8. A quasi-decadal cyclic pattern dominates the recruitment abundance time series. Maxima of recruitment and biomass occurred in the mid-1970s and mid-1980s. Its maximum catch was recorded in 1989, leading to highest fishing mortality prior to the stock collapse. The combination of low recruitment and excessive fishing as well as the *Mnemiopsis* outburst were the major causes of the 1990 stock collapse since the survey indices, age and size composition consistently showed a drop in recruitment, biomass, mean size, and age (Daskalov and Prodanov, 1994; Prodanov *et al.,* 1997; Daskalov, 1998).

After the 1990 stock collapse, sprat recruitment, biomass and catches started to increase, and the stock reached the previous peak-level recorded in the 1980s by the mid-1990s and even higher stock size at 2005. The catch, however, stayed at relatively low level because of the stagnated economies of Bulgaria, Romania and Ukraine, although the fishing mortality increased from 0.1 in 1990 to 0.3 in 2000. Consequently, the catch attained its former level in the 1980s after 1995 and reached ~70 000 tons in 2001 - 2005. The decreasing CPUE and mean catch size in Bulgarian and Romanian fisheries in 2006 - 2007 indicate that the current level of fishing pressure might be too strong for the size of exploited stock biomass and therefore further catch limitations may be needed.

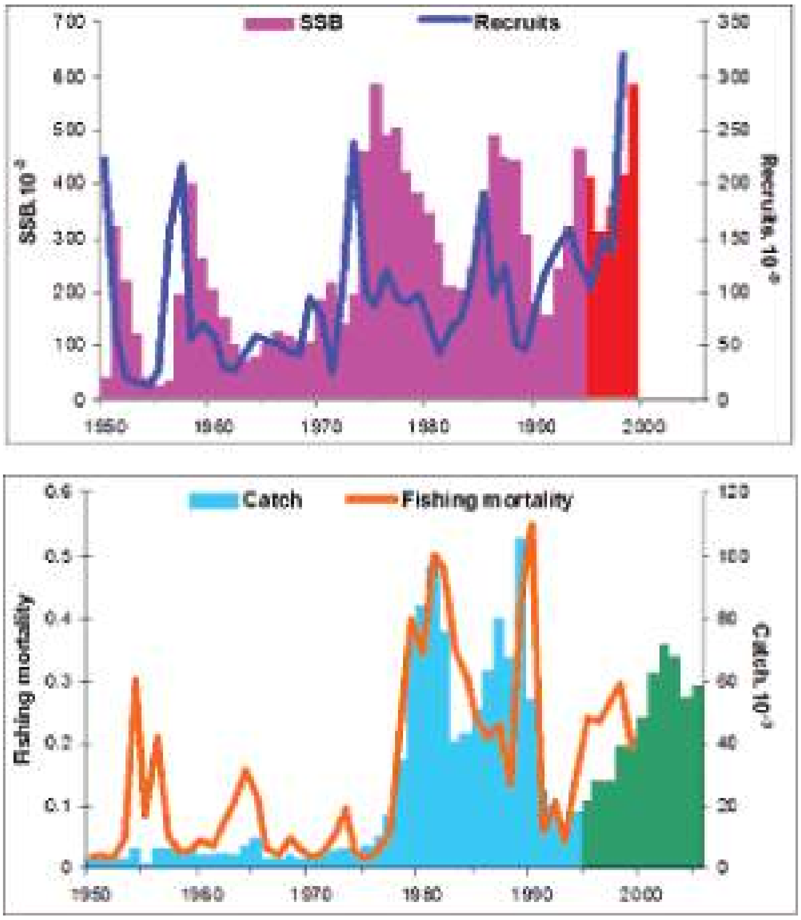

Fig. 9.8. Time-series of recruitment, spawning stock biomass (SSB), catch and fishing mortality of Black Sea sprat.

9.3.2. Black Sea anchovy

Two different anchovy populations exist in the Black Sea: the Black Sea and the Azov Sea anchovies (Ivanov and Beverton, 1985). The latter reproduces and feeds in the Azov Sea and hibernates along the northern Caucasian and Crimean coasts. The stock of the former species is of bigger ecological and commercial importance and the information given below concerns only this stock. Anchovy plays a crucial role in the Black Sea pelagic food web as a prey of many predators such as bonito, blue fish, horse mackerel, dolphins, and the others. It is also an important consumer of zooplankton, especially when the stock is large; thus they act as a predator of zooplankton and competitor of other planktivores (Daskalov *et al.,* 2007).

The Black Sea anchovy is distributed over the whole Black Sea. In October - November, it migrates to the wintering grounds along the Anatolian and Caucasian coasts and forms dense wintering concentrations until March and becomes subject to intensive commercial fishery. It occupies its usual spawning and feeding habitats across the sea in the rest of the year with preferentially in the shelf areas including the northwestern part of the sea being the largest and most productive shelf (Faschuk *et al.,* 1995; Daskalov, 1999).

Anchovy reaches maturity several months after spawning that takes place during the summer within the warm surface mixed layer in coastal and shelf waters (Arkhipov, 1993; Fashchuk *et al.* 1995). Eggs and larvae are retained in coastal regions protected from offshore waters by thermohaline fronts. A large convergence zone formed in the northwestern and the western shelf (the main anchovy spawning area) due to the River Danube inflow favors fish offspring retention.

Anchovy is subject to both artisanal (with coastal trapnets and beach seines) and commercial purse-seines fishery on their wintering grounds. The total anchovy standing stock biomass (SSB) in the Black Sea until 1993 has been assessed using the catch-at-age data in the VPA method (Prodanov *et al.,* 1997). Its more recent changes (after 1993) was estimated using a linear regression between logarithmically transformed SSB and CPUE data of the Turkish purse seine fleet and using the fishing mortality estimation as the ratio of landings and SSB (Daskalov *et al.,* 2007).

Time-trajectories of abundance, catch and fishing mortality shown in Fig. 9.9 reveals pronounced decadal fluctuations as in the case of sprat. The increase in biomass and catch during the 1970s and 1980s was promoted by the expansion of powerful trawl and purse seine fishing fleets in Turkey and thus a steady increase in fishing effort (Anon, 1997; Gucu, 1997). During the years 1974 to 1980, the anchovy stock (largely formed by juveniles of the age 0.5 year) showed upward trend increasing from 800 to 1600 - 1800 thousand tons. The anchovy catch also increased from 152 to 460 thousand tons but the rate of removal did not exceed 50% of the stock (Prodanov *et al.,* 1997). After the 1981/82 fishing, the limit of fishing mortality for safe stock exploitation ($F_{0.1}$) has been systematically exceeded (Shlyakhov *et al.,* 1990), causing an average annual reduction of 7% over 1981-1986. The high catches were however maintained by the relatively large reproductive stock. First signs of overfishing appeared after 1984 (Shlyakhov *et al.,* 1990) when anchovy shoals were difficult to be found and the fishery enterprises incurred losses. However, the real catastrophe happened after 1986, when the stock shrunk from 1200 to 500 thousand tons in two subsequent years. Catches during the 1986/87 and 1987/88 remained high, at the level of 452 - 469 thousand tons, but in the following 1988/1989 fishing season the catch suddenly dropped to 188 thousand tons. The annual rate of stock reduction was 25% for 1987 and 44% for 1988 on average 29% for 1987 - 1988. The fat content was lower by 40 - 60% than the previous years. Then, the stock experienced an abrupt decline to less than 300 thousand tons in 1990 that was the lowest level over the period 1967 - 1993. The fishing effort and fishing mortality also dropped subsequently because of decreasing profitability of fishing. During the collapse phase the size/age structure of the catch shifted toward a predominance of small, immature individuals (Prodanov *et al.* 1997; Gucu 1997; Mikhailov and Prodanov, 2002). In 1995 - 2005, the stock partially recovered and catch increased to 300,000 - 400,000 tons (Fig. 9.9), but because the fishing effort and catch remained relatively high (Zengin, 2003), the exploited biomass could not reach its levels in the 1980s. Anchovy compete for food with *M. leidyi* (Grishin *et al.,* 1994) and this competition probably further affected the anchovy population growth (Oguz et al., 2008).

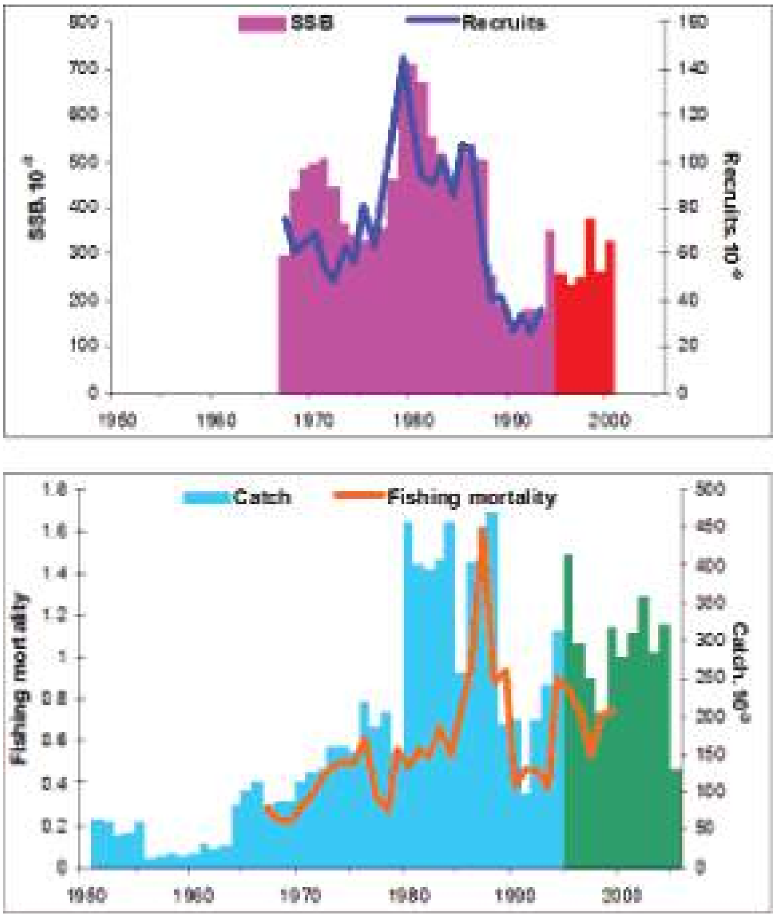

Fig. 9.9. Time-series of recruitment, spawning stock biomass (SSB), catch and fishing mortality of the Black Sea anchovy.

Simonov *et al.* (1992) and Panov and Spiridonova (1998) have found that anchovy abundance and aggregation behavior depended on hydro-climatic factors. They used some climate indices like SST at Batumi and atmospheric circulation to identify climatic regulation of the anchovy stock. As in the case of sprat, the generalized additive modeling (GAM) related favorable anchovy reproduction to high stratification, high SST, low wind stress as well as biological production expressed by the phosphate concentration as a proxy variable (Daskalov, 2003). Probably the strongest environmental effect on anchovy stock by the end of the 1980s was the food competition with and predation by the invasive ctenophore *M. leidyi* as supported by the modeling studies (Oguz et al., 2008). The initial outbreak of *M. leidyi* was reported in 1988-89 in the Black and Azov Seas. It appears that the catastrophic reduction of the Black Sea anchovy stock in the late 1980s was due to the combined action of two factors: the excessive fishing and *M. leidyi* outburst (Grishin *et al.,* 2007). The total loss from the anchovy catch over the years 1989-1992 due to *M. leidyi* outbreak can be roughly estimated of about 1 million tons causing estimated losses of US$16.8 million (Knowler, 2005). Damage by *M. leidyi* to the anchovy population was most likely done through food competition, as unusually low levels of the summer food zooplankton have been observed in the top 50m layer in the early 1990s (Grishin *et al.,* 2007; Oguz et al., 2008). Anchovy larvae could also be affected by *M. leidyi* predation. Mass appearance of anchovy larvae in the plankton occurred in July and August during the *M. leidyi* biomass seasonal peak (Grishin *et al.,* 2007). *M. leidyi* was capable of consuming a daily ration several times greater than its own weight (Lipskaya and Luchinskaya, 1990; Grishin, 1994). Its food spectrum was quite wide and included anchovy eggs and larvae as well (Tsikhon-Lukonina and Reznichenko, 1991). There was an overlap in the distributions of anchovy larvae and *M. leidyi,* even though anchovy larvae were predominantly found in the narrow coastal zone while the ctenophore was also distributed further offshore.

The state of the anchovy stock has improved after the collapse in 1990s, and in 2000-2005 the catches reached ~300 thousand tons. However, the anchovy catch dropped substantially in 2006 indicating a distressed stock condition (M. Zengin, personal communication). The other possible cause of the drop in anchovy stock include climatic effects (higher water temperature may cause a dispersal of fish schools making them less accessible to the fishing gears) and abundant predators (bonito). Given the strong natural variability, transboundary migratory behaviour, and sensitivity to various environmental impacts, the protection and sustainable use the anchovy resource can be achieved only by coordinated international management and regulation based on sound scientifically grounded stock assessment.

9.3.3. Horse mackerel

The Black sea horse mackerel is a subspecies of the Mediterranean horse mackerel *Trachurus mediterraneus.* It is a migratory species distributed in all over the sea (Ivanov and Beverton, 1985; Fashchuk *et al.,* 1995). In the spring, it migrates to the north for reproduction and feeding. In the summer, it is distributed preferably in the shelf waters above the seasonal thermocline. In the autumn, it migrates towards the wintering grounds along the Anatolian and Caucasian coasts (Ivanov and Beverton, 1985). It matures at an age of 1 - 2 years during the summer, which is also the main feeding and growth season. It spawns in the upper layers, both in the open part of the sea and near the coast (Arkhipov, 1993; Fashchuk *et al.,* 1995). Eggs and larvae are often found in areas with high productivity (Daskalov, 1999; 2003).

The horse mackerel (*Trachurus mediterraneus*) fishery operates mainly on its wintering grounds in the southern Black Sea using purse seine and mid-water trawls. The horse mackerel of age 1-3 years generally prevails in the commercial catches, but strong year classes (for example, the 1969 year class) may enter into exploitation at the age of 0.5 year. Over the last 40 years, highest horse mackerel catches were reported in the years preceding the *M. leidyi* outbreak (Prodanov *et al.,* 1997; FAO, 2007). The maximum catch of 141 thousand tons was recorded in 1985, from which ~100 thousand tons were caught by Turkey (Prodanov et al., 1997). In the next four years catches remained at the level of 97 - 105 thousand tons. In the period 1971 - 1989, the stock increased, although years of high abundance alternated with years of low abundance due to year class fluctuations, typical of this fish (Fig. 9.10). VPA estimates showed that the stock was highest in 1984-1988 (Fig. 9.10). According to Bryantsev *et al.* (1994) and Chashchin (1998), the intensive fishing in Turkish waters in 1985 - 1989 led to overfishing of horse mackerel population and reduction of the stock and catches in the subsequent years. A drastic decline in stock abundance occurred after 1990 when the stock was diminished by

56%. In 1991 the horse mackerel stock dropped to a minimum of 75 thousand tons and the catch dropped to 4.7 thousand tons that was a twenty fold reduction compared to the average annual catch in 1985 - 1989.

In contrast to anchovy and sprat, the horse mackerel stock still remained in a depressed state. The horse mackerel fishery was extremely limited in the former USSR countries during 1992 - 1998 because of the lack of fishable aggregations on the wintering grounds. Small quantities of horse mackerel were caught with trap-nets in coastal areas of the Crimea and Caucasus. In Turkish waters, horse mackerel catch in 1994 - 2006 were 9 - 11 thousand tons, i.e. at the level of the years 1950 - 1975 before the start of industrial fishing.

The horse mackerel recruitment has been highly variable that therefore supported sporadic year-class strength (Fig. 9.10). The influence of a strong year-class can be traced through biomass increase in the subsequent one-two years. The relationships with selected environmental variables (Daskalov, 1999; 2003) suggested a strong negative correlation with surface temperature (SST) as also reported by other studies (Mikhayluk, 1985; Simonov et al., 1992). It may appear surprising for a warm-water summer spawning species to correlate with cold SST. The effect of the wind stress was significant and generally positive. These results indicated that horse mackerel recruitment has been more abundant in years with increased physical forcing and enrichment.

During 1985 - 1993, a relatively successful recruitment was recorded only in 1988 (Fig. 9.10). Despite its coincidence with the first year of *M. leidyi* outbreak, the juveniles from this cohort were sufficiently well-supplied with food. As the first outburst of *M. leidyi* occurred in the autumn of 1988, the summer zooplankton maximum production did not suffer much from the devastating effect of *M. leidyi*. The copepods *Oithona nana* and *Oithona similis* which constituted the main food of larval horse mackerel (Revina, 1964) were especially abundant. However, the favorable trophic conditions for larvae in summer 1988 failed to ensure the formation of a strong year-class because juveniles were faced with strong feeding competition with *M. leidyi* further in the year. Sharp decline in *Oithona* under the predation pressure of *M. leidyi* in the subsequent years (Shushkina and Musaeva, 1990; Vinogradov *et al.,* 1993) affected the survival of horse mackerel. Dietary studies of juvenile and adult horse mackerel (Revina, 1964) have shown that both the habitat diet of juvenile horse mackerel and *M. leidyi* overlapped; therefore the strong feeding pressure by *M. leidyi* on zooplankton directly affected larval and juvenile horse mackerel.

9.3.4. Ecosystem effects on pelagic fisheries

Over the decades, fishing has become a leading anthropogenic stressor, affecting not only fish stocks but also triggered large-scale ecosystem effects such as trophic cascades and regime shifts characterized by sudden, irreversible switches (Daskalov *et al.,* 2007). Overfishing in combination with fluctuating climate was recognized as main causes of the fisheries collapses (Oguz and Gilbert, 2007). Deteriorating environment and alien introductions exacerbated the problem. Overfishing and alien intrusion at high trophic levels drove trophic cascades and switched dominance from valuable fisheries resources to an excess of jellyfishes and microalgae. Interaction between environmental, biological and anthropogenic factors generated feedbacks resulting in harmful plankton blooms, hypoxia, and hydrogen sulphide production, adversely affecting the ecosystem as a whole and fish stocks in particular. The complex nature of ecosystem responses to human activities calls for more elaborate deterministic-based management approaches than currently provided by traditional environmental and fisheries assessment methodologies.

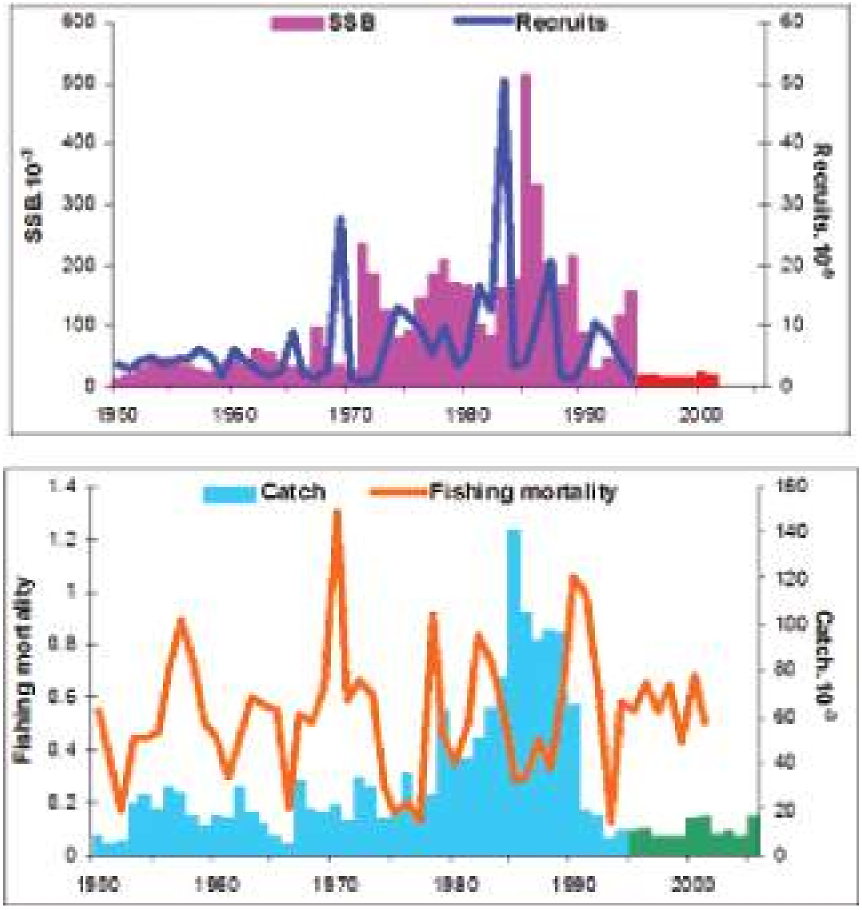

Fig. 9.10. Time-series of recruitment, spawning stock biomass (SSB), catch and fishing mortality of the Black Sea horse mackarel.

9.4. The state of populations of key demersal fishes

From the Black Sea fisheries perspective, the most important demersal fish species are whiting (*Merlangius merlangus*), picked dogfish (*Squalus acanthias*), turbot (*Psetta maxima*), striped, red mullets (*Mullus barbatus, M. surmuletus*), and four species of family *Mugilidae,* including so-iuy mullet (*Mugil soiuy*). The total catch of these demersal fish species in 1996-2005 was lower on the average than in 1989 - 2005 and had tendency of reduction after 2000 (Fig. 9.11).

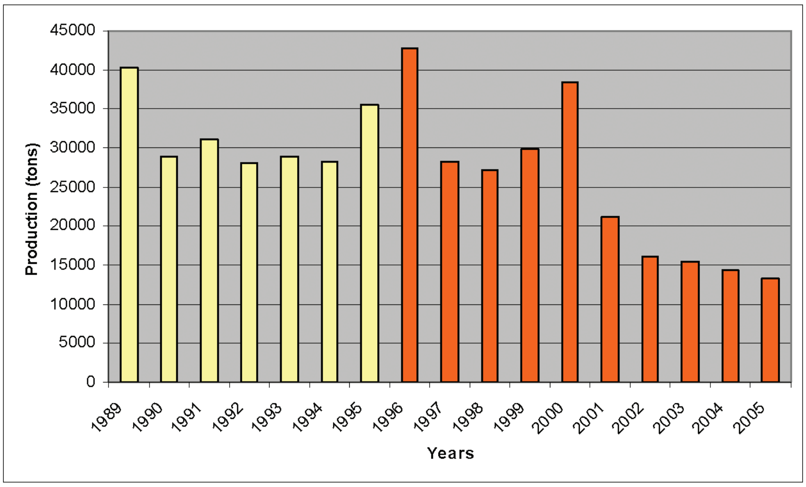

Fig. 9.11. Total catch of main demersal fishes in the Black Sea during 1989 - 2005.

9.4.1. Whiting

In the Black Sea, whiting is one of the most abundant species among the demersal fishes. It does not undertake distant migrations, spawns mainly in the cold season within the whole sea. Whiting produces pelagic juveniles, which inhabits the upper 10-meter water layer for a year. The adult whiting is cold-living species at temperatures 6 - 10ºC (Shlyakhov, 1983). Species younger than 6 years old dominate the populations, and older year classes are found rarely in catches. Dense concentrations are formed by 1-3 year old fishes at depths up to 150 m, most often at the depth range 60 - 120 m (Özdamar *et al,* 1996; Shlyakhov and Charova, 2003).

In Bulgaria, Georgia, Romania, the Russian Federation and Ukraine, whiting was rarely a target species and collected mainly as by-catch during trawl fisheries or non-selective fisheries with fixed nets in the coastal sea areas. This fishery was most developed in Romanian waters. In 1996 - 2005, the total mean annual catch of whiting by Black Sea countries (except Turkey) according to the data of official statistics submitted to FAO was less than 0.6 thousand tons (Table 9.4). Whiting landings by-caught in larger quantities during target trawl fisheries for sprat and other fishes in Bulgaria, Georgia, Romania and the Russian Federation were specified in the official reports of these countries. Thus, the whiting by-catch in the waters of Ukraine in 1996 - 2002 was assessed in the range of 0.65 - 1.8 thousand tons (Shlyakhov and Charova, 2003). On the other hand, by-catches of small-sized whiting populations were often not graded and merely discarded (although it is prohibited by the Regulations of Fisheries) or recorded in statistics as sprat.

In the vicinity of southern coast, whiting concentrations are more stable. Turkey is the only country in the region to conduct the target trawling fisheries for this fish with permission between September and April within offshore areas outside the 3 miles zone from the coast. Among by-catch fishes in the Turkish fisheries, whiting usually is therefore ranked third or fourth. Its annual catch varied from 6 thousand tons to 19 thousand tons during 1996 - 2005, making on the average 10.8 thousand tons. As compared with 1989 - 1995, when the mean annual catch of whiting was 17.6 thousand tons, the tendency towards reduction of both its catches and CPUE is observed (Fig. 9.12).

Using the VPA method, Prodanov et al. (1997) produced assessments for whiting abundance and biomass for the period of 1971 - 1993. No such basin-scale assessments however existed for 1996 - 2005, except for the western Black Sea excluding the western Turkish coastal waters (Prodanov and Bradova, 2003). According to this latter assessment, whiting biomass in 1997 was assessed as 121 thousand tons, which was comparable with the long-term mean after decline in 1990 - 1991 (Fig. 9.14).

Table 9.4. Whiting and picked dogfish catches in the Black Sea according to the official statistics. The last three rows provide the average catches for the periods indicated in the subscripts.

Year	Whiting						Picked dogfish					
	BG	GEO	RO	RF	TR	UKR	BG	GEO	RO	RF	TR	UKR
1989	0	5	2739	7	19283	579	28	217	30	135	4558	1191
1990	0	70	2653	235	16259	87	16	128	45	183	1059	1330
1991	0	82	59	210	18956	24	21	18	26	67	2017	755
1992	0	70	1357	37	17923	0	15	14	52	15	2220	595
1993	0	172	599	2	17844	5	12	131	6	5	1055	409
1994	0	187	432	125	15084	64	12	45	2	11	2432	148
1995	0	146	327	91	17562	17	80	31	7	90	1562	67
1996	0	223	389	11	19326	3	64	71	0	15	1748	44
1997	0	58	441	10	12725	29	40	1	0	9	1510	20
1998	0	53	640	119	11863	55	28	550	0	6	855	38
1999	0	41	272	184	12459	18	25	18	0	9	1478	94
2000	0	45	275	341	15343	20	102	21	0	12	2390	71
2001	8	32	306	642	7781	18	126	27	0	27	576	134
2002	16	37	85	656	7775	9	100	65	0	19	316	97
2003	13	45	113	93	7162	21	51	40	0	29	1840	172
2004	2	29	118	55	7243	43	47	31	0	34	111	93
2005	3	37	105	49	6007	30	15	45	0	17	102	74
Y89/95	0	105	1167	101	17559	111	26	83	24	72	2129	642
Y96/05	4	60	274	216	10768	25	60	87	0	18	1093	84
Y00/05	7	38	147	306	8552	24	74	38	0	23	889	107

Along the eastern coast of Turkey in 1990 - 2000, more than 80% of landings of whiting were caught by trawl (Zengin, 2003). The research on trawl fisheries in the vicinity of Samsun indicated that as much as 75% of whiting trawl catches were discarded in 2005 (Knudsen and Zengin, 2006) due to their small size average length (Fig. 9.13).

In the Russian sector of the Black Sea, trawl surveys showed that stocks of whiting and other *Gadidae (Gaidrosparus mediterraneus)* were estimated about 7.6 - 8 thousand tons, and the total annual allowable catch (TAC) for whiting was 2 thousand tons (Volovik and Agapov, 2003). The corresponding assessments for 1999 - 2005 given in Table 9.5 testify rather high stable level of biomass in the Russian waters with an average value of 6.6 thousand tons. If the whiting portion of total by-catch is assumed to be 9% of sprat catch in 1996 - 2005 (as in Bulgarian case), the average annual capture of whiting is assessed as 1.2 thousand tons that, in agreement with the estimate by Volovik and Agapov (2003), suggests under-exploitation of whiting resources.

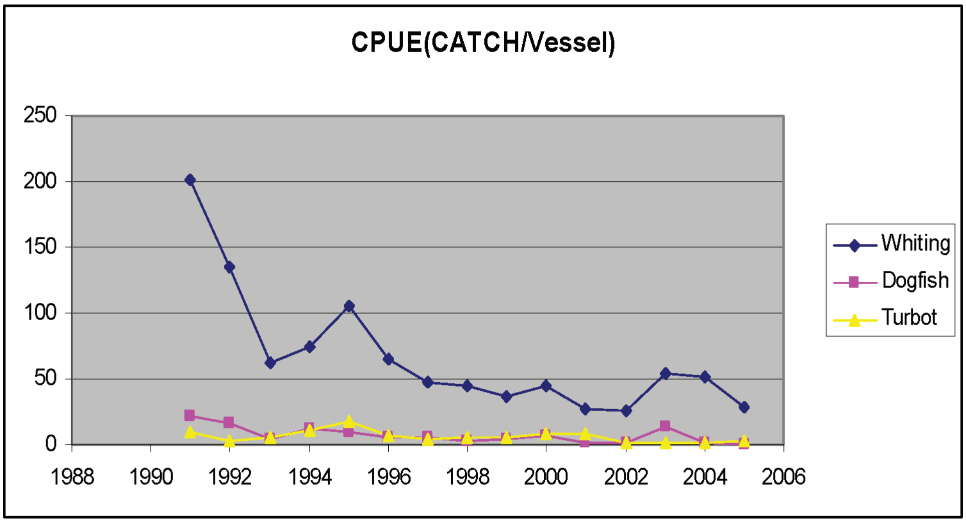

Fig. 9.12. Long-term changes of CPUE for three demersal species in Turkish waters of the Black Sea in 1989 - 2005 (from the TDA Technical Task Team National Experts - Turkey Report, Duzgunes, 2006).

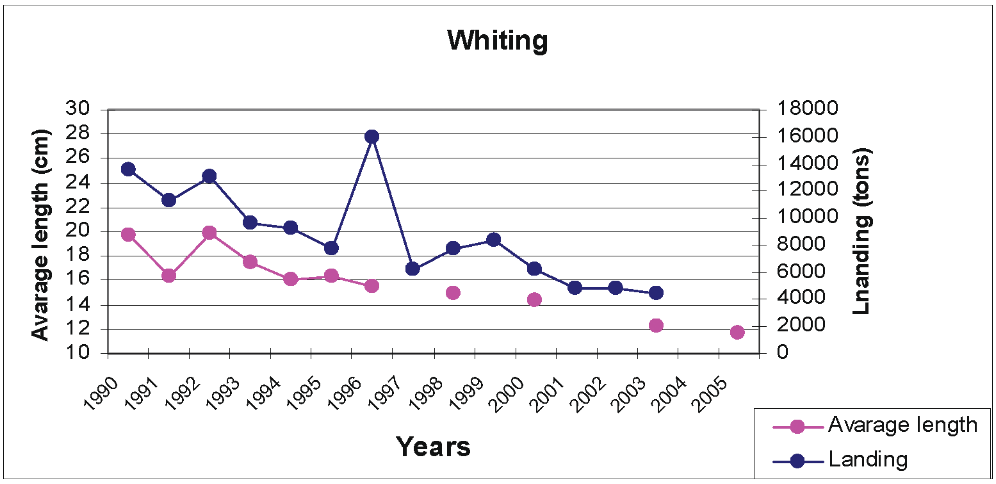

Fig. 9.13. Whiting landings and average length of whitings harvested in the eastern Black Sea region of Turkey. (Taken from Knudsen and Zengin, 2006).

Along the Turkish coasts, the total biomass of whiting in local trawling areas was estimated by A. İşmen (2003). The highest biomass of 30 thousand tons was found between Sinop and Sarp (eastern Black Sea), which is the area closed to trawl fishing in 1992. The biomass between Sinop (central Black Sea) and İğneada (western Black Sea) was estimated within the range of 1.1 - 1.7 thousand tons in 1990. But, there are no similar published assessments for the period of 1996 - 2005. It is therefore more difficult to identify the present state of rather intensively exploited whiting stocks in the Turkish waters. However, the change of mean length of whiting from 16 - 20 cm range in 1989 - 1995 to 14 cm in 2000, 12 cm in 2003 and 11 cm in 2005 highly likely implies an intensive whiting fishery within the recent years as further supported by independent statistical-based studies conducted by Genç *et al.* (2002) and İşmen (2003). Thus, whiting stock in the waters of Turkey may be characterized as excessively exploited. The main reason for whiting overfishing in Turkey may be the lack of any limitation for annual catch sizes and/or fishing efforts.

Fig. 9.14. Whiting biomass by age groups (in thousand tons) in the western part of the Black Sea during the period of 1971 - 1997. (Taken from Prodanov and Bradova, 2003).

Table 9.5. Whiting stock in the Russian waters in the northeastern Black Sea (thousand tons) (taken from the TDA Technical Task Team National Experts - Russian Federation Report, 2006).

Years	1999	2000	2001	2002	2003	2004	2005
Stock	7.1	7.6	7.0	5.8	6.85	6.0	6.0

For 1992 - 1995 whiting biomass in the waters of Georgia, the Russian Federation and Ukraine was identified within the range 64 - 103 thousand tons, on the average 82 thousand tons. The range and the average stock size for 1996 - 1998 were 68 - 77 thousand tons and 72 thousand tons, respectively (Shlyakhov and Charova, 2003). In 1992 - 1995 whiting biomass in the Ukrainian waters changed from 43 to 70 thousand tons, on average 54 thousand tons. For the subsequent decade, they were 40-68 thousand tons and 52 thousand tons, respectively (Shlyakhov, Charova, 2006). These data testify rather high inter-annual fluctuations but rather stable average level of whiting biomass in the regions where whiting specialized fisheries was almost absent and trawling fisheries were not conducted on the grounds with the densest whiting distributions. In the Ukrainian sector, whiting catch in 1996 - 2005 did not exceed 30% of allowable catch (Shlyakhov, Charova, 2003; 2006). Therefore resources of whiting are underexploited in Ukraine.

These official statistics provided by the Black Sea countries however may not reflect the true harvesting that may indeed higher. For this reason, the assessments of the stock abundance made from the scientific trawl surveys or estimates produced using the obligatory correction of unregistered catch seem to be more realistic. Using one latter type data set, an independent assessment of whiting average annual capture in 1996 - 2005 on the shelf from the border with Turkey to the Danube estuary was computed as 670 tons that turned out to be 2.4 times higher than the value of 278 tons based on the official catch statistics. Thus, it appears that the official statistics underestimates considerably the real catch.

Prodanov and Bradova (2003) and Radu et al. (2006) noted the important role of improved ecological conditions of the Black Sea environment after 1993 for the tendency of increasing whiting biomass along the Bulgarian and Romanian coasts. In their opinion, rehabilitation of small-sized pelagic fish stocks reduced the pressure on whiting populations, thus leading to a slight recovery of their stock. Another likely cause of rehabilitation of the whiting stocks may be naturally-caused year-to-year variations in their reproduction, length-weight and age parameters (Shlyakhov, 1983), whereas intensity of whiting fisheries along the coasts of Bulgaria and Romania has been too low to exert major effect on its abundance and biomass.

Table 9.6. Fish stocks protection measures for whiting implemented by the Black Sea countries.

Fish Stocks Protection Measures applied in the Black Sea coastal states	**Coastal states**					
	BG	GEO	RO	RU	TR	UA
Periodic ban	+	+	+	+	+	+
Total Allowable Catch (TAC)	+	+	+	+		+
Total Permitted Catch (Limit)				+		+
Minimum admissible size	+	+	+	+	+	+
Periods for fishing bans	+	+	+	+	+	+
Fishing Free Zones		+	+	+		
Prohibited fishing gears	+	+	+	+	+	+
Allowable mesh size for nets	+	+	+	+	+	+

In all the Black Sea countries, protection measures for fish stocks were adopted including whiting (Table 9.6). However, implementation of TACs, quotas without efficient enforcement of the measures does not avoid the overfishing problem and other negative impacts of fisheries on exploited species. On the basis of the assessments of national experts in fisheries, the main transboundary threats for whiting are listed as follows.

Lack of regional cooperative management of fisheries. For the group of non-migratory fishes with shared stocks where whiting belongs, management of shared stocks can be successful only with rather developed regional cooperation. It requires a unique methodological approach in all the aspects of stock assessment (methodology, collection, processing and analysis of common data set, etc.), agreed measures of fisheries regulation (terms and grounds of banning, permitted fishing gears, mesh size for nets, fishable length of fishes, allowable by-catches for juveniles, etc.), agreed system of satellite monitoring for commercial fishing vessels and many other aspects.

Illegal fishing and use of destructive harvest techniques. Illegal fishing has never been and will not be a real threat for whiting population. But the use of destructive harvest techniques by trawls due to high by-catch capture rate of the year 0+ small-sized populations is a real threat. In addition to its direct threat on the reduction of whiting recruitment, it may indirectly cause wrong TAC assessments and thus false decision-making.

Eutrophication and pollution. The alterations of trophic flow structure due to eutrophication-induced effects in the ecosystem may be critical for whiting populations because zooplankton, small pelagic fishes and benthos organisms (crustaceans and Polychaetae) are among their important diet. In turn, whiting is an important prey species for large predators, dolphins and fish-consuming birds. Whiting juveniles and bottom-dwelling whiting at age less than 2 years old distributed mainly in shallow depths are the most vulnerable for eutrophication effects.

9.4.2. Picked dogfish

Picked dogfish inhabits the whole Black Sea shelf at water temperatures 6 - 15º C. They migrate in the form of large schools for feeding and overwintering on anchovy and horse mackerel to the Crimean, Caucasus and Anatolian coasts in autumn. In the Ukrainian and Romanian grounds of whiting and sprat concentrations, abundant wintering concentrations of picked dogfish are also observed at depths from 70-80 m to 100 - 120 (Kirnosova and Lushnicova, 1990). Reproductive migrations of picked dogfish take place in spring and autumn at coastal shallows at 10 - 30 m depths zones (Maklakova and Taranenko, 1974). The major grounds for reproduction are the Crimean coastal waters such as the Karkinitsky Bay, the vicinity of Kerch Strait, and the Feodosia Bay. Picked dogfish belongs to long-living viviparous fish; therefore reproduction process includes copulation and birth of fries. Near the coasts of Bulgaria, Georgia, Romania, Russian Federation and Ukraine the maximum copulation takes place in March - May. Two peaks of birth of juveniles can be distinguished - spring (April-May) and more powerful - summer-autumn (August - September) at water temperature range of 12-18°C (Serobaba *et al.,* 1988). The picked dogfish population includes 19 year-classes and among commercial fish species of the Black Sea this species is inferior only to sturgeons in duration of life cycle.

It is not a target species of fisheries, and mostly caught as by-catch in trawl and purse seine operations mainly during their wintering period. The largest catches of picked dogfish are along the coasts of Turkey. In the Ukrainian waters, picked dogfish is mainly harvested in spring and autumn months by target fishing with nets of 100 mm in mesh and with long-lines as well as during sprat trawl fisheries as by-catch. For the whole population of picked dogfish in the Black Sea stock assessments for 1972 - 1992 were produced by the VPA method (Prodanov *et al.,* 1997), and trawl surveys and mathematical modelling (Shlyakhov and Charova, 2006) (Table 9.7). In 1989 - 2005, picked dogfish stock on the Ukraine shelf reduced gradually. Such dynamics of the stock agrees well with Turkish data concerning variations of CPUE (see Fig. 9.15). According to the assessments of Prodanov *et al.* (1997), the picked dogfish stock increased until 1981 due to increased abundance of their main dietary species (whiting, sprat, anchovy and horse mackerel), and then started decreasing due to intensification of the dogfish fishery.

Evidently, the role of fisheries in reduction of picked dogfish stock was over-estimated at that time. In fact, for 1979 - 1984 the mean annual capture from the stock in the Black Sea made up 8254 tons or about 4% of the initial stock, and it reduced to 3.5% in 1989 - 1992 (Kirnosova, 1990). Even taking into account unreported catches of picked dogfish, which in late 1980s seemed not to exceed the official catch (at least in the waters of Ukraine - Shlyakhov and Charova, 2003), real capture was not excessive. The mean length of picked dogfish in the northwestern Black Sea in trawl catches in 1989 - 2005 did not reduce and even increased (Fig. 9.15), that do not imply overexploitation of this species. The causes of reduction of picked dogfish stock should therefore be related to the changes in the Black Sea ecosystem due to pollution and subsequent progressive deterioration of reproductive ability of females (Shlyakhov and Charova, 2003). In the 1970-1980s, the mean number of yolk ovocytes and embryos for one female was 22 and14, respectively, and they were reduced to 19.5 and 12.4 by late 1990s. As a result, the abundance of recruits reduced year by year.

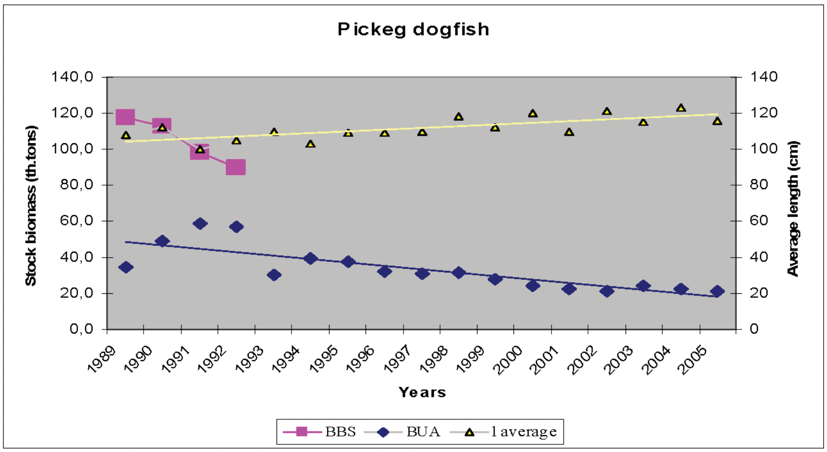

Fig. 9.15. Biomass of picked dogfish in the Black Sea-BBS (Prodanov et al., 1997), in the waters of Ukraine- BUA (Shlyakhov, Charova, 2006) and the mean standard length (l average) in trawl catches of picked dogfish in the northwestern part of the sea: Trend lines are shown for the BUA and l average data series.

Table 9.7. Commercial stock of picked dogfish in the Black Sea and along the coast of the former USSR and in the water of Ukraine in 1989 - 2005, thousand tons

Years	Whole Black Sea shelf	Waters of Ukraine, the Russian Federation and Georgia		Waters of Ukraine	
	VPA	Trawl survey	Modeling	Trawl survey	Modeling
1989	117.8	58.5	63.5	34.6	-
1990	112.9	58.7	63.2	48.8	-
1991	97.9	17.2/69.9*	64.0	14.4/58.5*	-
1992	90.0	62.9	60.3	56.9	-
1993	-	-	57.1	30.2	-
1994	-	-	52.9	36.0	42.1
1995	-	-	-	-	37.6
1996	-	-	-	-	32.1
1997	-	-	-	-	31.0
1998	-	-	-	32.0	30.8
1999	-	-	-	-	28.0
2000	-	-	-	-	24.3
2001	-	-	-	-	22.3
2002	-	-	-	-	21.0
2003	-	-	-	-	22.1
2004	-	-	-	-	22.3
2005	-	-	-	-	21.0

* stock assessment is reduced to the average area of the registration (survey) zone

The main threats for the Black Sea picked dogfish resource with transboundary significance are the same as for whiting. One more threat may be added to that list:

Pollution from land based sources (rivers) and direct discharges (inshore area). As a long-living predator as compared with other fishes in the Black Sea, picked dogfish has the ability to accumulate toxic pollutants - heavy metals (mercury, arsenic, lead, copper, cadmium and zinc) and chlorine organic compounds (including and its metabolites, polychloride biphenyls, etc.).

9.4.3. Turbot

Turbot occurs all over the shelf of the Black Sea. It is a large-sized fish with long life cycle; it reaches length of 85 cm, weight of 12 kg and age of more than 17 years old in the Black Sea (Svetovidov, 1964). Turbot fecundity is very high, up to 12.8 million of eggs per year. Larvae and fries in the first two months inhabit in the pelagic zone, feeding on zooplankton. Adults feed on fish mainly, both on demersal (whiting, red mullet and gobies), and with pelagic species (anchovy, sprat, horse mackerel, shad) species. Diet of turbot also includes crustaceans (shrimps, crabs, etc.), mollusks and polychaetes. Like whiting, it does not undertake distant transboundary migrations. Local migrations (spawning, feeding and wintering) have a general direction from the open sea towards the coast or from the coasts towards offshore. It matures in majority at the age of 3 - 5 years in the waters of Bulgaria (Ivanov and Beverton, 1985), at the age of 5 - 6 years in the waters of Ukraine and the Russian Federation (Popova, 1967). It spawns in spring, from the late March until the late-June, at water temperature range 8 - 12ºC. The peak of spawning occurs in May at depths from 20 - 40 to 60 m. After the spawning, turbot moves downwards to the depths 50 - 90 m and maintains low-activity life with limited feeding until the early autumn. In autumn turbot returns coastal waters again, where it feeds intensively. For wintering it migrates to the depths from 60 m to 140 m.

In all the Black Sea countries, turbot is one of the most valuable fish species. Its target fisheries is conducted with bottom (turbot) gill nets with minimum mesh size 180 mm in the waters of Bulgaria, Georgia, Romania, the Russian Federation and Ukraine (Prodanov *et al.,* 1997) and with minimum mesh size 160 - 200 mm as well as with bottom trawls with minimum mesh 40 mm in the waters of Turkey (Tonay and Öztürk, 2003). Turbot as a by-catch is harvested during target fisheries of other species with trawls, long-lines and purse seines. According to Zengin (2003), 72% of turbot fishing in Turkish waters of the Black Sea has been carried out by bottom gill nets, 26% by trawls and 2% as the by-catch from purse seines. More than 80% of the Ukrainian turbot catches were performed by target fisheries using nets with mesh size 180-200 mm, the rest part mainly corresponded to by-catch. In 1996 - 2005, the mean annual Turkish turbot catch was 1235 tons, and 177 tons for the rest of the Black Sea countries (Table 9.8). The turbot fishery was completely banned or largely limited by the Total Permitted Catch in all countries except Turkey in the early 1990s and therefore was at a negligible level.

Like for many demersal fish species, the serious problem for estimating the status of turbot population and justifying efficient measures for its fisheries regulation is considerable difference between the recorded statistics and the real catches. According to the expert assessments (Shlyakhov and Charova, 2003), the unregistered annual yield of turbot for Ukrainian waters was in the range of 0.2 - 0.8 thousand tons in 1992 - 2002. These assessments are not complete, as they included only the unregistered turbot by-catch during sprat fisheries and poaching (illegal) catches of Turkish vessels. But, this unregistered annual yield was even higher than official turbot statistics.

Table 9.8. Turbot catches in the Black Sea in 1989 - 2005 in tons. The last three rows show the average catches for the years indicated in the subscripts.

Year	Turbot					
	BG	GEO	RO	RU	TR	UA
1989	1	8	0	0	1449	2
1990	0	1	0	0	1383	9
1991	0	0	2	0	915	18
1992	0	0	1	1	418	19
1993	0	0	6	2	1585	18
1994	0	0	6	5	2114	16
1995	60	0	2	19	2850	10
1996	62	0	4	17	1924	39
1997	59	0	1	11	911	42
1998	64	0	0	14	1468	42
1999	54	5	2	15	1804	73
2000	55	9	2	4	2639	80
2001	57	11	13	24	2323	129
2002	136	11	17	15	335	104
2003	41	1	24	15	119	124
2004	16	7	42	2	274	133
2005	13	6	28	15	548	129
Y89/95	9	1	2	4	1531	13
Y96/05	56	5	13	13	1235	90
Y00/05	53	8	21	13	1040	117

Caddy (2006) interpreted the landing data in terms of trends and suggested the baseline trend before 1989, the decreasing trend in the collapse years 1989-92, gradually increasing trend in 1992 - 2002, a more pronounced increasing trend in 1998 - 2002. The landing in 1998 - 2002 was 70% of the baseline and therefore suggested partial recovery in recent years. If the catch analysis takes into account exploitation of different stock units, the interpretation given by the trend analysis however changes greatly. In the base period (1967 - 1988) Turkish landings made up 82% of total catches of all the countries. Its fisheries was conducted mainly on local turbot stocks existed in its own waters in 1967-71 and 1985-92, but extended into the western and northwestern stocks within the international waters in 1972 - 1984 (Acara, 1985). By 1985, the western and northwestern stocks appeared to be overfished; for this reason since 1986 the former USSR imposed banning for turbot fisheries in its waters to which Bulgaria and Romania joined soon but Turkey refused to join to this banning. In 1986 - 1992 (i.e. at the end of the base period and in the years of collapse) recovery of the stocks took place with the negative trend of landings, as in this period only stocks in the Turkish waters were fished. The positive trend of landings in 1992 - 2002 and its steep increase in 1998 - 2002 was explained not only by recovery of turbot stocks in the waters of Ukraine, but by the intensification of illegal fishing of the western and northeastern stocks by Turkish vessels. As indicated by the available studies carried out in different Black Sea countries (Table 9.9), turbot stocks decreased prior to 1989 and a partial recovery of turbot biomass took place in waters of all countries except Turkey as a result of banning and limiting the fisheries by the early-1990s.

Table 9.9. Some studies carried out in the Black Sea regions on turbot stocks.

Researchers	Location	Years and periods	Biomass assessment (tons)	MSY or TAC (tons)	Methods
Prodanov et al., 1997	Waters of the Black Sea	1989-1990 1991-1992	19100 6200	-	LCA Jones' method
Bingel et al., 1996	Southern Black Sea (Sinop-Georgia board) Western Black Sea	1990 1991 1992 1990	124 410 766 130.5	-	Swept area method (trawl surveys)
Zengin, 2000	Southern Black Sea (Sinop- Georgia board)	1990 1991 1992 1993	686.3 250.4 222.4 134.3	96.1 26.3 24.5 15.4	Swept area method (trawl surveys)
Prodanov and Mikhailov, 2003	Waters of Bulgaria	2002	Mean - 352 Initial - 425	60	LCA Jones' method
Shlyakhov and Charova, 2003	Waters of the Russian Federation	1992	1800	-	Swept area method (trawl surveys)
Volovik, Agapov, 2003	Waters of the Russian Federation	2000-2002	1000-1700	100	Swept area method (trawl surveys)
Shlyakhov and Charova, 2003	Waters of the Russian Federation	1992-1994	4280 (1800-5900)	-	Trawl surveys and Baranov's modified equation
Maximov et al., 2006	Waters of Romania	2003-2005	427-1066	-	Swept area method (trawl surveys)
Shlyakhov and Charova, 2003; 2006	Waters of Ukraine	1992-1995 1996-2002 2003-2005	8830 (8200-10400) 10980 (8400-13700) 9570 (8500-10200)	-	Swept area method (trawl surveys)
Shlyakhov and Charova, 2003; 2006	Waters of Ukraine	1992-2002 2003-2005	10590 (8200-13700) 8900 (8200-10200)	-	Trawl surveys and Baranov's modified equation
Panayotova et al., 2006	Waters of Bulgaria	2006	1440	-	Swept area method (trawl surveys)
Raykov et al., 2008	Waters of Bulgaria	2006	1567	-	Swept area method (trawl surveys)

Analyzing the state of the stock using official statistics of turbot capture near the coasts of Bulgaria, Prodanov and Mikhailov (2003) concluded that biomass of this species was about 2500 tons in early 60s. By late 1970s biomass reduced to 355 tons as a result of overfishing and deteriorating environment, and to 100 tons in 1993. Applying LCA method, they assessed the turbot stock as 424 tons in 2002. Increased biomass was the consequence of five-year banning for fisheries. However, comparing stock abundance and capture, they determined that the catches were composed by fish size 42 - 47 cm and 2 - 4 year old indicating turbot excessive exploitation again. According to the official statistics, landings in 2003 made up 49 tons, and in subsequent two years it reduced to 16 tons and 13 tons respectively. The last assessment indicated the turbot biomass in the Bulgarian waters as 1440 - 1567 tons in 2006 (Panayotova *et al.,* 2006; Raykov *et al.,* 2007).

Table 9.10. Biomass and catches of the turbot of the Black Sea in the waters of Ukraine in 1996 - 2006 (tons), mean fishing mortality, relevant to its official catches in 1992 - 1995 and 1996 - 2005.

Years	Biomass of stocks (B)		Catch (Y) for:		Total Permitted Catch (Limit)	Official landings
	Swept area method (trawl surveys)	Baranov's modified equation	F0.1=0.15	Fmax=0.20		
1996	-	13500	1792	2333	84	39
1997	-	13600	1805	2350	90	42
1998	8400	13300	1440	1875	90	42
1999	-	12600	1672	2177	190	73
2000	-	9600	1274	1659	185	80
2001	9900	10500	1354	1762	370	129
2002	10000	8700	1241	1616	395	104
2003	10000	8900	1254	1633	310	124
2004	8500	8200	1108	1443	350	133
2005	10200	7800	1194	1555	319	129
2006	10400	7600	1194	1555	323	162
1992-95	8871		1177	1533	-	14 Fof = 0.001
1996-05	10094		1411	1744	238	90 Fof = 0.009

The last research on turbot stock in the waters of Bulgaria and Romania pointed to their level of exploitation. In 2005 biomass of this species was assessed as 1066 tons (Maximov *et al.,* 2006). Near the Russian coast, the long-term banning for turbot fisheries (since mid 1980s till mid 1990s) resulted in improvement of the state of northeastern stock. By the end of banning it was assessed as 1800 tons. According to AzNIIRKH research, the state of turbot stock is not stable, but changes occur in a rather narrow range of 1000 - 1700 tons (Volovik, Agapov, 2003). The observed interannual fluctuations in biomass assessments in 2000s may be caused by re-distribution of turbot between Russian and Ukrainian waters. In the opinion of Russian scientists, overexploitation of turbot in their waters for recent 10 years has not been observed.

Direct assessments of turbot biomass made using the data of trawl surveys near the coasts of Turkey eastwards to Sinop for 1990 - 1992 differed greatly. According to Bingel *et al.* (1996) increase in biomass took place in those years, and according to Zengin (2000), on the contrary, reduction in biomass occurred. According to the assessments of Prodanov *et al.* (1997) on the grounds of cohort analysis of the length composition of catches between 1989 and 1992 turbot biomass reduced 3.1 times in the waters of Turkey, and this tendency agreed well with 3.9 times reduction assessed by Zengin (2000). Composition of Turkish catches was evidence of capture of immature turbot at ages under 4^+ that was about 63% in 1990 - 1995 and 62% in 1996 - 2000 of the population.

For recent 10 years, continuous set of the published assessments of turbot biomass is available for the waters of Ukraine where the greater part of its western population distributes. Table 9.10 gives the most detailed information on biomass dynamics and potential catch of turbot after 1996.

According to the data of the last trawl surveys proportion of biomass of the western stock and northeastern is close to 9:1, and the percentage of fish from the western stock in the annual catch of Ukraine is even more. As compared with 1992 - 1995, in 1996 - 2005 turbot biomass in the Ukrainian waters increased slightly. Trawl surveys undertaken each year since 2001 is the evidence of stable level of turbot biomass in the waters of Ukraine. In 1996 - 2005 the control measures enabled to avoid overfishing of turbot, and stabilized the length-weight composition of catches in the northwestern Black Sea (Fig. 9.16).

The list and significance of the main threats for turbot resources in the Black Sea are similar to those for whiting. The first place should be given to Illegal fishing and use of destructive harvest techniques. In the broad sense it is not only poaching but deliberate avoidance of adopted measures of regulation by fishermen. This threat is of social and economic character, and not easy to reduce it. An almost equivalent, in experts' opinion, threat is the lack of regional cooperative management of fisheries.

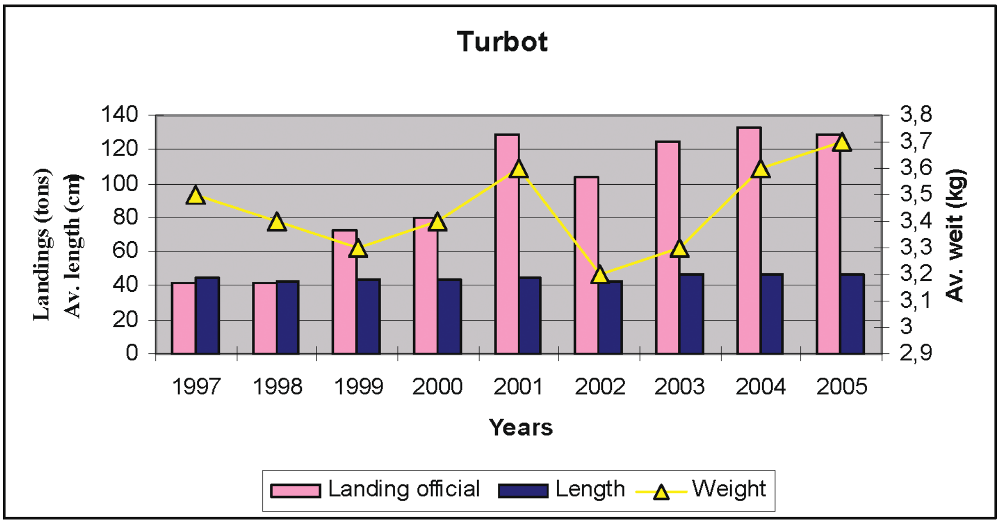

Fig. 9.16. Mean length and weight of turbot in the northwestern Black sea and its landings by Ukraine in 1997 - 2005.

9.4.4. Striped and red mullets

Two physiologically similar species *Mullus barbatus* and *Mullus surmuletus* belong to the family *Mullidae*. The species *M. barbatus* is also called as red mullet or striped mullet. In FAO terminology, *M. barbatus* is also named as striped mullet. For the convenience's sake we use hereinafter this name to both species of the family *Mullidae*.

Striped mullet is distributed all over the shelf of Black Sea. It prefers waters with the temperature higher 8º C and salinity more than 17‰. Striped mullet reaches maturity in the first-second year of its life. It lives usually until 4 - 5 years old reaching length of 20 cm and more. Striped mullet spawns in the warm period of time with a maximum in mid-summer. Eggs and juveniles (up to the age of 1.5 months) are pelagic; adults live near bottom, feeding on *Polychaetae*, crustaceans and mollusks. In the vicinity of the Crimean and Caucasus coasts, it is customarily distinguished in two particular forms - settled and migratory ones. The latter has higher rate of growth.

Migratory form has the greater commercial value, moving to the Kerch Strait and the Sea of Azov for fattening and spawning in spring and coming back to the coasts of the Crimea for wintering.

Due to its taste, the striped mullet is a valuable target species for fisheries. Most of all striped mullet is harvested in the Turkish waters (Table 9.11) where it is the second important target species in the bottom trawling fisheries after whiting. In 1990 - 2000, around 75% of landings of striped mullet were caught by trawl along the eastern Black Sea coast of Turkey (Zengin, 2003). Its mean annual catch made up 2590 tons and as compared with the previous 7-year period it reduced 46% in 1996 - 2005 due mainly to decreased catches in the eastern part of the sea. Beginning from 1999, more than half of striped mullet landings have realized on the western Black Sea of Turkey where the proportion of trawl fisheries is much less (Fig. 9.17). To some extent it is the evidence of excessive pressure of trawl fisheries on striped mullet stocks near the Turkish coasts. The years 1989, 1993 and 1996 are identified as particularly abundant years with relatively high catches in the eastern part whereas higher catches in the western part follows with a 2 - 3 years phase lag (1991, 1996 and 1999).

Table 9.11. Landings of mullets in the Black Sea according to the official statistics (tons).

Year	Striped mullet						Mullets (Mugilidae)					
	BG	GEO	RO	RU	TR	UA	BG	GEO	RO	RU	TR	UA
1989	0	0	5	324	6753	0	3	5	8	12	2843	22
1990	0	0	7	132	3507	0	1	19	0	4	1749	6
1991	0	0	25	210	3610	0	7	0	0	2	4026	8
1992	1	0	0	37	2988	5	5	0	0	2	2358	0
1993	0	0	0	0	2877	12	6	0	0	70	4061	0
1994	0	0	5	25	2337	10	6	0	0	70	5112	0
1995	0	0	9	324	4348	13	24	0	1	65	7779	4
1996	0	0	1	76	5419	2	29	3	0	382	12901	12
1997	0	14	3	68	4040	17	30	0	0	480	8680	118
1998	0	11	3	119	2536	26	13	0	0	401	8198	82
1999	0	8	1	92	2989	26	16	9	0	35	9887	211
2000	0	3	2	127	2355	10	15	19	0	85	14189	178
2001	26	22	3	119	1498	19	57	28	1	7	6705	459
2002	33	67	2	47	1651	40	96	73	2	33	4048	187
2003	36	50	3	177	1073	26	34	80	1	312	3711	59
2004	17	35	40	99	1187	16	18	68	3	366	4191	51
2005	1	51	15	92	1649	15	10	74	2	92	3882	91
Y89/95	0	0	7	150	3774	6	7	3	1	32	3990	6
Y96/05	14	28	8	114	2590	22	38	38	1	220	8310	191
Y00/05	19	38	11	110	1569	21	38	57	2	149	6121	171

In the waters of Bulgaria and Romania the striped mullet is not a valuable target species for fisheries. It is harvested as by-catch during trawl fisheries or together with other fishes during non-selective fisheries with trap nets. In 1996 - 2005 catches of striped mullet in the Bulgarian waters increased slightly. In the waters of Georgia according to the data of official statistics in 1989 - 1996 catches of striped mullet were absent or was categorized within the "other fish" group. In 1997 - 2005, its mean annual catch was equal to 28 tons. According to Komakhidze *et al.* (2003), the striped mullet was captured recently in higher amounts that provided an indirect evidence of increasing abundance. Along the coasts of the Russian Federation target fisheries of striped mullet are performed mainly with passive fishing gears. The stocks exceeded over 100 tons by 1998, which was mainly related to the reduction of *Mnemiopsis leidyi* population (Volovik, Agapov, 2003). In 2002, the total biomass was estimated as 1200 tons, exploited biomass as 960 tons and TAC as 200 tons. In the Ukrainian waters, target fishing of the striped mullet was permitted only with beach seines and scrapers; however, the greater part of its catches corresponded to the non-target fishing with bottom traps (Shlyakhov and Charova, 2003). The major share of striped mullet was harvested in autumn in Balaklava Bay, near Sebastopol. The amount of non-registered catches of striped mullet was undefined. The annual determination of limits for striped mullet harvesting was made without TAC, but taking into account the monitoring of the whole status of the population (size and age composition of catches, proportion between the rest and recruitment, etc.). Its value was estimated as 50 - 60 tons for recent years.

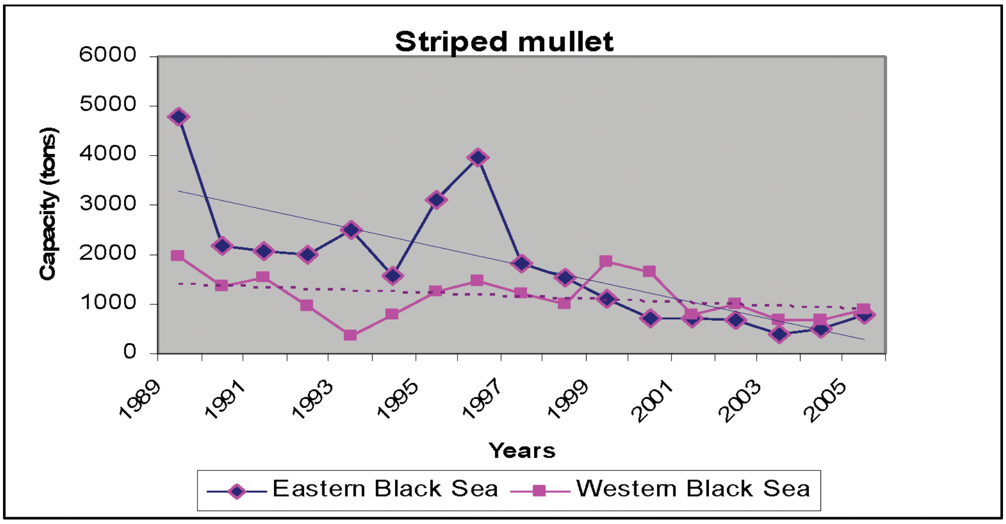

Fig. 9.17. Landings of striped mullet in the Black Sea waters of Turkey (according to data of the TDA Technical Task Team National Experts - Turkey, Duzgunes, 2006).

9.4.5. Mullets *(Mugilidae)*

Among 6 species of mullets from family *Mugilidae* inhabiting the Black Sea, three aboriginal species *Liza aurata* (Risso), *Mugil cephalus* L., *Liza saliens* (Risso) and one acclimatized species *Mugil so-iu*y Basilevsky (*Liza haematocheilus* (Temminch et Schlegel) are of commercial value. Mullets are distributed all over the coastal waters and in the estuaries adjacent to the sea. Their migration routes run along the whole coast and via the Kerch Strait (to the Sea of Azov and back). Wintering migrations of mullets are the most intensive in November. Wintering of warm-loving aboriginal mullets takes place in the narrow coastal band and bays at depths less than 25 m. The wintering grounds of *so-iuy* mullet are not studied well-enough but known to spend winter in the northwestern Black Sea in the vicinity of the Crimean coast, in the Dneprovsky estuary and in other estuaries connected to the sea (Donuzlav, Berezansky, etc.). Often it spends winter under the ice. Spawning migrations of aboriginal mullets from feeding grounds to the Black Sea take place in late August-September. Their stock is the most abundant in the northern Black Sea in the waters of the Russian Federation and Ukraine Crimean-Caucasus.

All coastal countries are engaged in mullet fisheries. Due to their geographical position and wide application of active fishing gears for mullets capture, Turkey has the largest landings (Table 9.11). *So-iuy* mullet fisheries along the coasts of Anatolia are mainly based on fishing off pre-spawning and spawning concentrations. Vessels with engine power from 5 to 380 Hp are engaged (Knudsen and Zengin, 2006). In other countries, the mullet fisheries are carried out with passive fishing gears with traps of different design.

The separate statistics for catch of mullets by species is not available although the Russian Federation and Ukraine compiled the separate statistic for *So-iuy* mullet. Lack of separate statistics for catches of mullets, availability of local stocks as well as their un-reporting catch obstructed producing the mullet biomass assessments for the whole Black Sea.

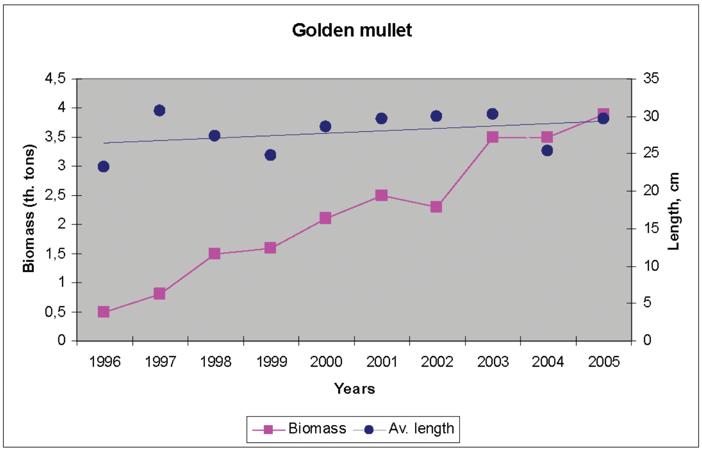

Fig. 9.18. Biomass and mean length changes of golden mullet in the Crimean waters of Ukraine during 1996-2005.

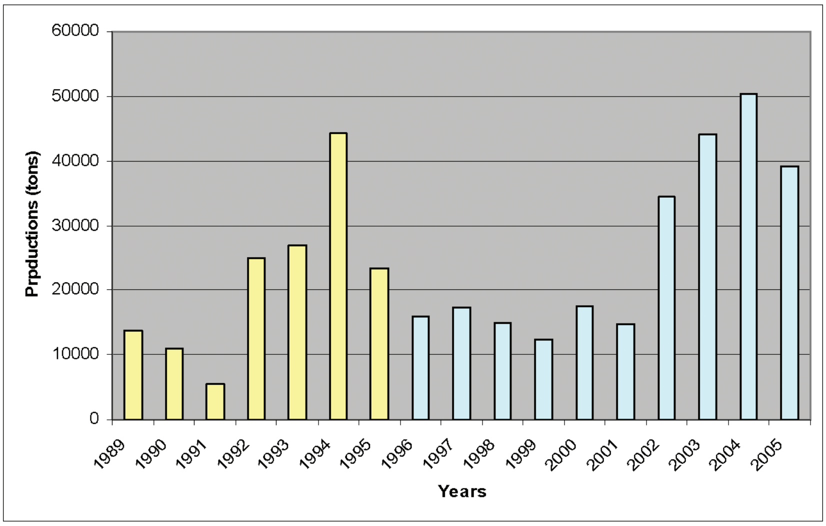

Fig. 9.19. Total catch of main mollusks in the Black Sea in 1989 - 2005.

The 1980s and early 1990s was a period of very low mullet stocks in the Crimean-Caucasus coasts and thus their fisheries were prohibited. Populations of mullets started to be restored only by the late-1990 (Fig. 9.18); however, their renewed fisheries became less intensive. Its stock increase was accompanied by an increase in its total length (Fig. 9.18) that is an additional evidence of improvement of stocks of this fish in the waters of Ukraine. Along the coasts of Caucasus in the waters of the Russian Federation, the state of So-iuy mullet stocks, golden mullet and flathead grey mullet stocks was rather favorable in 2002 to conduct target fisheries within TAC 150 tons (Volovik and Agapov, 2003).

9.5. Commercial mollusks

Among mollusks, the clams (*Chamelea gallina, Tapes spp.*), Mediterranean mussel (*Mytilus galloprovincialis*), and sea snail (*Rapana thomassiana*) have the greatest commercial value. The former two species are harvested only by Turkey and the latter species - by all the countries of the region except Romania. The capture of mollusks in 1996 - 2005 has the tendency to increase (Fig. 9.19).

9.5.1. Mediterranean mussel

Among the Black Sea mollusks, Mediterranean mussel (*Mytilus galloprovincialis*) is the one with highest commercial value. It is one of the most abundant macrozoobenthos species in the Black Sea. It forms the communities along all the coasts from the shoreline to the depth of 55 - 60 meters.

In 1989 - 2005 mussel fisheries was developed in Turkey and Ukraine, while its harvesting in the waters of Bulgaria and the Russian Federation was much less, and Georgia and Romania did not harvest this mollusk at all. Comparison of mussel harvesting in 1989 - 1995 and 1996 - 2005 demonstrated a major reduction in the waters of Turkey and Ukraine for the last10 years (Table 9.12).

According to the opinion of Turkish experts, Mediterranean mussel banks were seriously affected and production rates were decreased. Recently mussel harvesting in the eastern part has not been conducted. In the Ukrainian waters degradation of the mussel settlements occurred mainly due to the deterioration of the environmental conditions and anthropogenic impacts (Fashchuk *et al.,* 1991). The most abundant settlements of this mollusk were concentrated in the northwestern part. Up to the mid-1970s, mussel biomass in the northwestern Black Sea varied between 8 and 12 million tons. In subsequent years, massive death of bottom organisms was registered almost every year due to the oxygen deficiency in near-bottom water layer. It results in rejuvenation of the mussel population as compared with the preceding period. In 1980s the total mussel stock on the Ukrainian northwestern shelf reduced to 4-6 million tons (Zaitsev, 1992). The juveniles made up the basic population at the age of fingerlings and yearlings, up to 35 - 40 mm long. In some years juvenile proportion became as high as 75% of the total population.

Up to 1992, on the banks located in the vicinity of the Black Sea Ukrainian coasts, mussel was harvested with drags more than 1000 tons per year. Almost all the mussels were small-sized and were designed for foraging purposes. At present, only «Mezhvodnoye» bank remained for mussel exploitation. Analysis of the mussel stock status on this bank for the period of observations indicated moderate fluctuations in the range of average amount of 60 thousand tons for mussels of 5 to 70 mm long and 20 thousand tons - for mollusks of more 50 mm long. Mussel harvesting on this bank is recommended annually for 2 thousand tons; however it never exceeded 0.5 thousand tons after 1992.

9.5.2. Sea snail (Rapana spp.)

This species of mollusk is considered to be *R. thomasiana* in most Black Sea countries, and the name *R. venosa* is used rarely for this species. It is thought that sea snail came to the Black Sea with ballast waters from its home places of the Indian-Pacific oceans (Sorokin, 1982). Near the Ukrainian coast sea snail becomes mature at the age of 2 - 3 old; it lives till 8 - 9 years and reproduces during the warm period (July - September). Pelagic larvae of sea snail feed on nanoplankton algae and their adults feed mainly on bivalves of families Cardiidae, Mytilidae, Veneridae, Arcidae and they travel over large distances for feeding. In some periods of a year it buries itself into the ground. Introduction of this predatory mollusk into the ecosystem of the Black Sea turned out to be a catastrophe for oyster biocenoses. Distribution of sea snail is associated with reduction in area and density of mussel settlements, in particular near the coasts of Anatolia and Caucasus. In the Ukrainian waters sea snail destroyed the oyster banks in the area of the Kerch Strait and in Karkinitsky Bay, biocenoses of other mollusks associated with depth down to 30 m suffered as well.

Turkey has been conducting large-scale harvesting of sea snail since the mid-1990s. The other Black Sea countries joined to its fisheries excluding Romania. The Turkish catch remained, however, much higher than other countries, followed by Bulgaria. Their catch increased noticeably during 2000s (Table 9.12). It also became commercially important resource in Bulgaria after 1994. Prior to beginning of its regular harvesting, the biomass on the coastal grounds between Kaliakra and Pomorie was about 2 thousand tons (Prodanov and Konsulova, 1993). Taking into account all the area and the buried part of mollusks, its total biomass was assessed as 7.5 thousand tons. Bottom trawling and dredging were officially forbidden, although these fishing gears were used for the sea snail fishery. According to the assessments of the Private Bourgas Fishery Association, sea snail landings almost 17 times higher than the official report 8557 tons in 2005 (TDA Technical Task Team National Experts - Bulgaria report, Raykov, 2006).

Table 9.12. Landings of Mediterranean mussel and sea snail in the Black Sea (tons).

Year	Mediterranean mussel						Sea snail (Rapana spp.)					
	BG	GEO	RO	RU	TR	UA	BG	GEO	RO	RU	TR	UA
1989	0	0	0	26	2637	1128	0	0	0	4	10032	0
1990	0	0	0	9	2544	2189	0	0	0	156	6094	0
1991	0	0	0	88	26	399	0	0	0	11	3730	0
1992	0	0	0	0	5678	449	0	0	0	192	3439	14
1993	0	0	0	0	5914	210	0	0	0	29	3668	3
1994	0	0	0	0	6038	226	3000	0	0	2	2599	5
1995	0	0	0	0	5741	578	3120	700	0	54	1198	303
1996	5	0	0	0	1400	74	3260	711	0	1	2447	376
1997	57	0	0	0	2952	159	4900	118	0	440	2020	476
1998	92	0	0	0	2435	82	4300	0	0	46	3997	369
1999	100	0	0	4	1584	155	3800	0	0	45	3588	619
2000	0	0	0	0	178	111	3800	184	0	182	2140	913
2001	7	0	0	0	17	61	3353	517	0	224	2614	395
2002	55	0	0	0	2500	71	698	503	0	56	6241	91
2003	15	0	0	1	4050	68	325	295	0	62	5500	149
2004	34	0	0	9	2867	78	2428	65	0	62	14834	159
2005	10	0	0	3	2908	60	511	288	0	87	12153	161
Y89/95	0	0	0	2	4083	740	874	100	0	64	4394	46
Y96/05	38	0	0	2	2089	92	2738	268	0	121	5553	371
Y00/05	20	0	0	2	2087	75	1853	268	0	112	7247	311

In Turkey, harvesting of sea snail is greatly increased for the recent two years. Analysis of fisheries along the eastern coast of Turkey (Samsun Province) showed that number of vessels using drags for sea snail harvesting in 2000 - 2005 increased by large rates, especially in the vessel group 33 - 149 Hp, typically boats that combine sea snail dredging, bottom trawling and net fishing (Knudsen and Zengin, 2006). The small boat non-trawler engine power has increased at a much greater extent (468%), which are also used for sea snail harvesting. Although resources of this mollusk are still withstanding such high intensity of fisheries, large-scale implementation of drags has a destructive effect on bottom biocenosis and the ecosystem as a whole.

Until the early 1990s along the Ukrainian coast sea snail was harvested in an amateurish way for a fine shell used as souvenirs. The distribution and the stock assessment of sea snail in the Ukrainian territorial waters in the area from Takil Cape to Chauda Cape were undertaken in 1990, 1994 and 1999. Stocks of this mollusk were, respectively, assessed as 2.8 thousand tons, 1.5 thousand tons and 1.3 thousand tons. The former two assessments belonged to the initial commercial exploitation of this ground, the latter to the period of the intensive fisheries. Reduction in sea snail stocks from 1.5 - 2.8 thousand tons (virgin population) to 1.3 thousand tons (exploited population) is the evidence of drag fisheries impact. The use of knife-edge drags adversely affected the bottom biocenoses.

In 1994 sea snail stocks were assessed along the southern and western coasts of the Crimea from Cape Ilya to the Cape Evpatoriisky as 14 thousand tons, and the limit for its harvesting in the waters of Ukraine begin to be established as 3 thousand tons. Maximum sea snail harvest reached the amount of 913 tons in 2000. After 2000 small-sized sea snail of 50-60 mm long was predominant in the catches from this ground.

The causes of present rejuvenation of sea snail population was most probably overfishing, accompanied by the intensive harvesting of individuals of older ages (more than 75 mm long). Therefore since 2002, the annual limit for sea snail harvesting in the Ukrainian waters was reduced to 400 tons. After this limit, snail harvests reduced greatly. By mid-2000s, an increase in abundance and individual size of this mollusk was noted along the coast of the Crimea.

9.5.3. Clams

Striped venus (*Chamelea gallina* L., 1758) is a small-sized bivalve mollusk, inhabiting sandy ground at depths up to 35 m. It maturates at the second year of life. It reproduces during the warm period of the year (July - September); larvae are pelagic. Adult mollusk is a filtrator and seston-eater. Biocenoses of striped venus are characterized by abundant biomass. In northwestern Black Sea the largest abundance of clam is observed at 7 - 8 m depth on sands and sandy-shells up to 600 - 800 individuals/m2 and even higher in southern areas of the sea.

Among Black Sea countries Turkey is the only one to conduct regular striped venus harvesting. Dynamics of its harvesting is characterized by rapid growth for the first three years after beginning of harvesting and subsequent five-year period of decline (Fig. 9.20). In 1996 -2005 increase in landings was observed; mean annual catches made up 9459 tons.

Due to its non-consumption within the country, it is exported to EU countries as frozen or canned food. According to Dalgıç and Okumuş (2006), the hydraulic dredge boats operated in clams fishing was 39 in 2006, the majority of which were concentrated along the southwestern coast of the Black Sea. Fishing season begins with 1st of September and ends at 30th of April. Pressure on different sites of the coast is regulated by means of their opening or closure from season to season. Its sustainable production requires standardizing the sieves, freezing the fishing license of striped venus, putting quotas and sharing out the fishing grounds between the boats.

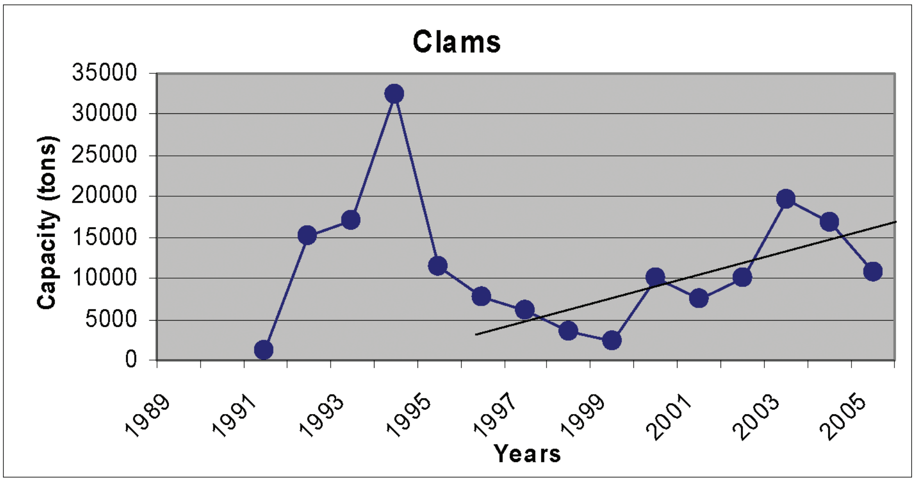

Fig. 9.20. Harvesting of striped venus in the Black Sea along the Turkish coasts.

9.6. Water plants

Water plants have commercial value only in the Ukrainian sector of the Black Sea. They are red algae, represented mainly by species *Phyllophora nervoza*, one species of brown algae (*Cystoseira barbata*), and eel-grass (*Zostera marina*). The share of water plants in the regional value of MLR capture was never high, and for the last 10 years after ceasing red algae capture it became insignificant. (Fig. 9.21).

In the Black Sea, Ukraine is the only country conducting harvesting red algae (*Phyllophora nervosa, Ph. brodia*) and sea grass (*Zostera spp.*). For the last 10 years, their harvesting had no regular character and no significant commercial value. Phyllophora harvesting ceased after 1996. The primary cause was economic problems that resulted in bankruptcy and suspension of plant for phyllophora processing and agar production (Odessa). The second cause was the rise in the cost of production due to the reduced productivity of phyllophora harvesting. In 1960s, the area of phyllophora field occupied about 12 thousand km2 with total biomass of 9 million tons (Kaminer, 1971). Since the early 1970s with the deterioration of environmental conditions in the northwestern Black Sea, the size of this unique biocenosis and stock began to reduce quickly. In the mid-1980s, the area of its settlements reduced to 4 thousand km^2 and the total biomass to 0.3 million tons (Zaitsev, 1989). Reduction in phyllophora field likely took place as a combination of increased chemical pollution of the marine environment and eutrophication, reduced transparency including lifting of mud particles in the water column during bottom trawling, hypoxia and subsequent mass mortalities.

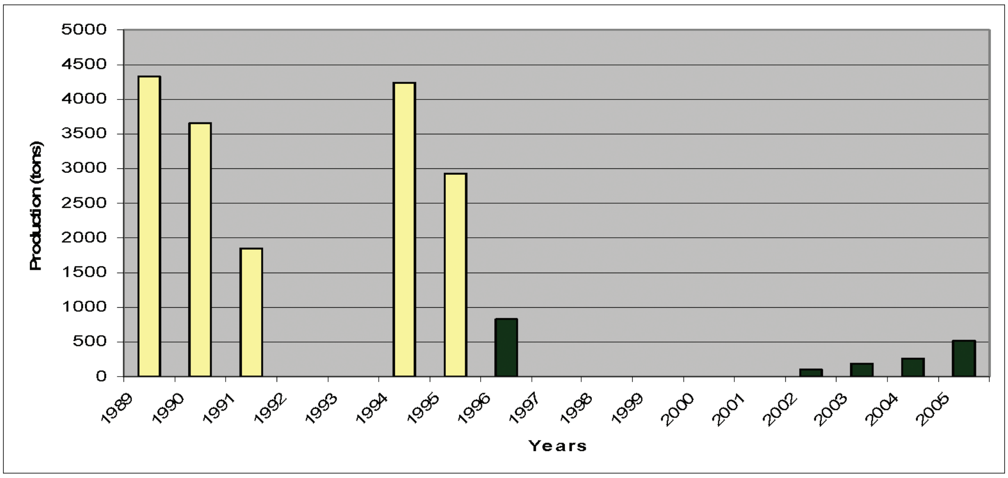

Fig. 9.21. Total capture production of main water plants in the Black Sea in 1989 -2005.

According to the data from the YugNIRO's survey in 2000, the area of the northwestern part of the sea was covered by 1.5 thousand square kilometers that was the densest commercial phyllophora aggregations observed during the last years. Its stock was assessed to be around 8 thousand tons which used to be 121 thousand tons in 1993.

9.7. Conclusions

Historically, the main factors leading to stock collapses and great losses in fisheries were eutrophication-induced changes in the food web, overfishing and the invasion of the comb-jelly *M. leidyi*. In the recent period 2000-2005, the major threat for the fish resources appear to be the illegal fishing and the use of destructive harvest techniques as well as the lack of regional cooperative management of fisheries and eutrophication. At present, no recovery of the spawning and nursery habitat for sturgeons took place in rivers and lagoons. The amounts of restocking of the Dnieper sturgeon populations reduced considerably and the state of sturgeon stocks after 1999 deteriorated definitely with collapse not being excluded. The state of Danube shad stocks did not improve; nevertheless the situation is less disastrous as compared to sturgeons. The sprat, anchovy, picked dogfish, and mullet stocks partially recovered in 1995 - 2005, but the current level of relatively high fishing efforts and catches impose a risk of deterioration of their stocks. On the other hand, the horse mackerel stock continues to be in a depressed state with low stock size and there is no sign of its recovery. The whiting and turbot stocks are exploited rather intensively and declining. In 2000 -2005, mussel catch had a negative trend in the Ukrainian sector but as a whole the state of mussels improved in the Black Sea. The total state of water plant resources continues to be in deteriorated state.

The summary table describing the current status of MLRs with respect to the previous phases (Table 9.13) in general suggests an improvement in the state of MLR during 2000 - 2005 with respect to the collapse period (1989 - 1992) but the overall situation is still inferior when compared with the baseline state (1970 - 1988). The highly variable stock dynamics and the lack of effective control measures for the fisheries quite likely may lead to sharp stock declines in the future. In order to avoid this risk and to achieve sustainable development of fisheries in the Black Sea, implementation of a regional fisheries management strategy is necessary.

Table 9.13. Indicators for the fisheries in the Black Sea for 1970 - 2005 (Caddy's method) .

Category/ Species	**Baseline (1970-1988)**		**"Collapse years" (1989-1992)**		**"Post-collapse" years (1993-2005)**	**Present decade (2000 - 2005)**			
	Trend	Average tons/year	Trend	Average tons/year	Trend	Trend	Average tons/year	Landings as % of baseline	Landings as % of "collapse years
Resident pelagic species									
Anchovy	+	341060	-	131100	0	-	280757	82%	214%
Horse mackerel	+	52684	-	50048	0	-	13323	25%	27%
Sprat	+	40042	-	49412	+	0	60537	151%	123%
Migrants									
Bluefish	+	8250	-	6501	+	+	10120	123%	156%
Bonito	0	8303	+	9275	+	+	16137	194%	174%
Demersal									
Turbot	-	2807	-	1045	-	-	1250	45%	120%
Whiting	+	13737	-	20059	-	-	9091	66%	45%
Spiny dogfish	+	4633	-	3684	-	-	1132	24%	31%
Барабули	-	1119	+	1198	-	-	1770	158%	148%
Mullets (Mugilidae)	0	2401	+	2765	-	-	6538	272%	236%
Rapana	N/A	N/A	-	5918	+	+	9832	122% of 1993-2005	166% 166%
Ratio (trends)	6/3		3/8		4/5	3/7			
+ve/-ve	=2.00		=0.38		=0,80	=0.43			

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CHAPTER 10 THE STATE OF CETACEAN POPULATIONS (A. Birkun)

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10.1. Introduction

There are only few taxonomic groups of marine mammals in the Black Sea fauna that include three cetacean (odontocete) species/subspecies - the harbour porpoise (*Phocoena phocoena relicta*), the short-beaked common dolphin (*Delphinus delphis ponticus*) and the common bottlenose dolphin (*Tursiops truncatus ponticus*) - and one pinniped species, the Mediterranean monk seal (*Monachus monachus*). The quality of the Black Sea ecosystem is dependent, in particular, on the survival and welfare of these top predator populations. It is difficult to foresee all negative consequences for the regional biodiversity, if cetaceans disappear as it has almost happened with the monk seal (Öztürk, 1992, 1996; Kıraç and Savaş, 1996; Güçlüsoy et al., 2004).

The present state of Black Sea cetacean populations is not quite clear or encouraging in spite of certain research and conservation progress achieved during last decade, since the two essential instruments have been adopted in 1996 - the Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and Contiguous Atlantic Area (ACCOBAMS), and the Strategic Action Plan for the Rehabilitation and Protection of the Black Sea (BS SAP). The insufficiency of scientific information includes population abundance, distribution, migrations, critical habitats, anthropogenic and natural threats as well as some basic aspects of life history and pathology.

In the past, the most important factor for the depletion of cetacean populations was commercial dolphin fishery. Mass legal killing (= devastating overexploitation) of Black Sea dolphins and porpoises peaked in the 1930s and 1950s; it was banned in 1966 in the USSR, Bulgaria and Romania, and in 1983 in Turkey. Currently, the most obvious threats affecting Black Sea cetacean populations are accidental mortality in fishing gear; habitat degradation causing the reduction of prey resources; water pollution and epizootics resulting in cetacean mass mortality events. All these factors are directly or indirectly dependent on enhanced (and poorly managed) human activities in the sea and in the entire Black Sea Basin.

The present chapter describes the state of Cetacean populations and emphasizes the need for multidisciplinary research that, with adequate financial and technical support, provides a reliable basis for developing and implementing efficient conservation and management strategies. Cetaceans do not know state borders as they are migratory species, so regional efforts are necessary and all the Black Sea countries need to be in co-operation.

10.2. Harbour porpoise (*Phocoena phocoena relicta* Abel, 1905)

10.2.1. Taxonomy and genetics

The Black Sea harbour porpoise is the sole representative of the family Phocoenidae and genus Phocoena in the Black Sea fauna (Table 10.1). It is recognized as a subspecies possessing morphological and genetic () differences from other *P. phocoena* subspecies and populations elsewhere in the world (*e.g.,* Tzalkin, 1938; Rosel *et al.,* 1995, 2003; Fontaine *et al.,* 2005), except the Aegean Sea in the northeastern Mediterranean (Rosel *et al.,* 1995). Black Sea and Aegean harbour porpoises have identical mtDNA sequence in the hypervariable control region (Rosel *et al.,* 2003) and may constitute separate subpopulations of this subspecies (*P. p. relicta*). At the same time, no fine population structure was indicated so far within the Black Sea proper despite the fact that genetic polymorphism at 11 microsatellite loci was examined in 61 individuals sampled in the western (Bulgaria), eastern (Georgia) and northern (Ukraine) areas of the basin. According to Fontaine *et al.* (2005), the Black Sea population displays a lower genetic diversity compared to those of Atlantic.

Table 10.1. Taxonomic status of Black Sea marine mammals

Taxonomic categories	**English common names of Black Sea marine mammals**			
	Harbour porpoise	Short-beaked common dolphin	Common bottlenose dolphin	Mediterranean monk seal
Class	mammalia			
Order	Cetacea			Carnivora
Sub-order	Odontoceti			Pinnipedia
Family	Phocoenidae	Delphinidae	Phocidae	
Genus	Phocoena	Delphinus	Tursiops	Monachus
Species	P. phocoena	D. delphis	T. truncatus	M. monachus
Subspecies	P. p. relicta	D. d. ponticus (?)	T. t. ponticus	-

10.2.2. Distribution

Geographic range of the Black Sea harbour porpoise includes the Black Sea proper, Azov Sea, Kerch Strait (e.g., Tzalkin, 1938), Marmara Sea, Bosporus Strait (Öztürk and Öztürk, 1997), northern Aegean Sea (Frantzis *et al.,* 2001; Rosel *et al.,* 2003) and also, very likely, the Dardanelles Straits connecting the Marmara Sea and Aegean Sea (however, no solid information is available until now from the Dardanelles) (Table 10.2). The Black Sea population is completely isolated from the nearest conspecific population in the northeastern Atlantic by wide range hiatus in the Mediterranean Sea (Frantzis *et al.,* 2001).

One hypothesis is that harbour porpoises entered the Black Sea basin in the Pleistocene, after the Mindel glaciation (about 400-500 thousand years ago), when the Black and Mediterranean Seas were connected for the first time (Kleinenberg, 1956). Another hypothesis is that they entered the Black Sea much later, in the Holocene, approximately 7,000 years ago, when the last (present) connection between the two seas was established (Frantzis *et al.,* 2001). Either way, the species came to the Black Sea via the Mediterranean which, therefore, must have had its own harbour porpoise population in remote times (although now extinct).

Table 10.2. Geographic range of Black Sea cetaceans

Water body (sea or strait)	Country	Cetacean species (subspecies)		
		P. p. relicta	D. d. ponticus	T. t. ponticus
Black Sea	Bulgaria	+	+	+
	Georgia	+	+	+
	Romania	+	+	+
	Russia	+	+	+
	Turkey	+	+	+
	Ukraine	+	+	+
Kerch Strait	Russia	+	+?1	+
	Ukraine	+	±1	+
Azov Sea	Russia	+	-	±
	Ukraine	+	-	±
Bosporus	Turkey	+	+	+
Marmara Sea	Turkey	+	+	+
Dardanelles	Turkey	+?2	Nd	+?3
Aegean Sea (NE Mediterranean)	Greece	±2	Nd	+?3
	Turkey	+?2	Nd	+?3
Other parts of the Mediterranean Sea		-	Nd	±3

"+" - regular occurrence (numerous reiterated records);

"±" - rare or casual occurrence (several records are known);

"-" - no records available in spite of considerable observation effort undertaken over a long period of time;

"+?" - suspected occurrence (solid scientific data are required to prove this assumption based on indirect evidence);

"Nd" - no data (there are no any direct or indirect research data suggesting penetration of Black Sea common dolphins into the Mediterranean through the Dardanelles, although, in theory, such probability exists);

1_ a live stranding of *D. d. ponticus* was recorded in Kerch city, Ukraine, in August 1994 (Birkun *et al.,* 1999); similar cases could happen in the Russian Kerch Strait also, but no respective study was conducted there;

2 _ according to the genetics (Rosel *et al.,* 1995, 2003), *P. p. relicta* occurs in the Greek Aegean Sea, i.e. beyond the Dardanelles Straits and the northern part of the Turkish Aegean Sea; however, its presence in these "intermediate" waters was not confirmed yet by reliable observations;

3 _ bottlenose dolphins (*T. truncatus*) were recorded in the Dardanelles (Öztürk and Öztürk, 1997), they are also known in the Greek and Turkish Aegean Sea (Beaubrun, 1995; Frantzis et al., 2003). However, the genetics of bottlenose dolphins from these localities were not studied yet and, thus, the suspected presence of *T. t. ponticus* individuals among them is not confirmed. At the same time, one individual from the western Mediterranean was found to be a possible immigrant from the Black Sea population (Natoli *et al.,* 2005).

The range of the Black Sea subspecies covers territorial waters and exclusive economic zones of Bulgaria, Georgia, Romania, Russia, Turkey and Ukraine in the Black Sea; internal waters of Ukraine in the Black Sea (including the Dnieper-and-Boug Liman and Karkinitsky Bay); internal waters of Russia and Ukraine in the Azov Sea and Kerch Strait; internal waters of Turkey including the Bosporus Strait, the Marmara Sea and, probably, the Dardanelles Straits; territorial waters of Greece and, as expected, Turkey in the northern Aegean Sea. Sometimes, harbour porpoises can be sighted in the Danube, Dnieper, Don and Kuban Rivers, their estuaries, deltas and tributaries (e.g., in the

Danube in 1984-1989 and 2003 or in the Ingulets, a confluent of the Dnieper, in 1999) as well as in coastal freshwater, brackish and saline lakes and lagoons connected with the sea, including the Yalpug and Sivash lakes, Berezansky and Grigorievsky lagoons, Tendrovsky, Yagorlytsky and Jarylgachsky bays, and the Gulf of Taganrog (Tzalkin, 1940a; Geptner *et al.,* 1976; Birkun, 2006a). All these sites are situated in Ukraine and Russia, on the northern and northwestern coasts of the Black Sea and round the Azov Sea.

It might be assumed that the population of *P. p. relicta* consists of three or more subpopulations (which are not confirmed by means of genetic study yet) including those which spend the most part of year in geographically and ecologically different areas including the Azov Sea, northwestern Black Sea, and the Turkish Straits System (including the Sea of Marmara, the Bosporus and, possibly, the Dardanelles). Another subpopulation is thought to be resident in the northern Aegean Sea of the Mediterranean.

10.2.3. Abundance

The total population size is unknown. Past Black Sea region-wide estimates of harbour porpoise absolute abundance, based on strip transect cetacean surveys carried out in the USSR in 1967-1974 (Zemsky and Yablokov, 1974) and in Turkey in 1987 (Çelikkale *et al.,* 1989) have been discredited by the Scientific Committee of the International Whaling Commission (IWC) due to irremediable methodological and interpretative problems (Smith, 1982; IWC, 1983, 1992; Klinowska, 1991; Buckland et al., 1992). Some other estimates, conducted in 1975-1993 (Mikhalev *et al.,* 1978; Yukhov *et al.,* 1986; Sokolov *et al.,* 1990; Mikhalev, 1996; Yaskin and Yukhov, 1997), also suffered from inadequacies of survey design, record keeping and statistical analysis. Nevertheless, it was generally recognized that during most of the 20th century the abundance of harbour porpoises in the Black Sea was higher than that of bottlenose dolphins and less than that of common dolphins; besides, before the mid 1990s the harbour porpoise was considered the predominant cetacean in coastal waters of the northern and eastern Black Sea (Tzalkin, 1940a; Kleinenberg, 1956; Geptner *et al.,* 1976; Yaskin and Yukhov, 1997).

More recently, however, the bottlenose dolphin has become prevalent in inshore waters of the northern Black Sea (Birkun *et al.,* 2004c). It was estimated that sighting score of bottlenose dolphins increased five times in 1997 and 1998 in comparison with 1995 (see Section 10.4.3 for details), whereas the number of harbour porpoises on record declined dramatically. Mass incidental mortality in bottom-set gill nets was the most likely cause of the marked decrease in harbour porpoise abundance (Birkun *et al.,* 2004b,c; Birkun, 2005).

A series of line transect cetacean surveys have been conducted recently to estimate harbour porpoise absolute abundance in different regions (Birkun *et al.,* 2002, 2003, 2004a, 2006b; Krivokhizhin *et al.,* 2006). In particular, aerial surveys were conducted in the Azov Sea, Kerch Strait (July 2001 and August 2002) and northeastern shelf area (August 2002); vessel-based surveys were performed in the Kerch Strait (August 2003), the entire 12-miles zone of the Ukrainian and Russian Black Sea (September-October 2003), the southern portion of Georgian territorial waters (January 2005), and central part of the Black Sea between the Crimea peninsula, Ukraine, and Sinop province of Turkey

(September-October 2005). Results of those surveys (Table 10.3) suggest that present population size of *P. p. relicta* is at least several 1000s or, rather, some 10,000s. Very low concentrations of harbour porpoises (too scanty for customary statistic analysis) were determined at the height of summer in the Kerch Strait and over the northeastern Black Sea shelf area (Birkun *et al.,* 2002, 2003).

10.2.4. Habitat and ecology

Harbour porpoises inhabit mainly shallow waters (0-200 *m* deep) over the continental shelf around the entire perimeter of the Black Sea, although they may also expend quite far offshore in deep water area (*e.g.,* Mikhalev, 2004b). For instance, in late September - early October 2005, sizeable groups were recorded in the central Black Sea, beyond the shelf edge some 38-215 *km* from the nearest coast over depths of 450-2,170 *m* (Krivokhizhin *et al.,* 2006). During warm periods they are present in the Azov Sea and Kerch Strait (Tzalkin, 1940a; Kleinenberg, 1956; Birkun *et al.,* 2002) and in the Marmara Sea and Bosporus (Öztürk and Öztürk, 1997). Both of these small seas as well as the northwestern Black Sea shelf zone represent geographically disjunctive breeding-calving-feeding areas while the straits (the Kerch Strait and Bosporus) serve as migration corridors.

Harbour porpoises undertake penduliform annual migrations, leaving the Azov Sea (Tzalkin, 1938) and northwestern Black Sea (Birkun, 2006a) before winter and returning in spring. These animals have never been recorded along the Bosporus in January, February and March (Öztürk and Öztürk, 1997). The primary overwintering area of Black Sea harbour porpoises is the southeastern Black Sea (Birkun *et al.,* 2006b) that covers southern territorial waters of Georgia between Cape Anaklia to the north and the Turkish border near Sarp to the south, and eastern Turkish territorial waters. These are also well-known overwintering grounds of the Black Sea and Azov Sea anchovy populations (*Engraulis encrasicolus ponticus*)- a principal prey species for harbour porpoises during the cold season (Kleinenberg, 1956). It is possible that most of the Black Sea porpoise population congregates there every year. In January 2005, the density estimated in Georgian waters was 1.54 porpoises per km^2 (CV = 26.5%; Birkun *et al.,* 2006b), *i.e.* 6-39 times higher densities reported for any other Black/Azov Sea area surveyed in summer or autumn (Table 10.3).

The ecology of Black Sea harbour porpoises and other cetaceans residing in this basin is rather peculiar owing to the high degree of geographical isolation of their habitat, relatively low water salinity, significant seasonal fluctuations of water temperature, as well as a large amount of anoxic waters below 100-250 *m*.

Table 10.3. Estimates of Black Sea cetaceans density (individuals per 1 km^2) and absolute abundance in the selected maritime areas (values of 95% confidence interval are enclosed in brackets)

Surveyed area and observation effort	**Survey platform**	**Research period**	**Estimates uncorrected for availability or detection bias**						**References**
			harbour porpoises		common dolphins		bottlenose dolphins		
			density	abundance	density	abundance	density	abundance	
Turkish Straits System (Bosphorus, Marmara Sea and Dardanelles)	vessel	October 1997	na		na	773 (292-2,059)	na	495 (203-1,197)	Dede (1999), cited after: IWC (2004)
		August 1998	na		na	994 (390-2,531)	na	468 (184-1,186)	
Azov Sea in whole; 40,280 km2 / 2,735 km	aircraft	July 2001	0.07 (0.03-0.16)	2,922 (1,333-6,403)	0 no sightings		0 no sightings		Birkun et al. (2002)
Southern Azov Sea (within above area); 7,560 km2 / 413 km	aircraft	July 2001	0.12 (0.04-0.36)	871 (277-2,735)	0 no sightings		0 no sightings		Birkun et al. (2003)
Southern Azov Sea (the same area); 7,560km2 / 716 km	aircraft	August 2002	0.12 (0.06-0.27)	936 (436-2,009)	0 no sightings		0 no sightings		Birkun et al. (2003)
Kerch Strait in total; 890 km2 / 353 km	aircraft	July 2001	na small sample size: 5 sightings / 12 animals		0 no sightings		0.09 (0.03-0.22)	76 (30-192)	Birkun et al. (2002)
		August 2002	na small sample size: 4 sightings / 4 animals		0 no sightings		0.10 (0.04-0.27)	88 (31-243)	Birkun et al. (2003)
Kerch Strait; 862 km2 / 310 km	vessel	August 2003	0.06 (0.01-0.28)	54 (12-245)	0 no sightings		0.15 (0.08-0.28)	127 (67-238)	Birkun et al. (2004a)
NE shelf area of the Black Sea; 7,960 km2 / 791 km	aircraft	August 2002	na small sample size: 8 sightings / 15 animals		na small sample size: 1 sighting / 1 animal		0.10 (0.04-0.26)	823 (329-2,057)	Birkun et al. (2003)
NW, N and NE Black Sea (Ukrainian and Russian territorial waters); 31,780 km2 / 2,230 km	vessel	September-October 2003	0.04 (0.02-0.09)	1,215 (492-3,002)	0.17 (0.09-0.31)	5,376 (2,898-9,972)	0.13 (0.08-0.22)	4,193 (2,527-6,956)	Birkun et al. (2004a)
SE Black Sea within Georgian territorial waters; 2,320 km2 / 211 km	vessel	January 2005	1.54 (0.89-2.65)	3,565 (2,071-6,137)	4.18 (2.16-10.11)	9,708 (5,009-18,814)	0 no sightings		Birkun et al. (2006b)
Central Black Sea beyond territorial waters of Ukraine and Turkey; 31,200 km2 / 660 km	vessel	September-October 2005	0.26 (0.06-1.27)	8,240 (1,714-39,605)	0.15 (0.05-0.51)	4,779 (1,433-15,945)	0 no sightings		Krivokhizhin et al. (2006)

"na" - not available.

The mean group size varies from 1.4 to 10.7 in different areas (Birkun *et al.,* 2002, 2003, 2004a; Krivokhizhin *et al.,* 2006). Along paths of seasonal migration, harbour porpoises may remain for a few days in different sites (usually bays abundant in fish), forming dense aggregations consisting of some hundreds of individuals. Such accumulations were recorded off the southern coast of Crimea in December-January 1994 (Laspi Bay), March 1995 (near Cape Meganom) and April 2005 (between Cape Aya and Cape Fiolent) (A. Birkun, Jr. and S. Krivokhizhin, unpubl. data). Sometimes, early and rapid ice formation arising immediately after warm "indian summer" puts obstacle on the way of their evacuation from the Azov Sea and, thus the ice entrapment causes mass mortality events (Kleinenberg, 1956). Such die-off has happened in November 1993 (Birkun and Krivokhizhin, 1997). Black Sea harbour porpoises do not avoid waters with low salinity and transparency; they may occur in the estuarine and fluvial environment represented by brackish bays, lagoons, rivers and their estuaries (see Section 10.2.2; all records belong to warm season and northern half of the basin).

Table 10.4. Target fish species of Black Sea cetaceans (+ - prey species confirmed by identification of food residues in stomach contents of the cetaceans; ± - suspected prey species listed on base of indirect evidences)

Fishes	**Cetaceans**		
	P. p. relicta	D. d. ponticus	T. t. ponticus
Thornback ray, Raja clavata	-	-	+ c,g,h
Black Sea sprat, Sprattus sprattus phalaericus	+ l,m	+ c,d,e,g,h,i,j,m	-
Black/Azov Sea shad, Alosa spp.	+ f,g,m	+ h	-
Black Sea anchovy, Engraulis encrasicolus ponticus	+ c,f,g,h,i,m	+ c,d,e,g,h,i,m	+ c,g,h,i
Black Sea garfish, Belone belone euxini	-	+ m	-
Black Sea whiting, Merlangius merlangus euxinus	+ f,g,l,m	+ c,d,e,g,h,m	+ c,g,h
Pipefish, Syngnathus schmidti	-	+ c,h	-
Pipefish, Syngnathus typhle	-	+ c,h	-
Pelagic pipefishes unidentified, Syngnathidae gen. sp.	-	+ c,d,g,h	-
Striped mullet, Mugil cephalus	-	-	+ c,g,i
Golden mullet, Liza aurata	+ f	-	-
Far-east mullet, Liza haematocheila syn. Mugil so-iuy	+ m	-	± k,m
Black Sea mullets, Liza spp. (other than L. haematocheila)	+ g	± b	+ c,g,h,i
Black Sea silverside, Atherina boyeri syn. A. pontica	+ f,g	-	-
Bluefish, Pomatomus saltatrix	-	+ g,h	-

a, - Meyer (1794);, b, - Malm (1933);, c, - Kleinenberg (1936); d, - Tzalkin (1937);, e, - Malm (1938);, f, - Tzalkin (1940a); g, - Tzalkin (1940b);, h, - Kleinenberg (1956);, i, - Tomilin (1957); j, - Tarasevich (1958);, k, - Birkun and Krivokhizhin (1996);, l, - Tonay and Öz (1999); m, - Krivokhizhin et al. (2000); , n, - Bel'kovich (2001).,

Table 10.5. Life history parameters of Black Sea cetaceans

Parameters		**Cetaceans**					
		P. p. Relicta		D. d. ponticus		T. t. ponticus	
		raw original data	Defaults for porpoise a	raw original data	defaults for long-lived odontocete a	raw original data	defaults for long-lived odontocete a
Sexual maturity Age / first reproduction, years	female	3-4 b	4	2-4 c,d	7	12 e	7
	male	3.5-4 b		3 c,d		11 e	
Longevity (max agef), years		at least 12 b	20	20-22 d	70	25-30 g	70
Percentage of the population that is reproductively mature, %		na	52-55	na	68-90	na	68-90
Average age of parents in the popu-lation (generation time), years		6♀ and 6.7♂ b	9-10	15♀ d	21-33	26♀ and 19♂ e	21-33
Gestation time, months		9-10	Na	10-11 c	na	12 i	Na
Average interbirth interval, years		1 g	Na	1.3-2.3 j	na	from 2-3 to 6 g	na
Maximum potential annual rate of popula-tion increase, %		na	2	na	2	na	2
Birth rate k		na	0.4	na	0.1	na	0.1
Non-calf survival rate (SA) l		na	0.89	na	0.99	na	0.99
Survival rate in the first year of life (S0)m		na	0.62	na	0.84	na	0.84

[a] - The ACCOBAMS and IUCN Workshop on Red List Assessment of Cetaceans in the ACCOBAMS Area (Monaco, 5-7 March 2006; Reeves and Notarbartolo di Sciara, 2006) noted that reliable data and analyses of vital rates are unavailable for the populations of cetaceans in the Black Sea. Therefore, Philip S. Hammond (Sea Mammal Research Unit, St. Andrews, UK), based on the unpublished draft by Barbara L. Taylor (Southwest Fisheries Science Center, La Jolla, USA), has prepared a table of "defaults" for key parameters which are quoted here as "defaults for porpoise" and "defaults for long-lived odontocete";

[b] - BLASDOL (1999); [c] - Kleinenberg (1956); [d] - Kleinenberg and Klevezal' (1962); [e] - Klinowska (1991); [f] - maximum age at which 1% of a population remains alive;

[g] - Tomilin (1957); [h] - Tzalkin (1940a); [i] - Geptner *et al.* (1976); [j] - Perrin and Reilly (1984);

[k] - Birth rate is defined as the number of female births per female per year: 1 female per female every 2.5 years for porpoise, 1 female per female every 10 years for long-lived odontocete (including *D. d. ponticus* and *T. t. truncatus*); it is assumed that for long-lived odontocete reproductive senescence begins (no reproduction occurs) after age 50;

[l] - SA is defined as survival rate of all ages after the first birthday, and calculated to give 1% survival at maximum age;

m - S0 is calculated as a multiplier of SA (0.7 for porpoise and 0.85 for long-lived odontocete);

"na" - not available.

According to the data presented in Table 10.4, at least 18 fish species have been recorded in the stomach contents of *P. p. relicta* (Kleinenberg, 1936, 1956; Tzalkin, 1940a,b; Tomilin, 1957; Tonay and Öz, 1999; Krivokhizhin *et al.,* 2000) . They included four fishes which could be recognized as the most important prey: the anchovy (*E. e. ponticus*), sprat (*Sprattus sprattus phalaericus*), whiting (*Merlangius merlangus euxinus*) and gobies (Gobiidae).

10.2.5. Life history

In general terms, the Black Sea harbour porpoise is a relatively short-lived animal with the highest reproduction ability in comparison with other Black Sea cetacean species (Table 10.5).

Table 10.6. Known (documented) threats to Black Sea cetaceans[1]

Threat	Cetaceans		
	P. p. relicta	D. d. ponticus	T. t. ponticus
Harvesting (dolphin fishery) for fuel, materials, medicine and food	past	past	past
Harvesting (live capture) for scientific, military and leisure activities	past	past	ongoing
Accidental mortality caused by fisheries-related bycatch (mainly entanglement)	ongoing	ongoing	ongoing
Accidental mortality caused by explosion of gas-output platform	past, future (?)	unknown	unknown
Persecution (frightening and killing) by fishermen with fire-arms and pyrotechnics	unknown	unknown	ongoing
Unregulated release of captive animals and spontaneous escapes from captivity	unknown	unknown	past, future (?)
Habitat degradation (reduction of prey resources) caused by fisheries	ongoing	ongoing	ongoing
Habitat degradation (reduction of prey resources) caused by invasive alien species	ongoing	ongoing	ongoing
Water pollution (agricultural, domestic, industrial, etc.) affecting habitat and cetaceans	ongoing	ongoing	ongoing
Pathogens and parasites including those which cause cetacean mass mortality events	ongoing	ongoing	ongoing
Natural disasters (temperature extremes) causing cetacean die-offs by ice entrapment	past, future (?)	unknown	unknown
Intrinsic factors: restricted range of the subspecies	ongoing	ongoing	ongoing
Intrinsic factors: relatively low reproduction ability	no	no	Ongoing

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[1] - Besides threats listed in this table, there are some other threats suspected to be essential factors affecting Black Sea cetacean populations (*e.g.,* disturbance/ noise caused by marine traffic and other human activities, collisions with shipping, habitat degradation caused by man-made modification of the seabed and coasts, global warming, *etc.*). However, these factors were not investigated yet in the Black Sea region, and their study represents important task in view of further application of the results for cetacean conservation.

The life span is not studied well; perhaps, it is similar to conspecifics in the North Atlantic, estimated as long as 24 years (Read, 1999). Based on the counts of dentinal growth layers, maximum age of the bycaught Black Sea harbour porpoises was found as 10-12 years, whereas gross and histological signs suggested sexual maturity in males and females at the earliest age of 3.5-4 and 3-4 years, respectively (BLASDOL, 1999). In conformity with these data, the mean age of parental individuals comes to 6.7 years in males and 6.0 years in females. However, these values seem to be influenced (shortened) by past and ongoing threats and, thus, do not reflect natural generation length, which is probably similar to the generic generation time of about 9-10 years estimated for

Phocoena spp. (Table 10.5). According to data collected during the period of extensive Black Sea cetacean fishery (when thousands of *P. p. relicta* individuals and hundreds of their embryos/foetuses have been examined), the mating occurs mainly in summer; mature females become pregnant almost annually, with a gestation period of 9-10 months and usual birth of one calf between May and early August; the nursing/lactation period lasts 4-6 months (Tzalkin, 1940a; Kleinenberg, 1956; Tomilin, 1957; Geptner *et al.,* 1976). Somewhat different terms are known for the harbour porpoise, *P. phocoena,* from other areas: gestation - 10-11 months, lactation - at least 8 months (Read, 1999).

10.2.6. Past and ongoing threats

Up to 1983, the uncontrolled directed takes were primary threat to the population. Large numbers of harbour porpoises, as well as other Black Sea cetaceans, were taken during the 20th century by all Black Sea countries for manufacturing the lamp-oil, currier's oil, engine and lubricating oils, vitamin-D-containing medicines, paints, varnishes, soap, cosmetics, tinned meat and sausages, leather-shoe wares, "fish" meal for poultry, bone fertilizer and glue (Silantyev, 1903; Kleinenberg, 1956; Berkes, 1977; Buckland *et al.,* 1992; Birkun, 2002a). A total number of killed individuals is unknown. However, it is generally acknowledged that all Black Sea cetacean populations including the harbour porpoise were badly reduced by the dolphin fishery (IWC, 1983, 1992, 2004). Catches of harbour porpoises were numerically less than common dolphins until 1964 when they became dominant (Smith, 1982). From 1976 to 1981, harbour porpoises were believed to account for 80% of the total catch of cetacean fisheries in Turkey, with 34,000 to 44,000 taken annually (IWC, 1983). During last 15 years, since 1991, there was no evidence of illegal directed takes which were reported formerly (IWC, 1992). Nevertheless, it could be suspected that the population which did not recover till now continues to be depressed due to other, ongoing, threats.

At present, incidental catch in fishing nets is the most important threat and major source of human-induced mortality of *P. p. relicta* (*e.g.,* Birkun, 2002c). All three Black Sea cetacean species are known to be taken as bycatch, but incidental takes of harbour porpoises evoke the greatest concern. Harbour porpoise bycatches represent the majority (95%) of cetacean entanglements on record; however, absolute numbers of population losses caused by fishing operations were not estimated. Preliminary indications suggest that annual level of harbour porpoise bycatches is hardly sustainable and can be numbered by thousands of individuals. The porpoises are caught in a variety of fisheries, although 99-100% of bycatches occur in the bottom-set gillnets for turbot (*Psetta maxima maeotica*), spiny dogfish (*Squalus acanthias*) and sturgeon (*Acipenser* spp.) with a peak in April-June during the turbot fishing season. The bycatches occur in the Azov Sea and Kerch Strait and throughout shelf area of the Black Sea including territorial waters of riparian countries. Almost all (910.9%) recorded bycatches are lethal (BLASDOL, 1999). Illegal, unreported or unregulated (IUU) fishing is widespread in the Black and Azov Seas suggesting that significant share of bycatches takes place due to this human activity.

Large-scale pelagic and small-scale coastal fisheries affect Black Sea harbour porpoises also indirectly, by force of excessive exploitation of those fish species which represent the basic prey. First of all, this concerns anchovies in the Black Sea and gobies in the

Azov Sea. In particular, the overfishing combined with the eutrophication and population explosion of alien raptorial ctenophore *Mnemiopsis leidyi* led to dramatic decline of anchovy abundance in the late 1980s and early 1990s (Prodanov *et al.,* 1997; Zaitsev and Mamaev, 1997; Birkun, 2002b,c). The reduced prey availability concurred with two mass mortality events (in 1989 and 1990) impacted on all three Black Sea cetacean species but mostly on *P. p. relicta* (Birkun, 2002e). Severe pulmonary nematodosis, caused by *Halocercus* spp. and complicated by bacterial super-infection, was recognized as a primary cause of deaths that eliminated mainly young animals. The malnutrition along with bioaccumulation of POPs could provoke those epizootics, suppressing the resistance of porpoises to pathogens. High concentrations of organochlorines and relatively low concentrations of toxic trace elements have been detected in P. p. relicta by different authors (Birkun et al., 1993 ; Madhusree *et al.,* 1997; Tanabe *et al.,* 1997a,b; Glazov and Zhulidov, 2001; Joiris *et al.,* 2001; Das *et al.,* 2004). The contamination of Black Sea harbour porpoises by DDTs and HCHs in the 1990s was higher than that reported for this species elsewhere in the world (Tanabe *et al.,* 1997a); thus water pollution could be considered as a major problem on its own.

Black Sea harbor porpoises were also threatened by ice entrapment in the Azov Sea (see Section 10.2.4). Besides, in August 1982, the explosion of drilling platform in the Azov Sea caused mortality of over 2,000 porpoises (Birkun, 2002d). Another potential threat is the morbillivirus infection. Serological examination of bycaught animals revealed positive morbillivirus-neutralizing antibody titers in harbour porpoises from Bulgarian, Georgian and Ukrainian waters (Müller *et al.,* 2002). This suggests the persistence of morbilliviruses in the population, with possible outbreaks of devastating epizootics in future.

The cumulative data on past and ongoing threats to Black Sea harbour porpoises can be found in Table 10.6.

10.2.7. Population trend

In the 20th century, abundance of Black Sea harbour porpoises was considerably reduced by massive direct killing for the cetacean-processing industry which continued till 1983 (see section 10.2.6). However, the number of animals taken was not recorded accurately; much of the catch data was recorded as numbers of animals undifferentiated to species level (all three Black Sea cetacean species were targeted) and in the form of wet weight aggregates (*e.g.* pounds or tons of dolphin/porpoise landed). Nevertheless, it could be inferred from the available data that the population size of *P. p. relicta* was reduced due to the direct kills by some hundreds of thousands when the total ban on dolphin fishery has been introduced in the Black Sea. It could be suspected also that the population did not recover during the subsequent period (1983-2006) and, most likely its state became much worse and its size even diminished owing to the escalation of ongoing major threats, such as the fisheries-related bycatch, human induced habitat degradation, *etc.* These threats, including the bycatch in bottom-set gillnets, are poorly managed in most Black Sea countries; so, further decline of the population seems to be highly likely.

10.3. Short-beaked common dolphin (Delphinus delphis ponticus)

10.3.1. Taxonomy and genetics

The Black Sea common dolphins are recognized as a well isolated discrete population possessing clear genetic differences from *D. delphis* in the eastern and western Mediterranean (Natoli, 2003, cited after: IWC, 2004; Natoli, 2004). This cetacean is the sole representative of the genus *Delphinus* and one of two Delphinidae species in the Black Sea fauna (Table 10.1). The subspecies name, *D. d. ponticus,* was given based on some morphological features (Barabasch, 1935) which were criticized at least as inessential (*e.g.,* Kleinenberg, 1956). Subsequent comparative skull morphometrics (Amaha, 1994; Amaha *et al.,* 1996) and genetic analysis of nine microsatellite DNA loci (Natoli 2003, cited after: IWC, 2004) suggested differences between Black Sea and Mediterranean common dolphins, although no significant differentiation was revealed at the mitochondrial level, probably, owing to small sample size (Natoli, 2004). Thus, clear conclusion on taxonomic (subspecies) status of Black Sea common dolphins is still unfeasible (A. Natoli, pers. comm.). However, according to available data, it is likely that gene flow between the Black Sea and Mediterranean Sea is rare or non-existent, and the Black Sea population deserves to be treated as a discrete unit for conservation purposes (IWC, 2004).

10.3.2. Distribution

The range of the Black Sea common dolphin population is represented by the almost entire Black Sea (Table 10.2) including territorial waters and exclusive economic zones of Bulgaria, Georgia, Romania, Russia, Turkey and Ukraine, and internal waters of Ukraine in Karkinitsky Bay (Kleinenberg, 1956; Geptner *et al.,* 1976; Birkun, 2006a); and by internal waters of Turkey including the Bosporus Strait and Marmara Sea (Öztürk and Öztürk, 1997). Common dolphins do not occur in the Azov Sea and normally avoid the Kerch Strait, although a single live stranding was recorded there in 1994 at the time of morbillivirus epizootic (Birkun *et al.,* 1999). There is no reliable information on *D. delphis* presence on possible two-way transit between the Black Sea and Mediterranean Sea through the Turkish Straits System.

10.3.3. Abundance

The population size of Black Sea common dolphins is still unknown. Previous estimates, based on strip transect aerial and boat surveys conducted in 1960s-1980s, have been grimly criticized by the IWC Scientific Committee owing to methodological and interpretative imperfections (see Section 10.2.3 for references). However, it was widely acknowledged that originally and during almost two thirds of the 20th century the abundance of common dolphins in the Black Sea was by far higher than the abundance of bottlenose dolphins and harbour porpoises (Tzalkin, 1940b; Kleinenberg, 1956; Geptner *et al.,* 1976). During last decade (1997-2006) several line transect surveys have been conducted to estimate common dolphin abundance in the Turkish Straits System (Dede, 1999, cited after: IWC, 2004); northern, northwestern and northeastern Black Sea within the bounds of Russian and Ukrainian territorial waters (Birkun *et al.,* 2004a);

southeastern Black Sea within Georgian territorial waters (Birkun *et al.,* 2006b); and central Black Sea between territorial waters of Ukraine and Turkey (Krivokhizhin *et al.,* 2006). These abundance estimates (Table 10.3) suggested that current population size of *D. d. ponticus* is at least several 10,000s. The highest density of common dolphins (4.18 animals/km^2; CV = 31.4%) was revealed in the Georgian Black Sea in January 2005 (Birkun *et al.,* 2006b).

10.3.4. Habitat and ecology

Common dolphins are distributed mainly offshore and visit shallow coastal waters following seasonal aggregations and regular mass migrations of the preferred prey, small pelagic fishes, first of all, the Black Sea anchovy (*E. e. ponticus*) and Black Sea sprat (*S. s. phalaericus*) (Tzalkin, 1940b; Kleinenberg, 1956; Geptner *et al.,* 1976; Bushuyev, 2000; Bushuyev and Savusin, 2004; Mikhalev *et al.*, 2004). However, a full list of fishes consumed by *D. d. ponticus* contains not less than 11 species (Table 10.4). Winter aggregation of anchovies in the southeastern Black Sea and, to a lesser degree, to the south of Crimea sets suitable conditions for overwintering accumulations of these cetaceans. Summer concentrations of sprats in the northwestern, northeastern and central Black Sea also attract common dolphins to different feeding grounds. The cetaceans avoid waters with low salinity, and this can be a reason why they never occur in the Sea of Azov and, normally, in the Kerch Strait. The mean size of common dolphin groups recorded in 2003-2005 varied from 2.9 to 5.4 (S. Krivokhizhin, pers. comm.), and many such groups can be observed in places very close to each other.

10.3.5. Life history

Some original data regarding the life history of Black Sea common dolphins and relevant default estimates for long-lived odontocetes are present in Table 10.5. Given the small sample size (17 individuals), the estimated life span (20 years) and average age (15 years) of sexually mature females (Kleinenberg and Klevezal', 1962) can be considered as tentative parameters for preliminary analysis only. Besides, these parameters as well as the age of sexual maturity in females (2-4 years) (Kleinenberg, 1956; Kleinenberg and Klevezal', 1962) are likely biased because of convenience (unrepresentative) sample affected by "schooling segregation" of Black Sea common dolphins (Perrin and Reilly, 1984).

10.3.6. Past and ongoing threats

Known threats affected Black Sea common dolphins are listed in Table 10.6. Last century, the population was collapsed by the directed takes. A total number of killed animals is unknown, but it was estimated that before the mid-1950s the share of common dolphins killed and processed in the former Soviet Union reached 94.8% of all Black Sea cetaceans taken (Tzalkin, 1940b; Kleinenberg, 1956). Based on this value, it was calculated that USSR and Bulgaria have caught and landed about 179,000 common dolphins during the last six years of cetacean fishery (1961-1966), while this number was as high as 1,392,000 (Zemsky, 1996) or probably more during the preceding 30 years

(1931-1960). Between 1976 and 1981, *D. d. ponticus* was believed to account for 15-16% of the Turkish catch, estimated as 250,000 of all three species (IWC, 1983).

The reduced prey availability has been considered as ongoing major threat affecting the Black Sea common dolphins since the late 1980s (Bushuyev, 2000). Of two mass mortality events eliminated unknown but certainly large numbers of common dolphins in winter-spring 1990 and summer-autumn 1994 (Krivokhizhin and Birkun, 1999), the latter was considered to be due to the result of a morbillivirus epizootic (Birkun *et al.,* 1999). However, both die-offs concurred with drastic decline in abundance of both principal prey species, the anchovy (*E. e. ponticus*) and sprat (*S. s. phalaericus*), severely affected by overfishing combined with the consequences of water pollution (*e.g.,* eutrophication and water hypoxia) and population explosion of alien raptorial ctenophore *M. leidyi* (Zaitsev and Mamaev, 1997). This may suggest a cause-effect relationship between prey scarcity and common dolphin mass mortality.

Other known threats, including bycatch in pelagic trawls, parasitic invasions, accumulation of xenobiotics and live-capture for dolphinaria (Birkun, 2002a,b,c,e) are of secondary importance (at least for the present).

10.3.7. Population trend

According to the data described in Section 10.3.6, the population collapsed due to long-term dolphin fishery overexploitation in all Black Sea countries by the mid-1960s. However, the extermination continued until 1983 when cetacean hunting has been ceased finally in Turkey. The numbers of animals taken were not recorded properly, thus the overall population losses were not estimated. Nevertheless, it could be inferred that the population size of Black Sea common dolphins was reduced by the directed kills at least in half. Besides, it could be suspected that during the subsequent period (1983-2006) the population might have a tendency to increase but, possibly, with low success owing to mass mortality events (in 1990 and 1994) and pronounced depletion of common dolphin's primary prey within the same period. No doubt that the population has not fully or even substantially recovered from the survived stress till now, and further decline could be predicted if degradation of the Black Sea environment goes worse.

10.4. Common bottlenose dolphin (Tursiops truncatus ponticus)

10.4.1. Taxonomy and genetics

The Black Sea bottlenose dolphin is the sole representative of the genus Tursiops and one of two Delphinidae species in the Black Sea fauna (Table 10.1). It was recognized as a subspecies on the basis of morphological differences from Atlantic and Pacific conspecifics (Barabasch-Nikiforov, 1960; Geptner *et al.,* 1976). The genetic data support the subspecies status of *T. t. ponticus* based on clear differentiation of the Black Sea population from other bottlenose dolphin populations and subpopulations in the eastern Mediterranean, western Mediterranean, southern and northern parts of the northeastern Atlantic (Natoli *et al.,* 2005; A. Natoli, 2006, pers. comm.). According to those data, the Black Sea population is effectively isolated from the Mediterranean ones by ecological barrier in the Turkish Straits System, although limited gene flow between the both seas is probable, and possible vagrant from the Black Sea population was detected in the western Mediterranean (Natoli *et al.,* 2005).

10.4.2. Distribution

The range of Black Sea bottlenose dolphins (Table 10.2) includes the entire Black Sea; Kerch Strait along with adjoining southern part of the Azov Sea (Tzalkin, 1940b; Birkun *et al.,* 1997; Sokolov, 1997) and the Turkish Straits System (Kleinenberg, 1956; Beaubrun, 1995; Öztürk and Öztürk, 1997). In view of political geography, the range of this subspecies includes territorial waters and exclusive economic zones of Bulgaria, Georgia, Romania, Russia, Turkey and Ukraine in the Black Sea; internal waters of Ukraine in the Black Sea (including the Dnieper-and-Boug Liman, Karkinitsky Bay and Donuzlav Lake); internal waters of Russia and Ukraine in the Kerch Strait and Azov Sea; internal waters of Turkey including the Bosporus Strait, Marmara Sea and Dardanelles. There are a few records of bottlenose dolphins entering rivers, *e.g.* the Danube in Romania (Police, 1930, cited after: Tomilin, 1957) and Dnieper in Ukraine (Birkun, 2006a).

Population structure within the Black Sea is likely (Bel'kovich, 1996) with several sub-subpopulations or "semi-resident" communities including those that spend most part of the year in geographically and ecologically different areas, *e.g.* northwestern Black Sea, coastal waters off the southern Crimea, Kerch Strait and adjoining portions of the Black Sea and Azov Sea, shelf waters off the Caucasian coast, Turkish Black Sea, and Turkish Straits System.

10.4.3. Abundance

The population size of *T. t. truncatus* is unclear in spite of numerous (but imperfect in view of the applied methodology and thus unreliable) estimates accomplished in the former USSR and Turkey before the mid-1990s (see more information in Section 10.2.3). Nevertheless, the abundance of bottlenose dolphins was considered as the smallest of the three cetacean populations in the Black Sea during most of the 20th century (Tzalkin, 1940b; Kleinenberg, 1956; Geptner *et al.,* 1976; Yaskin and Yukhov, 1997). However, bottlenose dolphins became relatively prevalent in coastal waters of the northern Black Sea round the Crimea peninsula in the last quarter of the 1990s.

Over the period from 1990-1999, a total of 397 primary cetacean sightings were recorded in a coastal (20-60-km-wide) area surrounding the Crimean peninsula from the Karkinitsky Bay to Kerch Strait (Birkun *et al.,* 2004c). The surveys were carried out in 1995, 1997 and 1998 by means of sailing and motor yachts covering distances from 255 to 934 *km* (10,371 km of observation effort in total). It was estimated that sighting score of *T. t. ponticus* individuals increased in five times in 1997 and 1998 in comparison with 1995, whereas numbers of harbour porpoises on record have declined. Relative abundance of the both coastal species, evaluated as a *Tursiops/Phocoena* ratio, suggested clear trend towards the predominance of bottlenose dolphins: June 1995 - 0.8/1; June 1997 - 0.9/1; June-July 1998 - 6.8/1; September 1998 - 12.9/1. The difference between the last two figures could be explained by autumn accumulation of bottlenose dolphins in the waters closed to the southern extremity of the Crimea (between Cape Fiolent and Cape Sarych). Almost daily patrolling in that area in September-October 1997 and August-December 1998 confirmed the predominance of bottlenose dolphin abundance in comparison with harbour porpoises by 7-26 times. Bottlenose dolphin herds numbering hundreds of animals migrate every autumn to this relatively small area from the northeastern and, probably, other parts of the Black Sea (Birkun *et al.,* 2004c; Birkun, 2006a).

A series of line transect surveys, supported by the "Distance" sampling and analysis (Buckland *et al.,* 1993), have been conducted since 1997 to estimate bottlenose dolphin (and other cetaceans) density and absolute abundance in different parts of the range, including the Turkish Straits System (Dede, 1999, cited after: IWC, 2004), Kerch Strait, and Russian and Ukrainian territorial waters in the Black Sea (Birkun *et al.,* 2002, 2003, 2004a). These estimates, summarized in Table 10.3, suggested that the population size at present is not less than several 1000s.

10.4.4. Habitat and ecology

Bottlenose dolphins are distributed across the Black Sea shelf area and far offshore (Beaubrun, 1995; Yaskin and Yukhov, 1997; Mikhalev, 2004a). In the northern Black Sea, they form scattered communities of some tens to approximately 1.5 hundred animals in different places round Crimea including the Kerch Strait and coastal waters off the western and southern extremities of the peninsula (Zatevakhin and Bel'kovich, 1996; Birkun *et al.,* 2004a; Birkun, 2006a). The sizeable accumulations are known also off the Russian Caucasus (O. Shpak and A. Kryukova, pers. comm.) and close to the Turkish coast (S. Krivokhizhin, pers. comm.). Bottlenose dolphins typically aggregate during autumn, winter and spring in relatively small area at the southern Crimea between Cape Sarych and Cape Khersones (Birkun et al., 2006b). According to the results of two-year photo-identification study, this overwintering accumulation consisted of animals from other, "summer", concentrations. The mean size of bottlenose dolphin groups varied from 2.0 to 2.9 in different surveyed areas (Birkun *et al.,* 2002, 2003, 2004a).

Bottlenose dolphins are primarily piscivorous in the Black Sea, taking both benthic and pelagic fishes, large and small. At least 13 fish species have been reported as prey of *T. t. ponticus* off the Crimean and Caucasian coasts (Table 10.4) including several species of mullets (*Mugil cephalus, Liza aurata and L. haematocheila*) which admittedly represent the most preferable diet. Deliberately introduced far-east mullet, *L. haematocheila* (syn. *Mugil so-iuy*), is an example of the influence of aquaculture on Black Sea cetacean forage resources. The introduction of this species, originated from the Sea of Japan, was carried out during 1972-1984 in the lagoons and coastal waters of the northwestern Black Sea and the Sea of Azov (Zaitsev and Mamaev, 1997). Since the late 1980s this fish became abundant and widespread throughout the region. Bottlenose dolphins and harbour porpoises include this new species in their diet (Krivokhizhin *et al.,* 2000).

10.4.5. Life history

The ACCOBAMS and IUCN Workshop on Red List Assessment of Cetaceans in the ACCOBAMS Area (Monaco, 5-7 March 2006) noted that reliable information on vital rates is unavailable for the populations of cetaceans in the Black Sea (Reeves and Notarbartolo di Sciara, 2006). Thus, the data on wild Black Sea bottlenose dolphins (see Table 10.5 and text below) should be recognized as preliminary and, most likely, biased. Any use of them for scientific and conservation purposes demands meticulous care and verification.

The Black Sea bottlenose dolphin is considered as a cetacean with a life span of 25-30 years or more with relatively low reproduction rate (*e.g.,* Tomilin, 1957). The average age of parents in the population is unknown; but it possibly extends to 26 years in females and 19 years in males (Klinowska, 1991). The interval between births is from two or three to six years (Tomilin, 1957), but in captive females the reproductive cycle can be as short as two years (Ozharovskaya, 1997). It was assumed that one female is unlikely to produce more than eight calves in her lifetime (Tomilin, 1984, cited after: Ozharovskaya, 1997). Sexual behaviour can be observed during the whole year with a peak in spring and early summer. The ovulatory season (maximum five spontaneous ovulations per year) extends from March to October with a peak in June; the highest concentrations of testosterone in captive males were recorded in July and the lowest in January (Ozharovskaya, 1997). Gestation lasts 12 months; twinning was not recorded in Black Sea bottlenose dolphins, thus, litter size is invariably one; lactation can last from four months to more than 1.5 years (*e.g.,* Tomilin, 1957).

10.4.6. Past and ongoing threats

In the past, commercial killing was the main human activity affected the population, although the catch of bottlenose dolphins was usually less than those of common dolphins and harbour porpoises. Bottlenose dolphins were taken by all Black Sea countries for manufacturing various products mentioned in Section 10.2.6. A total number of killed animals is unknown, however, it is generally acknowledged that all Black Sea cetacean populations, including the bottlenose one, were reduced by the dolphin fishery (IWC, 1983, 1992, 2004). It was roughly estimated that a share of bottlenose dolphins constituted 0.5% of aggregate numbers of Black Sea cetaceans killed and processed in the USSR between the early 1930s and mid 1950s (Tzalkin, 1940b; Kleinenberg, 1956). At the same time, the statistics of Black Sea cetacean fishery were commonly expressed as total weight or total numbers of animals in the catch without species differentiation. Later on, this value (0.5%) was applied (with groundless extension of temporal and spatial frames of its use) for the re-computation of the recorded annual numbers of pooled cetacean catches/landings into the absolute numbers of *T. t. ponticus* directed catches in the Soviet Union (1931-1966) along with Bulgaria (1958-1966) (Zemsky, 1996). As a result, a total of 8,327 bottlenose dolphins were estimated during that 36-year period, with yearly variation from two (in 1944) to 738 (in 1938) individuals. In particular, the derived annual rates in 1946, 1961 and 1966 were 79, 304, and 30 bottlenose dolphins, respectively (Zemsky, 1996).

All these figures seem very dubious (i.e. utterly underestimated) given the three known facts: (a) more than 3,000 bottlenose dolphins were caught during a single day in one location close to the southern Crimea in spring 1946 (Kleinenberg, 1956); (b) the Bulgarian cetacean fishery was concentrated almost exclusively on *T. t. ponticus* and about 13,000 individuals of this subspecies were taken in 1961 (Nikolov, 1963, cited after: Sal'nikov, 1967); (c) only one dolphin processing factory in Novorossiysk, Russia, processed 53 bottlenose dolphins (27 males and 26 females including 63% of pregnant and 10.4% of lactating animals) in April 1966 (Danilevsky and Tyutyunnikov, 1968).

Thus, taking into consideration the unknown but presumably significant levels of the Romanian and Turkish catch, it could be inferred that the number of bottlenose dolphins killed before the mid 1960s was very high, in some periods even exceeding the kills of the other two species. From 1976 to 1981, bottlenose dolphins were believed to account for 2-3% of the total catch of cetacean fisheries in Turkey with 34,000 to 44,000 taken annually (IWC, 1983; Klinowska, 1991). That makes up between 680-1,320 individuals per year or between 4,080-7,920 individuals during those six years alltogether. No reliable information on illegal commercial killing of Black Sea bottlenose dolphins is available after the ban on cetacean fisheries in 1983. The isolated cases of deliberate killing and harassment (frightening by pyrotechnic means and fire-arms) occurred as a result of adverse interaction between dolphins and coastal fisheries. For instance, at least two bottlenose dolphins were recorded shot in Balaklava, Ukraine, in 2004 (S. Popov, pers. comm.).

Since the mid 1960s, hundreds (probably over one thousand) of bottlenose dolphins have been live-captured in the former USSR, Russia, Ukraine and Romania for military, commercial and scientific purposes (Birkun, 2002a). The capture operations sometimes were accompanied by the accidental death (usually unreported) of additional individuals. In recent years, up to 2002, the live-capture of 10-20 animals took place annually in May-June in the Kerch Strait, Russia. During the 1980s-2000s the number of facilities for dolphin show and "swimming with dolphins" programs has vastly increased in Black Sea countries. The export of bottlenose dolphins from Russia and Ukraine for permanent and seasonal shows has also expanded, for example, to Argentina, Bahrain, Byelorus, Chile, Cyprus, Egypt, Georgia, Hungary, Iran, Israel, Kuwait, Lebanon, Lithuania, Morocco, Oman, Romania, Saudi Arabia, Syria, Turkey, United Arab Emirates, Vietnam, and former Yugoslavia countries. A few captive animals were exported from Georgia to Yugoslavia and then re-exported to Malta. According to CITES statistics, at least 92 individuals were removed from the Black Sea region within 1990-1999 period (Reeves *et al.,* 2003).

At present, incidental catch in fishing gear is probably the major threat to *T. t. ponticus,* although these animals have never been the predominant species in national bycatch statistics, and their share in cetacean bycatches recorded in Black Sea countries during the 1990s comes to 3% at the most (Birkun, 2002c). Absolute numbers of the population losses caused by fisheries were not estimated; however, it was supposed that at least 200-300 individuals are taken annually as bycatch in Turkey (Öztürk, 1999). Bottlenose dolphins are known to be caught in a variety of fishing nets including bottom-set gillnets for turbot (*P. m. maeotica*), spiny dogfish (*S. acanthias*), sturgeons (*Acipenser spp.*) and sole (*Solea spp.*), purse seines for mullets (*Mugil* and *Lisa* spp.) and anchovy (*E. e. ponticus*), trammel and trap nets. Nevertheless, only bottom-set gillnets pose a primary threat, especially, during the turbot fishing season, between April and June (BLASDOL, 1999).

Small-scale coastal fishery affects Black Sea bottenose dolphins also indirectly by depleting their prey populations. Declining trends have been observed in the abundance of indigenous mullets (*M. cephalus* and *Lisa* spp.) (Zaitsev and Mamaev, 1997). At the same time, the suspected deficiency of cetacean forage resources (Bushuyev, 2000) might be compensated at least in part by the introduced far-east mullet, *L. haematocheila,* which became abundant in the northern Black Sea since 1990s (Zaitsev and Mamaev, 1997) and possibly caused the relocation of bottlenose groups with marked enhancement of their density in coastal waters off the Crimea coasts (see Section 10.4.3).

According to annual compilations of cetacean strandings in Crimea (Krivokhizhin and Birkun, 1999), there was a prominent peak of *T. t. ponticus* strandings in 1990 (20 dead animals, representing 44% of all bottlenose dolphin strandings reported from 1989-1996). The initial cause and magnitude of that spike in bottlenose dolphin mortality remains unclear, although severe purulent pneumonia was revealed in many cases. The multi-microbial pollution originated from untreated sewage contaminating coastal waters constitutes a permanent risk of opportunistic bacterial infections in both the bottlenose dolphin and harbour porpoise populations. Besides, there are certain evidences that bottlenose dolphins as well as other Black Sea cetaceans are exposed to morbillivirus infection (Birkun, 2002e). Another ongoing threat (as a potential source of exotic infections and genetic "pollution") is represented by poorly managed intentional releases and spontaneous escapes of captive bottlenose dolphins and other marine mammals from coastal dolphinaria/oceanaria. The releases of two Black Sea bottlenose dolphins returned to the Black Sea after their long-term residence in the Red Sea environment happened in 1996 and 2004 (Veit *et al.,* 1997; ACCOBAMS/SC, 2005).

The further information on major threats impacting *T. t. ponticus* is shown in Table 10.6.

10.4.7. Population trend

The population size of Black Sea bottlenose dolphins was reduced due to the direct kills by some tens of thousands when the total ban on dolphin fishery has been attained in the Black Sea region in 1983 (see Section 10.4.7). It could be suspected that the population had a tendency to increase during the subsequent period (1983-2006) but still did not recover adequately because of several mass mortality events occurred not long ago, and some persistent anthropogenic influences which show growing trend at present and, most likely, will represent major threats provoking the population decline in the future.

10.5. Conservation tools and strategies

Commercial dolphin fishery was banned in 1966 in the former USSR (present Georgia, Russia and Ukraine), Bulgaria and Romania, and in 1983 in Turkey. Since then a number of substantial improvements of national and international legislation were undertaken in order to protect the Black Sea ecosystem, biodiversity and the cetacean populations, in particular.

10.5.1. National instruments

On national level, Black Sea cetaceans are protected by environmental laws, governmental decrees and national Red Data Books. The bottlenose dolphin is listed in the Red Data Books in Bulgaria, Georgia, Russia and Ukraine, the harbour porpoise - in Bulgaria, Russia and Ukraine, and the common dolphin - in Ukraine only. All these national Red Data Books do not use the IUCN scale of categories and criteria, but implies that the species should be monitored and managed by appropriate state/national programs in Russia and Ukraine. Such a program exists in Ukraine since 1999 ("Delfin"-program adopted by the Ministry of Environment). National action plans for the conservation of Black Sea cetaceans were produced in Ukraine (2001) and Romania (2003) but they still have no legal effect.

1. Dunaysky (Ukrainian Danube Delta) Biosphere Reserve; 2. Odessa Center of the Southern Research Institute of Marine Fisheries and Oceanography; 3. Odessa Branch of the Institute of Biology of Southern Seas; 4. Chornomorsky (Black Sea) Biosphere Reserve; 5. Lebedyni Ostrovy (Swan Isles) Branch of the Crimea Nature Reserve; 6. "TDC Nazaret" Ltd.; 10. Brema Laboratory; 10. "Biological Station" PE; 10. NGO "Oasis"; 10. "Gamma" PE; 11. "Livadia Dolphinarium" JE; 12. Cape Martyan Nature Reserve; 13. Karadag Nature Reserve; 14. Opuk Nature Reserve; 15. Southern Research Institute of Marine Fisheries and Oceanography; 16. Kazantip Nature Reserve; 110. Azov and Sivash National Nature Park; 110. "Group for Scientific and Industrial Investigation" PE; 110. "Meotida" Landscape Park.

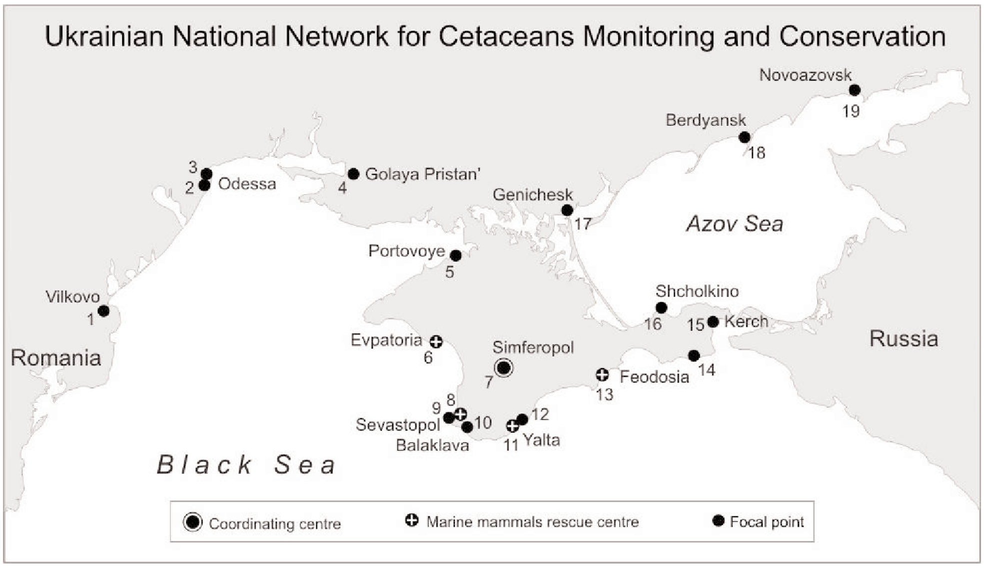

Fig. 10.1. Operational units of the Ukrainian National Network for Cetaceans Monitoring and Conservation (Birkun, 2006b).

Coastal and marine protected areas (PAs) are generally recognized as a primary tool for conservation of the marine environment and biodiversity (Hoyt, 2005). At present, over 60 protected areas and sites are established along the coastline of the Black Sea by the riparian states, and additional 40 areas were suggested for further development (Notarbartolo di Sciara and Birkun, 2002). Some of them contain marine mammal (cetacean and monk seal) habitats within their boundaries, and could thus serve for the monitoring and conservation of marine mammals if appropriate management objectives are set and the personnel is specifically trained. In this context, the most promising PAs are represented by existing biosphere reserves, nature reserves and national parks which have relatively well-developed infrastructure and research capabilities. The Romanian Danube Delta Biosphere Reserve and Vama-Veche - 2 Mai Marine Reserve are already involved in cetacean monitoring and conservation in Romania.

In 2003-2005, nine coastal protected areas joined the Ukrainian National Network for Cetaceans Conservation, informal fellowship consisting of 19 institutions (operational units) situated in 17 localities along the seaboard of Ukraine (Fig. 10.1). Those protected areas are (from west to east): the Dunaisky [Danube] Biosphere Reserve, Chornomorsky [Black Sea] Biosphere Reserve, Lebedyni Ostrovy [Swan Islands] Branch of the Crimean Nature Reserve, Cape Martyan Nature Reserve, Karadag Nature Reserve, Opuk Nature Reserve, Kazantip Nature Reserve, Azov and Sivash National Nature Park, and Meotida Landscape Park (the latter three PAs are situated in coastal zone of the Azov Sea, while the other six PAs relate to the Black Sea coasts and waters). The inventory of cetacean habitats has been completed and common methodology for cetacean monitoring was introduced in these Ukrainian PAs in 2005. Other Black Sea countries so far do not follow this initiative.

10.5.2. International and regional instruments

The riparian states assumed international obligations to protect Black Sea cetaceans as the contracting parties of the ACCOBAMS, the Convention on Biological Diversity (CBD), the Convention on the Conservation of Migratory Species of Wild Animals (CMS), the Convention on the Conservation of European Wildlife and Natural Habitats (Berne Convention), the Convention on the Protection of the Black Sea Against Pollution (Bucharest Convention), and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES, Appendix II). The harbour porpoise (*P. phocoena*) and bottlenose dolphin (*T. truncatus*) are mentioned in Annex II and the common dolphin (*D. delphis*) is listed in Annex IV of the EC Directive No.92/43/EEC on the conservation of natural habitats of wild fauna and flora. All these instruments should contribute to Black Sea cetacean conservation, especially, the ACCOBAMS and Bucharest Convention.

In 1996, the Ministers of Environment of Black Sea countries adopted some cetacean conservation and research measures in frames of the Strategic Action Plan for the Rehabilitation and Protection of the Black Sea (paragraph 62). In 1999, all three species were included as "Data Deficient" (DD) in the regional Black Sea Red Data Book. However, in 2002 they were re-listed as "Endangered" (EN) in the Provisional List of Species of the Black Sea Importance, an annex to the Black Sea Biodiversity and Landscape Conservation Protocol of the Bucharest Convention.

The Berne Convention's Recommendation No.86 (2001) and Resolution 1.12, adopted by the 1st Meeting of the Parties of ACCOBAMS (Monaco, 2002), are intended to strengthen prohibition measures for deliberate catch, keeping and trade of Black Sea bottlenose dolphins. At the 12th Conference of the Parties to CITES (Santiago, 2002), a quota of zero for mercantile export of live bottlenose dolphins wild-captured in the Black Sea has been secured. This measure prohibits transboundary transport of captive Black Sea bottlenose dolphins for "primarily commercial purposes".

The ACCOBAMS Implementation Priorities for 2002-2006 (Notarbartolo di Sciara, 2002) envisage the development of a pilot conservation and management project in the well defined area between Cape Sarych and Cape Khersones, southern Crimea (Ukraine; see Sections 6.4.3 and 6.4.4), for the purpose to establish a marine protected area specialized in conservation of bottlenose dolphins and harbour porpoises. The 1st Meeting of the ACCOBAMS Scientific Committee (Tunis, 2002) recommended that more areas be investigated for identification of critical habitats. Particular concern was expressed by the same meeting in view of large and potentially unsustainable bycatches of harbour porpoises in bottom-set gillnet fisheries throughout the Black Sea shelf area. It was concluded (Recommendation 1.2) that the conservation status of these animals would be greatly improved if existing fisheries regulations restricting fishing effort and the use of certain gear types is enforced.

The Sub-Committee on Small Cetaceans of the IWC Scientific Committee (Berlin, 2003) reviewed the status of Black Sea cetaceans in details and concluded that these populations of harbour porpoises, common dolphins and bottlenose dolphins, which are almost completely isolated from their conspecifics in the northeastern Atlantic and Mediterranean Sea, should be considered as the separate and discrete units for conservation purposes (IWC, 2004). At the same time, it turned out impossible to evaluate fully the status of Black Sea cetaceans due to a lack of basic information. In this respect, the Sub-Committee strongly recommended to improve the conservation-related cetacean research in the region by means of developing the region-wide (a) line-transect surveys, (b) photo-identification programme, (c) genetic analyses of population structure, (d) studies on cetacean life history, (e) comprehensive assessments of man-made threats including the incidental captures in fishing activities, disturbance caused by marine traffic, and past cetacean losses due to the directed catches.

A tentative list of cetacean research and conservation projects implemented in the Black Sea region in 2002-2006 is shown in Appendix A.

The 4th Meeting of the ACCOBAMS Scientific Committee (Monaco, 2006) devoted special consideration to the ACCOBAMS Work Programme on Marine PAs. In particular, it was reminded that the 1st Meeting of the Parties to ACCOBAMS (Monaco, 2002) proposed for the development a pilot PA within inshore waters between Cape Sarych and Cape Khersones in the southern Crimea. In addition to this area the Scientific Committee recommended that the Parties give priority to assessing the value of creating marine PAs for the following additional three areas in the Black Sea and adjacent waters:

maritime area from Cape Anaklia to Sarp (Georgia) - this represents winter habitat for harbour porpoises and common dolphins; in particular, there is a local problem with pelagic trawling for anchovy, which causes a dolphin bycatch;

the Kerch Strait (Ukraine and Russia) - used by semi-resident Black Sea bottlenose dolphins and as a migration corridor for several thousand harbour porpoises moving to and from the Azov Sea; there is intensive marine traffic and coastal fisheries with bycatch in gillnets and live captures of bottlenose dolphins; and the Turkish Strait System (Turkey) - used by all Black Sea cetacean species, including harbour porpoises which are present also in the Northern Aegean Sea.

10.5.3. The IUCN status

In 1996, Black Sea population of the harbour porpoise was included as "Vulnerable" (VU) in the IUCN Red List of Threatened Animals. The conservation status of Black Sea common dolphins and bottlenose dolphins is not evaluated by IUCN up to now, although global status, assigned to *D. delphis* and *T. truncatus,* is "Least Concern" (LC) and "Data Deficient" (DD), correspondingly.[2] At the same time, all three Black Sea cetacean populations are supported by the IUCN 2002-2010 Conservation Action Plan for the World's Cetaceans (Reeves *et al.,* 2003).

The 3rd Meeting of the ACCOBAMS Scientific Committee (Cairo, 2005) encouraged the initiative proposed by the Cetacean Specialist Group of the IUCN Species Survival Commission (IUCN/SSC/CSG) concerning the development of the IUCN Red List of Mediterranean and Black Sea cetaceans. As a result, the IUCN/ACCOBAMS Workshop on the Red List Assessment of Cetaceans in the ACCOBAMS Area (Monaco, March 2006) assessed the conservation status of Black Sea populations of the harbour porpoise, common dolphin and bottlenose dolphin as "Endangered" (EN) and confirmed their belonging to the Black Sea subspecies *P. p. relicta* Abel, 1905; *D. d. ponticus* Barabasch-Nikiforov, 1935; and *T. t. ponticus* Barabasch, 1940 (Reeves and Notarbartolo di Sciara, 2006). According to the IUCN Red List procedure, these assessments should be further reviewed by independent evaluators from IUCN/SSC/CSG and then submitted to IUCN/SSC for final consideration. Therefore, it may be expected that the new IUCN status of Black Sea cetaceans will be established in 2010. As interim measure, the results of the IUCN/ACCOBAMS Red List assessment of cetaceans in the Mediterranean and Black Seas (2006) were adopted by special resolution of the 3rd Meeting of Parties to ACCOBAMS (Dubrovnik, Croatia, 2007).

10.5.4. Conservation plan for Black Sea cetaceans

The development of regional activities on cetacean research, monitoring and conservation demands to be well-designed and coordinated. The regional Conservation Plan for Black Sea Cetaceans (Birkun *et al.,* 2006a) has been drafted in accordance with the ACCOBAMS International Implementation Priorities for 2002-2006 (Notarbartolo di Sciara, 2002). This plan was considered and supported by participants of the Round Table on Conservation of Black Sea Cetaceans conducted within the 1st Scientific Conference of the Black Sea Commission (Istanbul, May 2006). The contracting parties to the ACCOBAMS had approved this plan at their 3rd Meeting (Dubrovnik, Croatia, 2007).

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[2] Since 2003, the neighbouring population of common dolphins in the Mediterranean Sea is included as "Endangered" (EN) in the IUCN Red List of Threatened Animals.

The Conservation Plan for Black Sea Cetaceans

is prepared based on a strategy designed by ACCOBAMS and reflected in its Annex 2, the Conservation Plan;

is intended to complement the existing ACCOBAMS Implementation Priorities for 2002-2006, and Priority #6 in the first place, addressing cetacean conservation, management and research in the Black Sea. It is fully corresponds to the ACCOBAMS Working Programme 2005-2007, Resolutions of the 1st and 2nd Meetings of the Paties to ACCOBAMS, Recommendations and decisions of the 1st, 2nd and 3rd Meetings of the ACCOBAMS Scientific Committee;

is aimed to facilitate the co-operation among Black Sea riparian states and enhance their abilities essential for the conservation of cetaceans and their habitats;

envisages common mechanisms aimed to promote cetacean conservation and research actions, as well as capacity building, education and public awareness in the Black Sea subregion under the co-ordination role of ACCOBAMS institutions including the Meeting of the Parties, Permanent Secretariat, Bureau, Scientific Committee and, last but not least, Black Sea Co-ordination Unit represented by the Permanent Secretariat of the Commission on the Protection of the Black Sea Against Pollution (the Black Sea Commission);

expects that it will be adopted and promoted by all Black Sea countries, including those which are still not the Parties of ACCOBAMS, regardless of existing national differences in the available expertise, level of organization, scientific backgrounds and logistical constraints among areas;

expects also that its implementation will derive adequate support from national, regional, European and global agencies, intended for nature protection and sustainable development, and thus, will be provided with various sources to fund collaborative projects focused on the Black Sea cetaceans conservation.

The principal goals of this plan are to provide a framework and priority actions whereby the Black Sea Community (scientists, fishermen, industry, NGOs, local and national governments, and appropriate intergovernmental organizations) can in the short-term (2006-2010) begin to practically improve the conservation status of Black Sea cetaceans, and in particular obtain the necessary scientific information to allow a full long-term conservation plan to be developed at the end of the period and effective management decisions to be made.

The principal objectives of the Conservation Plan for Black Sea Cetaceans wholly correspond with appropriate items of the ACCOBAMS Conservation Plan:

consolidation of international and national legal system (Actions 1-4);

assessment and management of human-cetacean interactions (Actions 5-10);

habitat protection (Actions 11 and 12);

research and monitoring (Actions 13-15);

capacity building, collection and dissemination of information, training and education (Actions 16 and 17); and

responses to emergency situations (Action 18).

All 18 actions proposed are important for the conservation of Black Sea cetaceans (Appendix B). The order of the actions follows above objectives (*i.e.* corresponds to a format of the ACCOBAMS Conservation Plan) and their numbering does not indicate priorities. These actions consist of 57 smaller actions or sub-actions (activities) which were prioritized according their significance (primary and secondary) in the relation to each other - some actions are clearly more urgent or definitely propaedeutic to others (Appendix C). Besides, some actions are already on the way of their implementation and that is also underlined in the descriptions. They are interactive between the various categories of actions and the actions within categories. In particular, the Research and Monitoring section is absolutely crucial to provide the necessary background to almost all of the other groups of actions. In its turn, the **Basic Cetacean Surveys** action is the most important within the Research and Monitoring category.

The implementation of the Conservation Plan for Black Sea Cetaceans is estimated for a five-year period since the plan is approved by the Black Sea states. This term seems to be realistic under the stipulation that proper planning, coordination and monitoring of the actions proposed is established and adequate methodological, financial and logistical support is provided. This, hopefully, can be ensured under auspices and supervision of the ACCOBAMS, Black Sea Commission and their institutions. Establishing a coordinator position could be helpful for the success of this plan. It may be expected that the plan will serve as a suitable tool for transboundary conservation and management of Black Sea cetacean populations, with an ultimate aim to ensure their survival and welfare in the nearest and remote future.

10.6. Conclusions

This chapter has briefly described the conservation status of Black Sea cetaceans with clear emphasis on specific activities which were launched, declared or drafted on the national, regional and international levels during last decade. Most these activities require more efficient management procedures established on regular basis within a framework of existing legal and institutional arrangements including such important multilateral instruments like the ACCOBAMS and the Bucharest Convention on the Protection of the Black Sea against Pollution, with particular regard to the observance of the Black Sea Biodiversity and Landscape Conservation Protocol.

To further improve the transboundary management of cetaceans-related protection issues, the Conservation Plan for Black Sea Cetaceans was prepared in 2006 by international team of experts acted under the auspices of the ACCOBAMS' and Black Sea Commission's permanent secretariats. This plan reveals major gaps in the knowledge concerning the populations of Black Sea dolphins and porpoises (*e.g.,* a lack of solid data on the abundance, population structure and threats), sets up relevant regional strategies, and recommends concrete research and conservation actions to fill up the gaps. It is anticipated that correct and concerted implementation of the plan by Black Sea riparian countries improves the conservation status of Black Sea cetaceans to substantial extent during next five years under the stipulation that adequate methodological, financial and logistical support is provided.

Four Black Sea states (Bulgaria, Georgia, Romania and Ukraine), being the contracting parties to ACCOBAMS, are already on the way to put into practice the Conservation

Plan owing to the fact that it was approved recently by the 3rd Meeting of the Parties to ACCOBAMS (Dubrovnik, Croatia, 2007). Two other Black Sea countries (the Russian Federation and Turkey) have the opportunity to join to implementation of the plan by force of signing the Strategic Action Programme on the Protection and Rehabilitation of the Black Sea. This new instrument of Black Sea regional importance, drafted by the Black Sea Commission, envisages the *ad hoc* management target on the adoption of the Conservation Plan for Black Sea Cetaceans by the six Black Sea countries without exception.

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Appendix A. Examples of cetacean research and conservation projects implemented in the Black Sea region in 2002-2006

Programme / Initiative	Project (title)	Implementing organizations	Year
Programme for Research, Conservation and Restoration of Marine Mammals in the Black and Azov Seas ('Delfin'-program approved by the Ministry of Ecology and Natural Resources of Ukraine, in August 1999)	Pathological conditions of Black Sea common dolphins	Brema Laboratory (Ukraine)	2001-2002
	Infectious diseases in captive Black Sea bottlenose dolphins	Brema Laboratory (Ukraine)	2001-2002
	Workshop on conservation problems of Black Sea cetacean populations (Koktebel, 23-24 October 2002)	Brema Laboratory in co-operation with Crimean dolphinaria (Ukraine)	2002
	Preparation of three issues of the 'Black Sea Cetaceans' Information Base (CD-ROM)	Brema Laboratory (Ukraine)	2002, 2003, 2004
	Bacteriological aspect of Black Sea bottlenose dolphins adaptation to captivity	Brema Laboratory (Ukraine)	2002
	Feeding objects of Black Sea cetaceans and state of their forage reserves	Brema Laboratory (Ukraine)	2002
	Development of national network for the monitoring of Black Sea cetacean strandings and bycatches, formation of a system aimed to render assistance to sick and traumatized cetaceans in Ukraine, conversion of dolphinaria into centres for rescue and rehabilitation of marine mammals (MORECET)	Brema Laboratory, Biological Station PE, Livadia Dolphinarium JE, Karadag Nature Reserve and Nazareth Ltd (Ukraine)	2002-2006
	Pathological conditions of wild Black Sea harbour porpoises	Brema Laboratory (Ukraine)	2003
	Preparation of draft regulations on conservation-related activities of dolphinaria	Brema Laboratory (Ukraine)	2003
	Assessment of the state of Black/Azov Sea marine mammal populations listed in the Red Data Book	Brema Laboratory in co-operation with the Ukrainian Danube Delta Biosphere Reserve, Odessa Center of the Southern Research Institute of Marine Fisheries and Oceanography, Odessa Branch of the Institute of Biology of Southern Seas, Chornomorsky [Black Sea] Biosphere Reserve, Lebedyni Ostrovy [Swan Islands] Branch of the Crimean Nature Reserve, Cape Martyan Nature Reserve, Karadag Nature Reserve, Opuk Nature Reserve and Kazantip Nature Reserve (Ukraine).	2003

Programme / Initiative	Project (title)	Implementing organizations	Year
	Workshop on conservation problems of Black Sea cetacean populations (Kiev, 25 May 2004)	Ministry of Environment of Ukraine in co-operation with members of national network for monitoring of cetaceans (Ukraine)	2004
EU LIFE-NATURE Program	Conservation of the dolphins from the Romanian Black Sea waters	Grigore Antipa National Institute for Marine Research and Development, Mare Nostrum NGO, Museum Complex for Nature Sciences in Constantsa (Romania)	2001-2004
Joint initiative supported by the ACCOBAMS Secretariat	Genetic study of Black Sea bottlenose dolphins	University of Durham (UK) in co-operation with Brema Laboratory (Ukraine)	2002
Joint initiatives supported by the Ministry of Environmental Protection of Ukraine and Russian Academy of Science	Aerial survey of distribution, abundance and species composition of cetaceans in the Azov Sea (Azovka-2001).	Brema Laboratory (Ukraine) and Institute of Ecology and Evolution (Russia)	2001-2002
	Aerial survey of distribution, abundance and species composition of cetaceans in the Russian and Ukrainian waters of the Black and Azov Seas (Azovka-2002)	Brema Laboratory (Ukraine) and Institute of Ecology and Evolution (Russia)	2002-2003
	Study of accumulations, migrations and habitats of the Black Sea bottlenose dolphin in coastal waters of Russia and Ukraine (Afalina-2003)	Institute of Ecology and Evolution (Russia), Brema Laboratory and Karadag Nature Reserve (Ukraine)	2003-2004
	Distribution, abundance and photo-identification of cetaceans in the northwestern shelf waters of the Black Sea (Afalina-2004)	Institute of Ecology and Evolution (Russia), Brema Laboratory and Karadag Nature Reserve (Ukraine)	2004-2005
	Distribution and abundance of cetaceans in offshore waters of the central Black Sea (Belobochka-2005)	Brema Laboratory (Ukraine) and Institute of Ecology and Evolution (Russia)	2005
Joint Georgian, Ukrainian and Russian initiative	Assessment of cetacean distribution and abundance in coastal waters of the southeastern Black Sea (Afalina-2005)	Brema Laboratory (Ukraine), Marine Ecology and Fisheries Research Institute (Georgia) and Institute of Ecology and Evolution (Russia)	2005
EUROPHLUKES	Photo-identification of Black Sea cetaceans (Black Sea Fins)	Brema Laboratory (Ukraine) and Institute of Ecology and Evolution (Russia) with initiating support derived from the Permanent Secretariat of ACCOBAMS, and the training provided by Tethys Research Institute (Italy)	2003-2004
Small Environmental Projects Scheme (SEPS II) supported by the UK's Department for Environment, Food and Rural Affairs and managed by the British Council-Ukraine	Improvement of the Ukrainian National Network for Cetaceans Monitoring and Conservation (NNCC-project)	Brema Laboratory in partnership with the Ukrainian Danube Delta Biosphere Reserve, Odessa Center of the Southern Research Institute of Marine Fisheries and Oceanography, Odessa Branch of the Institute of Biology of Southern Seas, Chornomorsky [Black Sea] Biosphere Reserve, 'Oasis' NGO, Cape Martyan Nature Reserve, and Karadag Nature Reserve (Ukraine)	2004-2005

Appendix B. Conservation Plan for Black Sea Cetaceans: aims of actions proposed

Actions		Aims
1	Broadening the ACCOBAMS scope	Achieve that all six Black Sea riparian states are the Contracting Parties to ACCOBAMS; disseminate the ACCOBAMS process in the countries which have indirect outlet to the Black Sea through the rivers and exert their influence on the Black Sea environment and biota (including cetaceans) by means of fluvial discharges and marine-riverine traffic.
2	Proper conservation status of cetacean populations	Ensure that Black Sea cetacean species - the harbour porpoise, the short-beaked common dolphin and the common bottlenose dolphin - are properly classified in the international documents aimed to protect the Black Sea environment, ecosystems, living resources and biodiversity.
3	Cetacean conservation approach in fishery regulations	Ensure that Black Sea intergovernmental agreements and national regulations, purposed to manage Black Sea living resources and their exploitation, include items concerned in the conservation of cetaceans
4	Improvement and harmonization of national legislation	Ensure that in the Black Sea states their laws intended to regulate conservation activities, sustainable use and management of marine environment and resources are brought in accordance with international legislation standards related to cetacean conservation.
5	Retrospective analysis of human-induced cetacean mortality	Investigate the feasibility of obtaining meaningful estimates of human-induced cetacean mortality over the 20th century with the view of historical reconstruction of the 'initial' population sizes and, thereby, more clear evaluation of present status and trends of Black Sea cetacean populations.
6	Strategy for reducing cetacean bycatches	Develop a system of concordant measures able to decrease cetacean mortality in fishing gear at least to sustainable levels, with ultimate long-term goal of reducing it to zero if possible.
7	Mitigation of conflicts between cetaceans and fishery	Address the problem of adverse cetacean/fisheries interactions (other than bycatches) and develop measures for this problem solution.
8	Elimination of live capture of Black Sea cetaceans	Restrain intentional removal of live cetaceans from the wild.
9	Mitigation of disturbance caused by shipping	Address the problem of adverse impact of heavy marine traffic on Black Sea cetacean populations and develop appropriate conservation/management measures.
10	Management of threats from gas-and-oil producing industry	Address the problem of potential threats to cetaceans from gas and oil industry operating at sea, and develop pertinent management measures.
11	Network of existing protected areas eligible for cetaceans	Develop regional network of already operating protected areas containing cetacean habitats within their boundaries, taking into account the ACCOBAMS 2010 targets and the ACCOBAMS Criteria for Protected Areas of Importance for Cetacean Conservation.
12	Special marine protected areas for cetacean conservation	Set up particular cetacean protection modes in well- defined key areas containing cetacean habitats which are vitally important, first of all, for harbour porpoises and bottlenose dolphins, taking into account the ACCOBAMS 2010 targets and the ACCOBAMS Criteria for Protected Areas of Importance for Cetacean Conservation.
13	Basic cetacean surveys	Obtain and periodically refresh reliable basin-wide information on cetacean abundance and distribution.
14	Cetacean photo-identification programme	Consolidation of cetacean photo-identification studies in order to provide information on population structure, seasonal movements and ranging patterns of Black Sea cetaceans, mostly, bottlenose dolphins and common dolphins.
15	Regional cetacean stranding net work	Basin-wide systematic study of cetacean strandings in order to monitor mortality levels in cetacean populations, and to provide samples for research of cetacean genetics, life history, ecology, pathology, parasitology, ecotoxicology, etc.
16	Strategies for capacity building and raising awareness	Develop long-term capacity building and public awareness strategies in order to provide explicit improvement of cetacean research, conservation and management in the Black Sea region on basis of consolidated educational activities.
17	Access to information and cetacean libraries	Provide unimpeded access to the results of cetacean research and conservation activities implemented in the Black Sea region and beyond; accumulate, systematize, store and make available relevant published information by means of proper data carriers.
18	Measures for responding to emergency situations	Develop regional strategy, guidelines and operational network able to provide urgent and competent assistance to Black Sea cetaceans involved in emergencies.

Appendix C. Conservation Plan for Black Sea Cetaceans: actions and activities of high priority
URG **- activities addressed as a matter of urgency** (Istanbul Round Table, May 2006)

Actions		**Activities (sub-actions)**
1	Broadening the ACCOBAMS scope	(a) promotion of accession of the Russian Federation and Turkey to ACCOBAMS
2	Proper conservation status of cetacean populations	(a) proper listing Black Sea cetaceans in the IUCN Red List of Threatened Animals (b) providing correct references to the IUCN status of Black Sea cetaceans in relevant international instruments
3	Cetacean conservation approach in fishery regulations	(a) adopting the Black Sea legally binding document for fisheries and conservation of marine living resources
4	Improvement and harmonization of national legislation	(a) improvement of national legislation in respect of international requirements on the conservation of cetaceans
6	Strategy for reducing cetacean bycatches	(a) establishment of a regional bycatch network URG (b) estimation of bycatch levels and temporal and geographical distribution of bycatches (c) evaluation of sustainable bycatch levels for each cetacean species (d) investigation of effects causing by mitigation measures includig pingers and acoustically reflective nets (f) developing management objectives for reducing bycatches in the Black Sea region
8	Elimination of live capture of Black Sea cetaceans	(a) improvement of control assigned to eliminate live capture of cetaceans (b) preparation and adoption of national legal acts banning any intentonal capture of Black Sea cetaceans
11	Network of existing protected areas eligible for cetaceans	(a) assessment of existing protected areas with regard to their relevance to cetacean conservation (b) developing the regional network of eligible protected areas URG (c) preparation of the network's cetaceans-oriented strategy, action plan and guidelines (d) protected areas involved in the network should restrain human activities potentially harmful for cetaceans
12	Special marine protected areas for cetacean conservation	(a) developing management plans and creating ad hoc marine protection areas in the defined localities
13	Basic cetacean surveys	(a) carrying out region-wide survey and assessment of cetacean abundance, distribution and hot spots URG (b) carrying out cetacean survey in the Turkish Straits System
15	Regional cetacean stranding net work	(a) developing the existing national CSNs with their functional fusion into the basin-wide network URG (b) developing a Black Sea regional database of cetacean strandings (c) establishing cetacean tissue bank(s) accumulating samples from stranded and bycaught cetaceans (d) multidisciplinary study of samples collected from stranded and bycaught animals
18	Measures for responding to emergency situations	(a) assessment of emergency situations demanding special response (e.g. rescue-and-release operations) (b) developing guidelines on how to respond to emergency situations affecting Black Sea cetaceans (c) developing regional strategy (contingency plan) and national teams for responding to emergency situations

CHAPTER 11 SOCIO-ECONOMIC PRESSURES AND IMPACTS (D. Knowler)

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11.1. Introduction

For several decades, the Black Sea has exhibited signs of being one of the most polluted and mismanaged inland or semi-enclosed seas in the world. Outbreaks of cholera, reduced recreational opportunities and degraded life support systems for both wildlife and humans have hindered the development of the region (Mee, 1992). Yet the Black Sea is an important European resource, with its watershed accounting for over half the area of the continent and its productivity rated at several times that of the adjoining Mediterranean Sea. However, these very characteristics make it more vulnerable to the environmental degradation that has occurred.

Environmental degradation in the Black Sea Region has had social and economic costs in a number of sectors. One of the hardest hit is the fisheries sector, where catches of the most lucrative fish species fell dramatically in the 1980s and 1990s. The costs of environmental degradation have manifested themselves in many other sectors as well. Along with fisheries costs, the World Bank (2000) and more recent Tranboundary Diagnostic Analysis (Black Sea Commission, 2007a) document extensive tourism, agricultural and health costs that have resulted from degradation of the Black Sea.

The extensive pollution loads discharged by the Danube, by other major rivers and by the Black Sea states themselves, together with over-fishing, dumping of toxic wastes, intensive shipping activity, mineral exploitation, the introduction of non-native species and the damming of tributaries, have been recognized as the proximate causes of severe environmental degradation in the Black Sea (Duda and LaRoche, 1997). Nutrient pollution is among the most important environmental problems affecting the Black Sea. As a result of 30 years of heavy nutrient pollution, the Black Sea (which was once oligotrophic) is now critically eutrophic (ICPDR, 1999). The northwestern portion has been transformed from a diverse ecosystem to a eutrophic plankton culture (Middleton, 1999). Other important contaminants in the Black Sea include oil, synthetic organic compounds and radio nuclides deposited by the Chernobyl accident (Stanners and Bourdeau, 1995). This has had a major impact on the biodiversity and ecological integrity of the Black Sea (CEC, 2001).

However, underlying these more proximate causes of degradation has been a number of social and economic pressures. Poor initial conditions or rapid changes in social and economic pressures, serve as drivers of environmental change. In this chapter, these social and economic pressures are reviewed, together with the impact that the environmental degradation of the Black Sea has had on its dependent human population. The approach taken is to compare conditions during the 1995 to 2000 period with those of the more recent period (2001 to 2005). These periods correspond to the periods reviewed during two Transboundary Diagnostic Analyses. The emphasis here is on the social and economic pressures driving environmental change as well as the impacts of change on human populations. In addition to the standard methods employed for such analyses, consideration is also given to ecological economics perspectives by including a discussion of changes in non-market values due to environmental degradation, as well as a brief review of progress towards sustainability in the six Black Sea nations.

11.2. Valuing the Environmental Goods and Services Provided by the Black Sea

The Black Sea ecosystem generates a large number of environmental goods and services, some of which pass through markets, while others do not. Assessing the value of these environmental goods and services is a useful first step in understanding the human impacts of changes in the Black Sea marine system. However, to carry out such an assessment requires a framework for distinguishing and grouping these values. The concept of total economic value (TEV) provides such a framework. TEV makes a distinction between use values and non-use values, the former being further divided into direct and indirect use values. Direct uses refer to those uses which are most familiar, such as harvesting of fish and shellfish, collection of commercially valued marine products and use of the marine zone for recreation. Marine systems also perform ecological functions that support economic activity. These ecosystem services are referred to as indirect use values since it is not the functions themselves but their contribution to production that is valued. For example, marine systems can assimilate nutrients and other pollution to some extent, while coastal wetlands provide habitat for nursing and rearing of marine species.

Non-use value is often thought of as coinciding with the concept of existence value; individuals may be concerned about the continued existence of some environmental resource, such as a marine ecosystem or species, even though they have no plans to visit it. Non-use values are typically not commercially expressed since they are unrelated to use. As an example, marine biodiversity may be valued by persons living in distant countries. Due to their nature, non-use values are very difficult to measure.

For cases where values can be measured, we start with the economist's concept of willingness-to-pay, whether or not we actually make any payment. From this amount we then subtract what it costs to supply the good or service, recognizing that in situations where environmental goods and services are free gifts of nature this cost is zero. Measuring economic values for the environment relies on a number of valuation techniques. These techniques can be divided into those that use market prices to directly measure the economic value of environmental goods and services, and those that do not. The latter group constitutes methods for non-market valuation, and these can be subdivided into a several further groupings.[3]

What are the main values associated with the environmental goods and services provided by the Black Sea? Relatively little non-market valuation of ecosystem goods and services has been carried out involving the Black Sea marine ecosystem. Clearly, the Black Sea marine system supports a range of use and non-use values. For example, there

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[3] Examples of non-market valuation techniques include expressed preference techniques such as contingent valuation, contingent ranking or discrete choice modeling and revealed preference methods such as the travel cost method, hedonic pricing and production function techniques. (Freeman, 1993).

are numerous values associated with the Black Sea's coastal zone and wetlands. Gren (1996) carried out a valuation study of the Black Sea wetlands, using data for 35 wetlands. She considers the fish, reed harvesting, grazing and nutrient retention values. She found that these values totaled from US$314 million to 514 million per year. These values correspond to US$ 190 and 312 per ha, respectively. Studies of other coastal systems can be instructive for putting Gren's estimates in context. For example, Brander et al. (2003) reviewed several dozen coastal valuation studies and found that the median values for coastal goods and services such as recreation, water quality, commercial fisheries and biodiversity ranged from $200 to $500 per ha per year (Table 11.1). Thus, Gren's estimates would seem quite reasonable.

In addition to the values associated with the coastal areas, the living marine resources of the Black Sea provide direct, indirect and non-use values (Table 11.2). While no estimate is available of the aggregate magnitude of these values, they certainly amount to tens or perhaps even hundreds of millions of dollars per year (see below, for an estimate covering the anchovy fishery). Aside from these values, there are a number of other specific biochemical and hydrological functions that are performed by marine systems and these should be included as well.

Degradation of the Black Sea marine system has resulted in the loss of all or some of the values referred to above. In the next section, the social and economic forces driving this unfortunate situation is explored, and then an assessment of the impacts on social and economic systems is made, keeping in mind the general trends over the last decade or so.

Table 11.1. Estimated Value of Black Sea Coastal Wetlands (US$/ha/yr)

Wetlands	Area (ha)	Fish Value	Harvest of Reeds & Grazing	Nutrient Retention	Total
Danube R. Delta	592,000	25	76	62	163
Dniestr R. Delta	200,000	8	26	22	56
Lower Dniepr R.	150,000	-	19	16	35
Don R. Delta	55,000	2	7	6	15
Others	653,000	19	26	-	45
Total	1,650,000	54	154	106	314

Source: Gren (1996)

Note; figures are rounded and adjusted for rounding error. Lower values for nutrient retention from Gren (1996) are used in these calculations. Based on studies for 35 wetlands in the Black Sea region.

Table 11.2. Living Marine Resources of the Black Sea and their Values

Living Marine Resource	Direct, Indirect and Non Use Values
Fish stocks (e.g. anchovy, sprat, shad, whiting, horse mackerel)	fresh, frozen, salted, canned and reduced products for local consumption or export (direct use) commercial and non-commercial species serve as food for higher level predators (indirect use)
Molluscs, crustaceans, etc. (e.g. clams, mussels, crabs, sea snails, etc.)	commercially important as seafood (direct use) serve as biofilters for reducing pollution (indirect use)
Bottom plants (e.g. red algae, seaweed beds, etc.)	source of agar and sodium alginate (direct use) critical habitat/food for many fish species (indirect use)
Marine mammals (e.g. monk seals, dolphins)	previously harvested commercially (direct use) important ecological function as top predators (indirect use); may have high intrinsic value as rare or endemic, species (non use)

11.3. Socio-economic and Institutional Pressures

To understand the social and economic driving forces behind environmental change it is useful to employ a conceptual framework. Typically, the D-P-S-I-R model is used for this purpose (Fig. 11. 1). In this model, socio-economic drivers (D), environmental pressures (P), environmental state changes (S), social and economic impacts (I) and, finally, policy responses (R) work in sequence and through feedback mechanisms to describe the process of environmental change (Mee, 2005).

The main environmental pressures of human origin affecting the Black Sea marine systems living resources and habitats have been described in the 2007 transboundary diagnostic analysis as:

inflows of nutrients, resulting in eutrophication;

the loss of higher trophic level predator species, which has altered food chain structure;

the introduction of exotic species, especially the jellyfish *Mnemiopsis leidyi*;

modifications in river flow regimes, which have affected the salinity of the Black Sea and had other effects;

declines in populations of various living marine resources as a result of over harvesting; and,

inflows of chemical and toxic pollutants and erosion of coastlines.

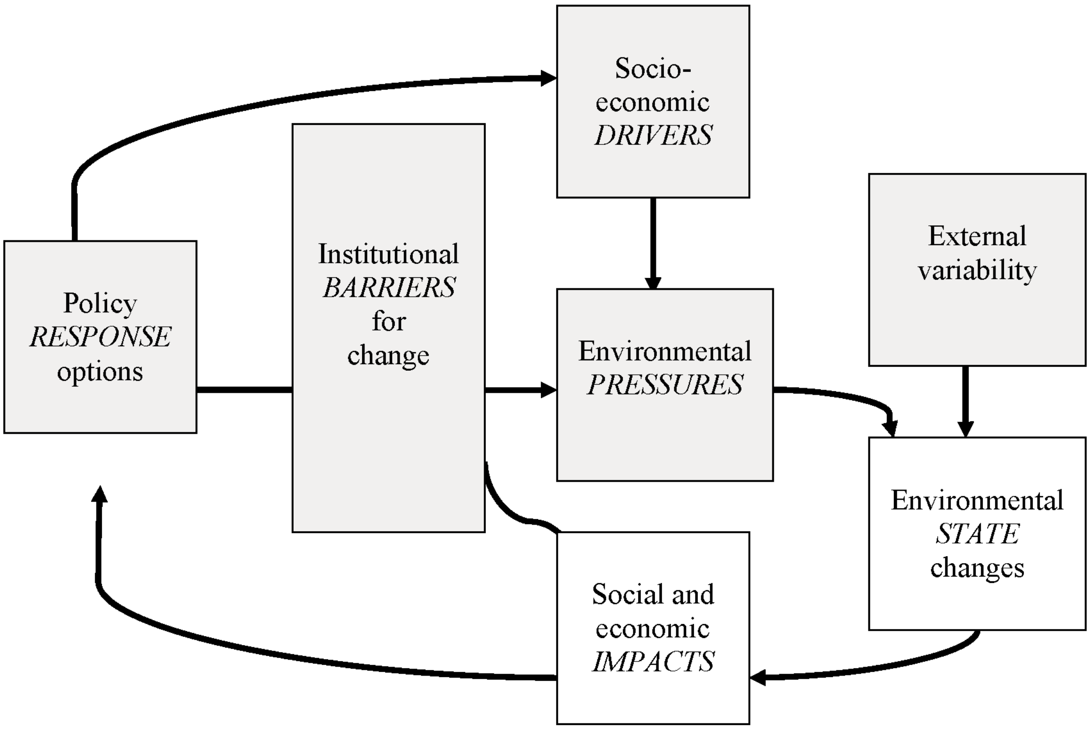

Fig. 11.1. Modified D-P-S-I-R model showing the Relationship between Drivers (D), Pressures (P), State Changes (S), Impacts (I) and Responses (R), with the Addition of Institutional Barriers. Source: Mee (2005).

Further details concerning the extent and severity of these environmental pressures can be found in other reports. Here, we examine the underlying causes or drivers behind these problems and these are largely social, economic and policy or institutionally related. However, the situation is not obvious. Unlike many rapidly growing regions of the world, the population of the Black Sea countries (except Turkey) has been contracting over the last decade (Table 11.3). Population growth rates have been consistently between zero and -1% per year (Fig. 11.2). This situation presents complex challenges for environmental management: while a declining population might be expected to put less pressure on the resource base, it may also lead to difficulties with mustering the necessary resources to address existing environmental problems. Our data does not indicate whether the coastal zone itself is experiencing a decline in population, but this may be the case where fisheries have historically been important (versus tourism) or where population density in this zone is much lower than the country as a whole (Table 11.3).

The trend is much more positive with respect to economic performance over the last decade (Table 11.4). This suggests that declining population may be a lagging indicator of national performance, since economic growth was significantly higher during 2001 - 2005, in comparison to 1995 - 2000. The exception is Turkey, where there was no significant change in the economic growth rate. However, Turkey and all other Black Sea countries experienced much lower consumer price inflation during the latter period, an indication of more stable macroeconomic conditions (Table 11.4). The main trend has been the reduction of importance of agriculture and the increasing significance of the service sector (Black Sea Commission, 2007a), a development that is typical of emerging economies.

Table 11.3. Demographic Data for the Black Sea Countries and their Coastal Zones, Selected Years

Countries	**Population (million)**		**Country Data, 2005**		**Coastal Zone, 2005**	
	1995	2005	Population 10-14 years (%)	Population density (per km2)	Population 1/ (million)	Population density 2/ (per km2)
Bulgaria	8.30	7.72	14.1	70	2.1	60
Georgia	4.79	4.32	19.5	64	1.7	76
Romania	22.68	21.71	15.9	94	0.97	62
Russia	148.40	142.70	15.7	9	0.89	100
Turkey	60.64	71.61	29.5	94	7.6	74
Ukraine	51.50	46.93	15.4	81	6.7	60

Source: World Bank. 2007. Key Development Data & Statistics. Data and Statistics. World Bank staff estimates from various sources including census reports, the United Nations Population Division's World Population Prospects, national statistical offices, household surveys conducted by national agencies, and Macro International. Accessed November 28, 2007.

http://web.worldbank.org/WBSITE/EXTERNAL/DATASTATISTICS/0,,contentMDK:20535285~menuPK:1192694~pagePK:64133150~piPK:64133175~theSitePK:239419,00.html.

1/ Georgia excludes Abkhazia; Russian population is only for Krasnodar Krai; Turkey excludes Istanbul.

2/ Turkey excludes Istanbul.

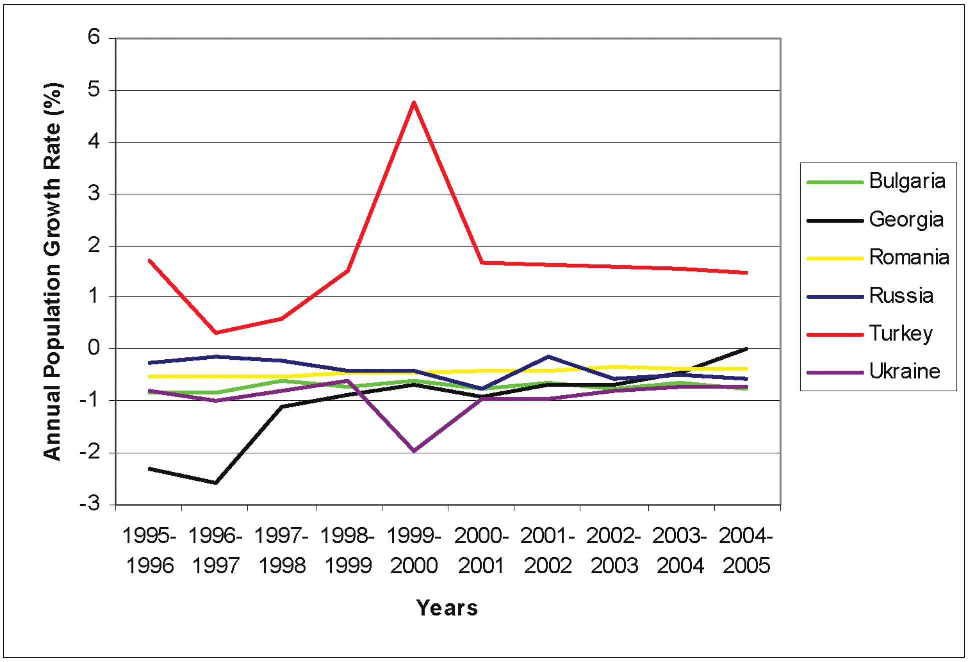

Fig. 11.2. Annual Population Growth in the Black Sea Countries, 1995 to 2005. data source: World Bank Development Indicators website (accessed November 27, 2007) at http://web.worldbank.org

What is the significance of improving economic conditions in the Black Sea countries for the marine environment? One theory holds that as countries stabilize and their per capita income increases, there is a general improvement in environmental conditions, but only after a threshold is surpassed.[4] Given that some Black Sea countries may be at or near this threshold it is possible that we could expect conditions to improve in response to higher per capita incomes. However, this is not certain and there may be a period of further deterioration before income levels are sufficient to stimulate more expenditure on environmental improvement. Further study of this phenomenon, as it affects the Black Sea region, is clearly required.

Table 11.4. Selected Economic Data for the Black Sea Countries, 1995 to 2000 and 2001 to 2005.

Countries	GDP, Per Capita (US$ current prices)		GDP, Growth (% change/year)		Consumer Prices (% change/year)	
	Average 1995-2000	Average 2001-2005	Average 1995-2000	Average 2001-2005	Average 1995-2000	Average 2001-2005
Bulgaria	1471.72	2565.74	-0.6	4.9	213.0	5.3
Georgia	655.88	1018.96	5.3	7.3	39.3	5.8
Romania	1644.38	2927.60	0.2	5.7	62.8	18.6
Russia	2074.24	3387.92	0.8	6.1	65.7	14.9
Turkey	2947.62	3523.07	4.6	4.5	75.9	28.1
Ukraine	781.48	1171.70	-3.6	7.7	89.0	8.1

Sources: International Monetary Fund, World Economic Outlook Database, October 2007. Data and Statistics. http://www.imf.org/external/pubs/ft/weo/2007/02/weodata/ weoselgr.aspx. Accessed November 28, 2007.

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[4] The concept referred to is the Environmental Kuznets Curve (EKC), which postulates an inverted U-shape governing the environmental performance of countries in relation to their per capita income (Dasgupta et al. 2002). The "turning point" is typically in the range of incomes characterizing middle income countries, such as those in the Black Sea region.

Another factor driving economic growth and potential environmental change in the region is petroleum development. Asmus and Jackson (2004, p23) describe the situation concerning this sector of the regional economy as follows: "The wider Black Sea region straddles and indeed dominates the entire Euro-Asian energy corridor from trans-Ukrainian oil and gas pipelines running to the markets in Europe's north to the Baku-Tbilis-Ceyhan pipeline running to the Mediterranean. A new Euro-Atlantic strategy geared towards anchoring and stabilizing the region can potentially bring the vast energy reserves of the Caspian Basin and Central Asia to European markets on multiple, secure, and environmentally safe routes. Not only will these energy supplies secure the prosperity of a politically independent Europe for decades to come, but the construction and maintenance of these routes will provide an important economic stimulus to the economies that were left behind in the revolution of 1989."

It seems obvious that the possibilities for harmful impacts on the environment are substantial. Progress in ensuring this development does not harm the Black Sea will need to be monitored.

Finally, policy and institutional factors also play a role and can inhibit progress in addressing the problems of degradation (Fig. 11.1). For example, most living marine resources are not owned but shared, and therefore can be referred to as common property or "common pool" resources. There has been relatively little control of commercial harvesting of fish and other species -- thus, there is at best "regulated open access" to the resource and this results in over harvesting.[5] Use of the Black Sea and its tributaries for the disposal of wastes is free (un-priced) and so this ecosystem service is overused, imposing external costs on the commercial fisheries. Meanwhile, the diversion of water flows from tributaries for power generation or irrigation is done without taking account of their value in maintaining suitable fish habitat and salinity levels in the Black Sea; this is another example of an external cost. On the policy side, general public policy failures include an inadequate regulatory framework, poorly coordinated planning mechanisms and a lack of enforcement of existing laws and regulations. Finally, insufficient international coordination, given the transboundary nature of most living marine resource stocks, contributes further to the problem.

11.4. Consequences of Environmental Change in the Black Sea

The pressures cited above have led to changes in the environmental state of the Black sea marine system, but these are intermediate effects, as they have further impacts in social and economic terms. Impacts on the key sectors of fisheries and tourism are reviewed below, along with a brief overview of the impact of environmental conditions on human health. Sufficient information for other sectors to consider the environmental impacts of Black Sea degradation was not available.

11.4.1 Fisheries

One of the key industries of the Black Sea is its fisheries. Only five of the 26 commercial fish species once abundant in the Black Sea in 1970 remained commercially viable in the mid 1990s (Stanners and Bourdeau, 1995), a result of pollution and the

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[5] Exceptions include regulations governing aspects of fishing (e.g. mesh size, seasonal openings, etc.), but the enforceability and success of these measures is uncertain (Black Sea Commission, 2007).

introduction of non-native species, most notably the comb jelly *Mnemiopsis leidyi.* The Black Sea's fisheries, which supported approximately two million fishers and dependents, suffered almost total collapse (Mee, 1 992; Travis, 1993). Some rough estimates were made of the losses incurred by the Black Sea commercial fisheries during this period (Caddy 1992, Campbell 1993):

> Catch values from the mid 1980s to early 1990s declined by about US$240 million, using total Black Sea landings values of 900,000 t and 100,000 t, respectively, and a unit catch value of $300/t.
>
> Separate estimates for Turkey alone suggest even higher losses, totalling $300 million annually.
>
> Processing plant losses were roughly estimated at about $10 million for the 50 plants in the Black Sea region, on the basis of the costs of switching over to an alternative production line.
>
> Using the more extreme replacement cost approach, the estimate for Turkish processing plants alone suggests losses of $20 to 30 million.
>
> Up to 150,000 people were estimated to depend directly on the Black Sea fisheries. Income losses have been more difficult to estimate. Wages lost in processing plants alone totalled approximately $10 million annually.

The most comprehensive economic valuation of the decline in Black Sea fisheries is provided by Knowler (2005), who modeled nutrient-induced eutrophication and its impact on the commercial anchovy fishery in the Black Sea. While increasing nutrient loads reduced the quality of fish habitat for many benthic species (e.g. turbot), it had the reverse effect on anchovy, since these species are not much affected by algal blooms and other eutrophication-related events, and benefit from increased marine system productivity (Caddy et al. 1995). As a result, the role of nutrients as an environmental influence was modeled as a positive effect on anchovy recruitment. Complicating the picture was the shift in environmental conditions in the Black Sea in the mid 1980s due to the introduction of *Mnemiopsis leidyi.* Since *Mnemiopsis* preys on anchovy juveniles, this reduces the anchovy's potential stock size, offsetting the perceived benefits from increasing nutrient loads.

For this reason, two historical periods were modeled, a pre-*Mnemiopsis* period (1971-86) and a subsequent period with *Mnemiopsis* present (1987-93).[6] Just considering the prevailing nutrient conditions (with no abatement), Knowler (2005) estimated that the comb jelly reduced the profits available in the Black Sea anchovy fishery from over $17 million per year to under $300,000 per year, a decline of 98% (Table 11.5). Similarly, the sustainable harvest of anchovy declines from almost 400,000 t per year to only 40,000 t per year and the optimal number of industrial purse seine fishing vessels goes from 72 to 13. In contrast, the fishery had been characterized by hundreds of vessels historically, many of these vessels representing overcapitalization and leading to overexploitation.

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[6] A structural change approach was used to capture the shift between marine system regimes. Initially, the concentration of phosphates was set at 5.5 μM, its average value in the northwest shelf of the Black Sea during the period. A second set of solution values was based upon a hypothetical 50% reduction in the phosphate level (to 2.75 μM).

Table 11.5. Potential Long Run Profits in the Black Sea Anchovy Fishery for the Pre-Mnemiopsis and Mnemiopsis Periods (US$ thousands, 1989/90 prices)

Historical Period	No Pollution Control	50% Reduction in Phosphate	Welfare Change due to Pollution Abatement
Pre-Mnemiopsis (1971-86)	17,080	14,336	2744
With Mnemiopsi (1987-93)	290	138	152
Welfare Change due to Mnemiopsis	16,790	14,198	-

Source: Knowler, 2005

The long run economic welfare change induced by nutrient abatement was calculated as the difference in available profits earned with and without the change in environmental quality but allowing for separate effects from nutrient abatement and the introduction of *Mnemiopsis*. The resulting values calculated for both scenarios show that: (i) nutrient abatement would have actually reduced profits in the anchovy fishery, and that (ii) the impact would have been much greater during the period before *Mnemiopsis* entered the Black Sea (Table 11.5). With the establishment of the invader, the productivity of the anchovy stock declines so significantly (as do fishery profits) that the effect of nutrient abatement is relatively small.

The recent recovery in some Black Sea countries' fisheries through the early part of this decade indicate there may be hope for restoring the fisheries to some desired level (Table 11.6). Compared to maximum production figures for the 1972 - 1992 period (Stamatopoulos, 1995), only Georgia and Ukraine exceeded this performance in the 2001 - 2005 period. Other countries (especially Romania and Bulgaria) show much lower production more recently, while even resurgence in the Turkish Black Sea fishery still leaves the harvest at 100,000 t per year below the maximum attained in 1988.

Recovery in the fisheries will depend on management improvements that reduce the risk of further collapses in the future. Thus, the increases in harvest need to be sustainable and not just an expansion in national fishing fleets that generate illusory gains, only to be lost as environmental conditions change or stock dynamics respond negatively. Data on fishing fleets suggest a mixed experience across countries (Table 11.6). While Georgia and the Ukraine have managed to increase harvest with a significant reduction in their fleets, Bulgaria's performance is the reverse and is suggestive of worsening conditions.

Table 11.6. Fishery Statistics for the Black Sea during 1995-2000 and 2001-2005

Country	Total Catch (t)			Number of Vessels (> 12m)		
	1995-2000	2001-2005	% Change	1995-2000	2001-2005	% Change
Bulgaria	7743	6024	(22)	34	47	39
Georgia	4326	9468	119	35	31	(12)
Romania	3223	1964	(39)	12	9	(28)
Russia	6233	14148	127	26	26	0
Turkey	348636	374708	7	1048	1236	18
Ukraine	34955	48914	40	160	112	(30)
Total	405116	455225	12	1315	1461	11

Source: Black Sea Commission, 2007a

11.4.2 Tourism

Tourism in the Black Sea region is an important industry. It benefits from general trends in world tourism, that have seen global tourism receipts grow an average of 8% per year from 1980 to 2000, while world economic growth averaged 3% (Lanza et al. 2005). Nonetheless, even at the national level, tourism in the Black Sea countries involves a relatively small number of visitors and expenditures. For example, Bulgaria, Russia, Turkey and Ukraine (no data for Georgia and Romania) accounted for only 13.7% of international tourist arrivals in Europe in 2006. For receipts, the share is even smaller: the same four countries received only 8% of total European tourism receipts and only Turkey indicates a share of receipts greater than its share of international arrivals (4.1% and 4.5%, respectively).[7]

Tourism can be both a source of environmental impact as well as being highly sensitive to the effects of degradation. According to Rudneva (2003), over 4 million persons visit the Black Sea coastline in summer but by the 1990s this had declined, compared to the 1980s, particularly in Romania where amenity values deteriorated significantly due to pollution and eutrophication. Beaches and coastal tourism resources are apparently of higher quality in Russia, Ukraine and the Caucuses but the region struggles to attract international destination tourists: Brown (1996) indicates that only 8% of tourists using the Black Sea region are from abroad.

Despite the localized nature of Black Sea tourism, international tourism trends offer insights into the general situation. Recent international travel trends suggest some improvements in visitation, comparing international arrivals for the Black Sea countries in 2001-2005 with 1995-2000 (Table 11.7). However, it is difficult to know how well these national trends reflect the experience in the Black Sea region and to what extent changes in environmental quality may be an influence. The improving trend is most noticeable in Bulgaria and Ukraine, where large increases in arrivals and receipts are noted for the more recent period (2001-2005). The increasing fortunes of tourism in these countries is demonstrated by the large rise in the share of exports attributable to tourism in 2001-2005, compared to 1995-2000, with as much as a doubling in the case of Ukraine (Table 11.7).

Table 11.7. General Tourism Statistics for Black Sea Countries

Country	**Number of Arrivals (thousands)**		**Receipts (millions current US$)**		**Receipts (% of total exports)**	
	Average 1995-2000	Average 2001-2005	Average 1995-2000	Average 2001-2005	Average 1995-2000	Average 2001-2005
Bulgaria	2860.8	4026.8	903.0	2105.6	14.3	19.0
Georgia	267.2	368.2	135.5	189.8	21.9	14.2
Romania	3031.8	n.a.	502.2	651.8	5.1	2.9
Russia	2016689.7	22338.0	n.a.	6078.8	n.a.	3.7
Turkey	298254.7	14802.6	n.a.	n.a.	n.a.	n.a.
Ukraine	785333.2	11958.5	506.0	1887.4	2.7	5.4

Source: World Bank. World Development Indicators 2007. Accessed at:
http://ddp-ext.worldbank.org/ext/DDPQQ/showReport.do?method=showReport

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[7] Tourism data presented here is from the World Tourism organization website, http://www.unwto.org/facts/menu.html. Accessed December 17, 2007.

Assessing the impacts of environmental degradation on tourism requires studying tourists' attitudes towards possible improvements in environmental quality. Brown (1996) used this approach to determine how tourist visitation would change given fixed improvements in environmental quality in the Black Sea. He used the travel cost technique and pilot studies in Romania to generate values for the entire Black Sea region (Table 11.8). Tourists were asked whether they would still visit the region given prescribed changes in environmental quality (5%, 10% and 20%) and this information was then used to project changes in visitation and the value of gains/losses in consumer welfare associated with these changes, measured as changes in consumers' surplus.[8]

Tourists responding to the survey interpreted environmental quality with respect to "debris in the water, poor water clarity, oil in the water and on beaches and other dimensions" (Brown, 1996, p15). Using 1995 visitation and expenditure as a baseline, the annual aggregate willingness to pay for a 5% improvement in environmental quality was $314 million per year (1995 prices). This contrasts with a willingness to pay of $551 million per year for a 20% improvement in environmental quality (Table 11.8).

Table 11.8. Estimated Annual Loss of Tourism Value from Environmental Deterioration of the Black Sea in the Mid-1990s

Country	Baseline Values		Estimated Value of Quality Change		
	Visitors (number)	Estimated value (1995 $millions)	5% improvement	10% improvement	20% improvement
Bulgaria	800	48	12	14	21
Georgia	250	15	4	4	7
Romania	870	52	13	15	23
Russia	12500	750	188	218	330
Turkey	2200	132	33	38	58
Ukraine	4250	255	64	74	112
Total	20870	1852	314	363	551

Source: Brown, 1996

While conditions have changed somewhat since this study was done, it is likely that the basic conclusions and order of magnitude estimates remain the same. One continuing cause for concern is the presence of large amounts of marine litter. In a recent study of marine litter from the Black Sea Commission high levels of marine litter (ML) on recreational beaches were noted (Black Sea Commission 2007b, p10): "Great numerical predominance of plastic ML (80-98%) has been determined in comparison with glass ML (2-20%) on the wild (unmanageable) beaches of Crimea, Ukraine, during different seasons. The density of beachfront pollution by polymeric garbage varied from 333 to 6,250 *kg/km*^{2}, while the density of glass ML fluctuated between 222 and 1,455 *kg/km*^{2}. The concentration of ML collected in different places of the Turkish Black Sea coast varied from 58 to 1,395 *kg* per linear kilometer of the coastline... According to interview data, most visitors of Bulgarian beaches (up to 90%) appreciated local

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[8] Consumers' surplus represents is estimated as the difference between what one must pay for a good or service and what one would be willing to pay.

climatic conditions but did not like rubbish on the coast. The opinion of holiday-makers was that ML strongly (or very strongly) affects quality of a beach."

Clearly, more needs to be done to improve environmental conditions for Black Sea tourism. If these improvements are made, then the opportunities to provide substantial gains to consumer welfare surely exist. Domestic tourism participation is closely tied to economic conditions so that rising incomes will be important as well. A generally increasing global trend in tourist activity will help.

11.4.3 Health

According to Rudneva (2003), the most important health-related effects of marine degradation are the presence of microorganisms from infected sea water, contact with polluted sea water or beach sand, and consumption of contaminated seafood. In an earlier World Bank cost-benefit study (World Bank n.d.), the main health threats in the Black Sea region were assessed for three locations according to whether they were of a continuous or incidental nature (Table 11.9). Extremely high to large risks were common. In recent decades, the Black Sea countries have experienced several incidents of cholera, *E. coli* outbreaks, hepatitis A and enterovirus infections. Most such problems stem from direct effluent discharges to the Black Sea near urban areas and beaches or from bioaccumulation of toxics within fish and mollusks harvested for human use.

Progress in addressing the problem of human health impacts has been made since the identification of waste water treatment hot spots in the original 1996 transboundary diagnostic analysis. As part of the investment program initiated since 1996 a number of waste water treatment plants have been funded and contamination problems are considered resolved at these sites. However, the number is not large. Of the 34 municipal hot spots identified in the 1996 Transboundary Diagnostic Analysis, upgrades on only 8 have been completed (Tsarevo, Constanta Nord/Sud, Eforie Sud, Mangalia, Gelendzhik, Dzoubga and Pivdenni), while work continues at several additional sites (Black Sea Commission, 2007a). Thus, there is still some progress to be made in addressing this critical environmental problem.

11.5. Sustainability: Progress and Prospects

In this section, we examine general progress towards sustainability in the six Black Sea countries using new indicators of sustainable economic welfare. Conventional indicators of socio-economic progress neglect the progress of countries towards attaining sustainability. Various indicators of sustainability are available to correct this shortcoming but most concern ecological status or are not appropriate at the national level (Bell and Morse 1999). The most appropriate for comparing the performance of whole national economics is the Adjusted Net Savings concept (or Genuine Saving), developed by the World Bank.[9] This sustainability indicator is related to green national accounts by using national accounts data to measure the true savings in an economy. It

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[9] Accessed on November 27, 2007 at www.worldbank.org.

takes account of investments in human capital, depletion of natural resources and damage caused by pollution via several adjustments to gross savings in the country:

Table 11.9. Degree of Health Risk Associated with Various Aspects of Black Sea Pollution

Nature of Pollutant	Health Threat	Continuous Risk			Incidental Risk		
		Istanbul	Odessa	Bourgas	Istanbul	Odessa	Bourgas
Discharges from harbours and ships	Allergic reactions	extremely high	extremely high	extremely high	extremely high	extremely high	extremely high
Industrial chemical discharges	Skin and outer mucosa diseases	large to very large	extremely high	substantial	Very large	extremely large	substantial
Industrial Organic Discharges	Allergic reactions	extremely high	extremely high	large	extremely high	extremely high	large
Toxic Industrial Chemical Discharges	Life threatening	insignif.	very small	insignif.	Small	large	small
	Contaminated Seafood	extremely high	large	average	Large	substantial	very small
Municipal Sewage	Typhoid fever, dysentery, cholera	extremely high	extremely high	large	large	large	small
	Contaminated Seafood	extremely high	large	average	large	substantial	very small
Agricultural chemicals	Allergic skin diseases	average	very high	average			

Source : World Bank, 2000. The threat levels are ordered in the following manner:

extremely high > very large > large > substantial> average > small >very small > insignificant.

Depreciation of manufactured capital is deducted to yield net national savings.

Current education expenditures are added to net domestic savings to capture investment in human capital.

Depletion of natural resources is deducted to capture the reduction in asset values resulting from extraction or harvest. The measure of depletion is taken as foregone natural resource rents.[10]

Residual pollution damages are deducted as measured by estimated health damages due to urban air pollution.

If adjusted net savings are negative, then the country's total wealth is falling (see http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/ENVIRONMENT/EXTEEI/0,contentMDK:20487828~menuPK:1187788~pagePK:148956~piPK:216618~theSitePK:408050,00.html). Policies resulting in consistently positive adjusted net savings suggest the country is on a path towards sustainability.

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10 The World Bank website states that: "An economic rent represents the excess return to a given factor of production. Rents are derived by taking the difference between world prices and the average unit extraction or harvest costs (including a 'normal' return on capital)".

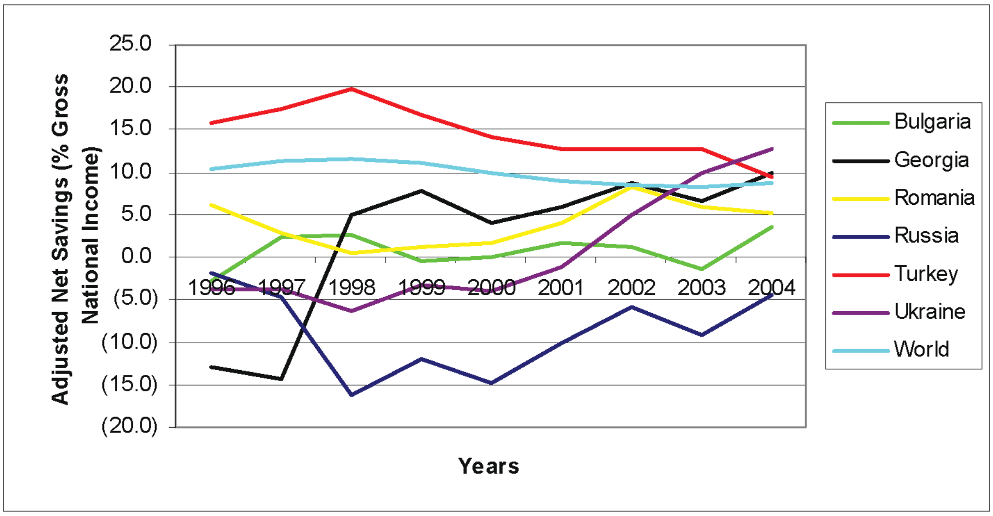

Fig. 11.3. Sustainability Indicators: Adjusted Net Saving in the Six Black Sea Countries, 1996 - 2004. Data source: World Bank website (accessed November 27, 2007) at http://web.worldbank.org

For the Black Sea countries the picture is one of widely divergent performance on sustainability during the years 1996 - 2000 (Fig. 11.3). Most countries showed a more-or-less constant trend but at quite different levels, while two performed more erratically. Russia indicates a dramatic downturn in sustainability after 1997, mostly due to an increase in energy resource depletion. Conversely, Georgia shows a dramatic increase in sustainability at the same time, resulting from an increase in gross savings and reductions in fixed capital depreciation and particulate matter pollution. Throughout the period, all countries show substantially lower adjusted net savings than the World average, except for Turkey (Fig. 11.3).

In the subsequent period from 2001 - 2004 there is a general converging trend in the sustainability performance of the Black Sea countries (Fig. 11.3). The strongest performers are Russia and the Ukraine, while Turkey's adjusted net savings decline gradually. For the former two countries, the improvement stems from higher gross savings and lower depreciation of fixed assets. It is of interest that the Black Sea countries seem to be converging around the World average performance.

11.6. Conclusions

The D-P-S-I-R model clearly suggested some progress on socio-economic dimensions of environmental improvement in the 2001-2005 period that may, in part, be tied to enhanced economic fortunes. More stable and prosperous economies are liable to (eventually) lead to improving environmental conditions. There is certainly some evidence that the Black Sea countries are converging on a path towards sustainability (as measured by net adjusted savings). On the other hand, there is more progress to be made: achievements in addressing hot spot investments to eradicate water quality problems have been modest and more is required if threats to human health are to be reduced.

An important element in making further progress is the development of a set of indicators that can measure achievements on social and economic issues. While developing a full set of appropriate indicators would be a substantive undertaking, and one that is not possible here, Table 11.10 provides a preliminary list of possible indicators as a starting point. These suggested indicators include some for which the data may exist now (e.g. national gross domestic product, international tourist arrivals, net adjusted savings), it also contains some for which data may be sparse or non-existent at present (e.g. marine fish stocks, coastal zone population density). Many of the latter are the more detailed indicators that reflect localized conditions within the coastal zone of the Black Sea countries. Thus, a concerted effort with the requisite funding will be required to make progress in this area.

Table 11.10. Preliminary Socio-economic Indicators for the Black Sea

Type of indicator	Indicators	Units
Population and Demographics	- Administrative units in coastal zone (cities, localities, villages, etc)	no.
	- Population, country and coastal zone	thousands pers.
	[Note: its useful to have country and coastal zone to place latter in national/comparative perspective]	
	- Population density, country and coastal zone	inhabitant/km2
	- Population growth, country and coastal zone	%
	- Net migration rate, country at least	%
Economic	- Land use change in coastal zone [by land use type]	%
	- Average monthly earnings, national	Euro/month
	- Fishing catch [by species]	t/year
	- Marine fish stocks [rare to find this]	t
	- Gross domestic product, national and regional	Thou Euro
	- Sectoral distribution of GDP	%
	- Changes in value of ecosystem services	Thou Euro
	- Changes in value of natural capital	Thou Euro
Social and Health	- Population with access to clean water	%
	- Population connected to WWTP	%
	- Unemployment rate, national	%
Transport	- Density of the public road network, coastal zone	km/km2
	- Number of airports, coastal zone	no.
	- Length of railways, coastal zone	km
	- No. of harbours	no.
	- Total harbour area	ha
	- Harbour traffic capacity	mil/tons/year
Tourism	- Touristic accommodation units in coastal zone	bed units
	- Number of tourist arrivals	no/year
	- Number of tourist overnight stays	bed-nights
	- Value of tourist expenditures	Thou Euro
Public Awareness and Sustainability	- Number of environmental NGO's	No.
	- Net Adjusted (Genuine) Savings indicator (World Bank)	
	- Ecological Footprint & related (Global Footprint Network, Moran et al. 2008)	

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CHAPTER 12 OVERALL ASSESSMENT OF THE PRESENT STATE OF BLACK SEA ECOSYSTEM (T. Oguz et al.)

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12.1. Introduction

During the last three decades eutrophication has been identified as a key ecological problem for the coastal Black Sea regions and especially for its northwestern part where strong anthropogenic nutrient and pollution loads resulted in dramatic alterations in chemical and biological regimes. Eutrophication refers to undesirable disturbances in ecosystem functioning due to anthropogenic enrichment by nutrients and subsequent accelerated growth of algae and higher life forms. Rapidly intensifying eutrophication in the 1970s and 1980s transformed the formally diverse ecosystem with a rich variety of marine life into a degraded system with marked changes in composition and abundance at species level, and species communities and their interactions at the ecosystem level. A schematic of the transformations in the ecosystem level is depicted in Fig. 12.1.

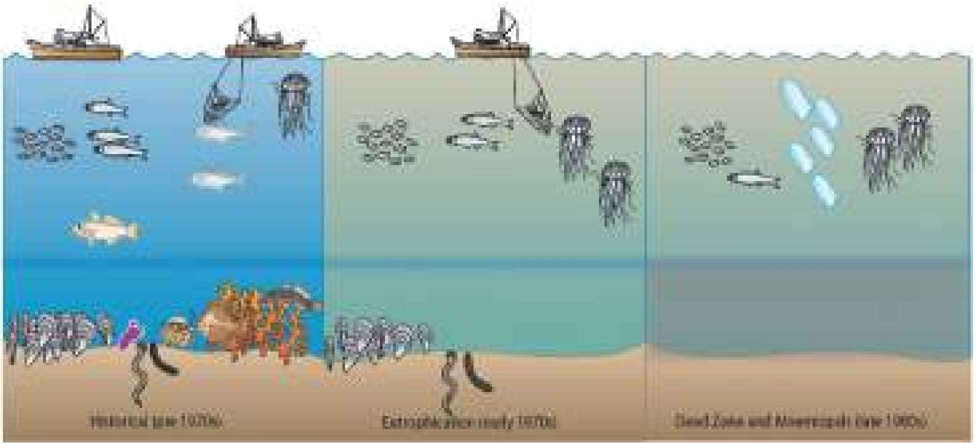

Fig. 12.1. Schematic representation of the Black Sea pelagic and benthic ecosystem transformations along the Black Sea western coast (after Friedrich *et al.,* 2006).

In addition to eutrophication, other high priority transboundary ecological problems are the decline in living resources (mostly fish stocks), chemical pollution, biodiversity change, habitat destruction, alien species invasions, climate-change impacts, and mesoscale variability of the circulation system (TDA, 2007). The present chapter provides an overview of overall assessment for the status of the Black Sea ecosystem and its likely trends of evolution since the implementation of the Black Sea Strategic Plan started with particular emphasis given to 2001-2005. First, the recent state of eutrophication in coastal and shelf waters is assessed in terms of nutrient enrichment levels, limiting nutrients in different water regimes, chlorophyll and dissolved oxygen concentrations. Then, the contribution of chemical pollution is evaluated. It is followed by an assessment of the pelagic and benthic systems and marine living resources. The assessment mainly focuses on the western coastal zone that has been subject to worst environmental degradation with respect to other coastal regions and but it is compared with the interior basin wherever appropriate. Modulation of the ecosystem properties by climate-induced changes is also highlighted.

12.2. Mesoscale variability of the circulation system

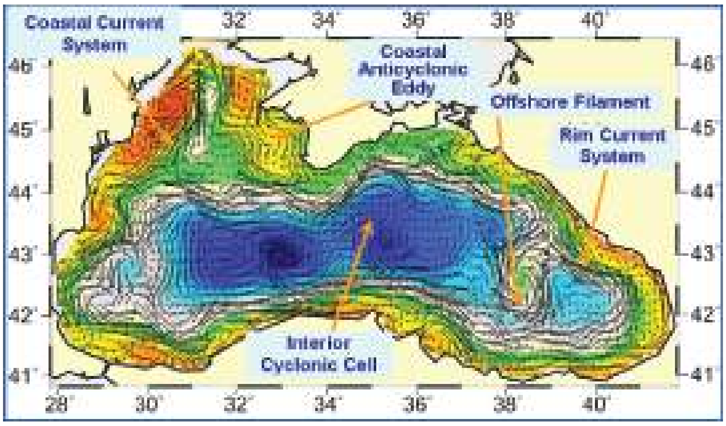

Fig. 12.2. A typical structure of the upper layer circulation field deduced from a circulation model using assimilation of altimeter sea level anomaly data. (after Korotaev *et al.,* 2003).

Primary feature of the Black Sea circulation system is highly dynamic structural organization of the interior cyclonic cell and the Rim Current. The latter flows along abruptly varying continental slope and margin topography around the basin, whereas the interior circulation, formed by several sub-basin scale cyclonic gyres and eddies, evolve continuously due to interactions among these eddies and meanders and filaments of the Rim Current (Fig. 12. 2). Coastal side of the Rim Current comprises a series of recurrent anticyclones. The overall basin circulation is primarily driven by the curl of wind stress throughout the year and further modulated by seasonal evolution of the surface thermohaline fluxes and mesoscale features arising from the basin's internal dynamics. In addition, fresh water discharge from the Danube and other northwestern rivers contributes to buoyancy-driven component of the basin-wide circulation system. Eddies, meanders, filaments, offshore jets of the Rim Current often introduces strong shelf-deep basin exchanges and two-way transports of biota and chemicals between near-shore and offshore regions.

Flow structure in the northwestern shelf is driven by spreading of the Danube outflow under temporally varying wind forcing. The Danube plume can spread northward or southward along the coast, or is expanded offshore depending on winds, internal dynamics, and initial vorticity of the plume. Southerly winds cause upwelling along the Romanian - Bulgarian coast bringing nutrient-rich deep sea waters into the surface layer and promote biological production. On the other hand, northerly winds trap the freshwater plume along the coast and the southward thin boundary current is separated from offshore waters by a well-defined front (Fig. 12.3a) which sometime displays unstable features, exhibits meanders, extends across the wide topographic slope zone and spawns filaments (Fig. 12.3b).

A branch of the Rim current may occasionally protrude into the NWS through outer branch of the Sevastopol eddy and modulates the shelf circulation system. In the case of alternative upstream deflection of the Danube outflow, the southward coastal current system weakens or may totally loose its identity. The river plume may then occasionally be trapped by the anticyclonic Danube eddy that covers the region between Odessa and Constanta (Fig. 12.3b). Other features of the western coastal flow system are the recurrent Kaliakra and Bosporus anticyclones (Fig. 12.2).

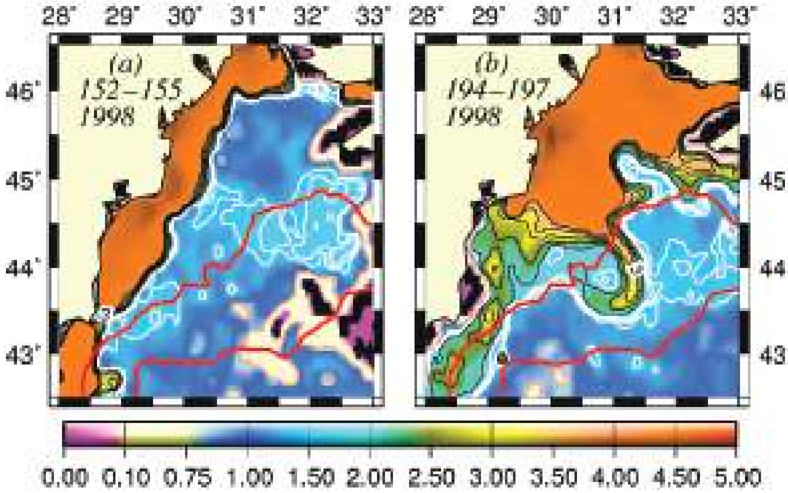

Fig. 12.3. SeaWiFS chlorophyll distributions showing two alternative forms of circulation structure in the northwestern shelf; (a) a southward coastal current system during days 152-155 (early June) and (b) a closed circulation system confined into its northern sector during days 194-197 (mid-July), 1998 (after Oguz *et al.,* 2002).

12.3. Climatic regulation of the Black Sea

The Black Sea ecosystem transformations in the 1980-1990s were accompanied with strong decadal scale climatic perturbations. These climatic changes modulated the ecosystem properties concomitantly with the anthropogenic impacts. As shown in Fig. 12.4 (blue curve), amplitude of decadal-scale fluctuations in the annual-mean basin-averaged SST anomaly since the beginning of 1960s was around 1.0 °C. They were locally even more pronounced as, for example, recorded by about 4°C changes in Galata monitoring site along the Bulgarian coast (Fig. 12.4, red curve). These decadal variations were an order of magnitude greater than the global SST changes of ~0.25°C for 1930-2005 (Fig. 12.4, green curve).

The annual-mean SST variations indicate a succession of decadal-scale cooling-warming cycles on the order of 1.0oC. The period 1937-1957 was characterized by 0.9 °C cooling followed by 1.0 °C warming during 1957-1978, and subsequently two concomitant cooling and warming cycles of ~1.5°C during 1978-1993 and 1993-2002. The system switched to the cooling cycle during 2002-2005. The switch to the warming phase in the

1990s occurred in the western coast as early as 1988 whereas it was disrupted by the 1997-1998 short-term cooling events. The strong warming trend in 1993-2002 brought the annual-mean sea surface temperature to the level in the mid-1960s.

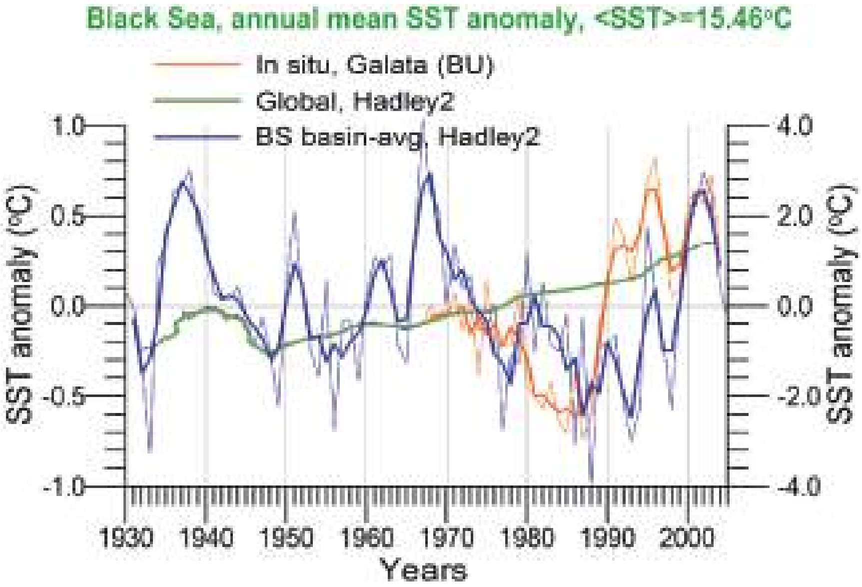

Fig. 12.4. Annual-mean sea surface temperature (SST) anomaly changes obtained by *in situ* measurements at 3 nm offshore of Cape Galata (Bulgaria, after Kamburska *et al.,* 2006; right axis, in red colour) and the basin averaging (left axis, in blue colour) of the Hadley-2 data, and their comparison with the globally-averaged SST fluctuations based on Hadley-2 data (in green; left axis). The Hadley-2 data is described by Rayner *et al.* (2003). All data show both the unsmoothed and smoothed (by three-year moving averaging) variations.

The North Atlantic Oscillation (NAO) and the East Atlantic-West Russia (EAWR) climatic indices relate the regional hydro-meteorological properties (such as the air and sea surface temperature and surface atmospheric pressure fields) to the surface pressure differences between the anomaly centres over the North Atlantic and the Eurasia. In general, a mild winter climatic cycle is characterized by relatively high sea surface and air temperatures, higher surface atmospheric pressures, and is correlated with decreasing trends of the NAO and EAWR indices and vice versa for the case of a severe winter climatic cycle. The intimate relationship between the local climate and hemispherical atmospheric motions is evident in Fig. 12.5 by the association of 1981-1993 cooling cycle with increasing trends of both the NAO and EAWR indices. The subsequent warming cycle is explained by decreasing mode of both the NAO and EAWR indices up to 2002, after which neither the NAO nor the EAWR climate index explain well the Black Sea SST variations.

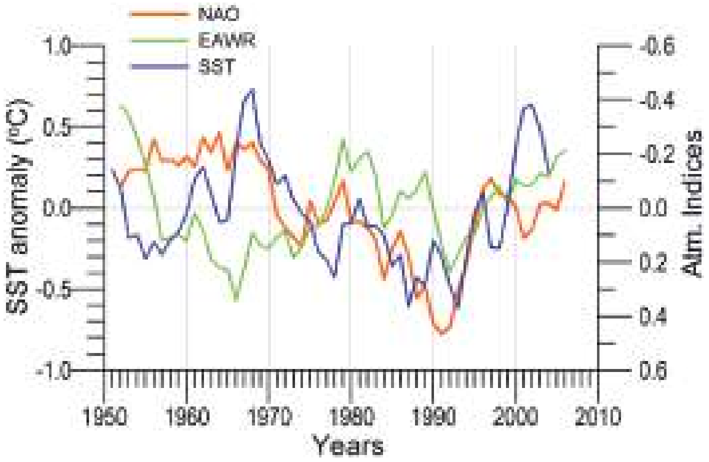

Fig. 12.5. The changes of annual-mean, basin-averaged sea surface temperature (SST) anomaly and the North Atlantic Oscillation and the East Atlantic-West Russia climate indices.

The SST changes are based on the Hadley-2 data set (Rayner *et al.,* 2003), the atmospheric indices are retrieved from NOAA Climate Prediction Centre data base; http://www.cpc.ncep.noaa.gov/ data/teledoc/telecontents.shtml). All data were smoothed by three-year moving averaging.

12.4. Eutrophication/Nutrient enrichment

River nutrient loads: Following the early 1990s, economical recession in the former eastern block countries indirectly resulted in closure of ecologically ineffective large animal farms (agricultural sources) and of nutrient discharging (e.g. fertilizer) industries. Phosphate content was also reduced in detergents, and nutrient removal from waste water was improved in the countries along the Danube River. Consequently, according to measurements at Reni located 34 km upstream of the Danube delta, the total P-load (TP) experienced a strong reduction from ~60 to 20-30 kt y^{-1} at the beginning of 1990s and dropped below 20 kt y^{-1} afterwards as in the case of the 1960's. The dissolved inorganic nitrogen (DIN) load, measured at Reni, remained around 400 kt y^{-1} since the beginning of 1990s without any sign of reduction.

Complementary measurements near the mouth of Sulina branch of the Danube River indicated a major reduction of the DIN load from ~700 kt y^{-1} during the late 1980s to 100 kt y^{-1} in the present decade (Fig. 12.6). 90% of this DIN load was contributed by N-NO_3. A roughly three-fold difference between the Reni and Sulina DIN flux estimations may arise due to methodological differences in the measurement techniques, high nutrient uptake in primary production in the Danube delta region as well as mixing and dilution associated with estuarine-type river-sea water interactions. Alternatively, a likely cause of higher DIN flux at Reni may be continuing emissions accumulated in soil stocks in the Danube catchment basin which continue to support high nitrogen load through ground-water emissions. Whatever the cause and the rate of reduction, their 2000-2005 average value was still roughly twice higher than the pristine level prior to the 1960s. The difference in the PO_4 load between Reni and Sulina is small and not critical as in the case of DIN. The SiO_4 flux at Sulina reveals an opposite trend; it decreased from 500 kt y^{-1}

to 100 kt y^{-1} during the 1980s but increased steadily afterwards up to 500 kt y^{-1} in 2005 again contrary to considerable silicate retention and decrease in Danube sediment load in response to the construction of reservoirs along the main river and its tributaries after the 1960s (Humborg et al., 1997). As described below, these trends may be related to the changes in phytoplankton bloom intensity and community structure.

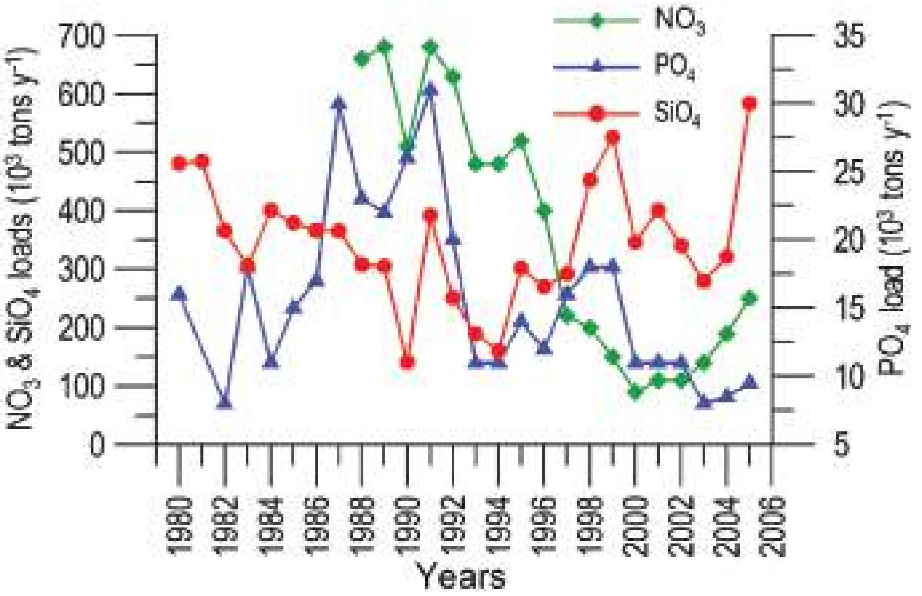

Fig. 12.6. River Danube annual dissolved inorganic nitrogen (DIN), phosphate (P-PO4) and silicate (SiO4) loads into the Black Sea based on the measurements conducted at Sulina. The data are taken from Cociasu *et al.* (2008).

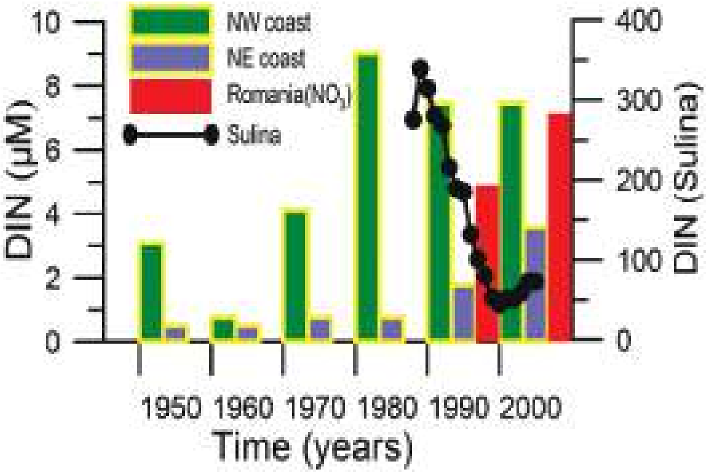

Fig. 12.7a. Decadally-averaged changes of surface dissolved inorganic nitrogen (DIN) concentration along the western and eastern coastal waters of the NWS as well as surface N-NO3 concentration in the Romanian shelf (red bars) and the Sulina exit of the River Danube solid dots). The data except at Sulina are amalgamated from several stations.

Nutrient concentrations: During the present decade, DIN concentration along the northwestern and northeastern coasts of the NWS as well as along the Romanian shelf experienced locally either a rising trend or maintained its level in the 1980s-1990s (Fig. 12.7a). Existence of N-NH$_4$ concentration comparable to N-NO$_3$ indicates high emissions from local point sources along the Romanian and Ukrainian coasts of the NWS. DIN concentration at Sulina varying around 50-70 µM during 2000-2005 was still high although it was declined from 350 µM level during the 1990s (Fig. 12.7a). Dissolved organic compounds constituted an important nutrient source for the NWS. Monthly DON and DOP measurements at Sulina discharge point during 2004-2005 suggested DON changes from the range of 60-120 µM during autumn, winter and early spring seasons to 20 µM in summer and DOP changes from 4-5 µM to 1 µM (Cociasu et al., 2008). The northwestern coastal waters of the Ukrainian sector were persistently characterized by high DON concentrations that increased from the decadal-mean value 25 µM in the 1980s to 40 µM in the 1990s and the present decade (Fig. 12.7b). Consequently, the western coastal waters presently continue to suffer from both dissolved inorganic and organic nitrogen enrichment and they do not show an apparent status of improvement during the last 10 years. DIN and P-PO_4 concentration levels along other coasts (southern, northeastern and northern) were found to be 3-4 times lower than the western coast. The interior basin water column nitrogen structure responded to the decline in the anthropogenic DIN load by reducing peak subsurface nitrate concentration below 6 µM in the 1990s and below 5 µM in the present decade (Fig. 12.8).

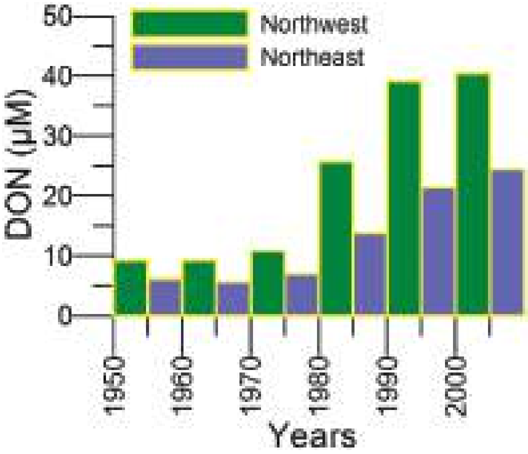

Fig. 12.7b. Decadally-averaged changes of surface dissolved nitrogen (DON) concentration along the western and eastern coastal waters of the NWS.

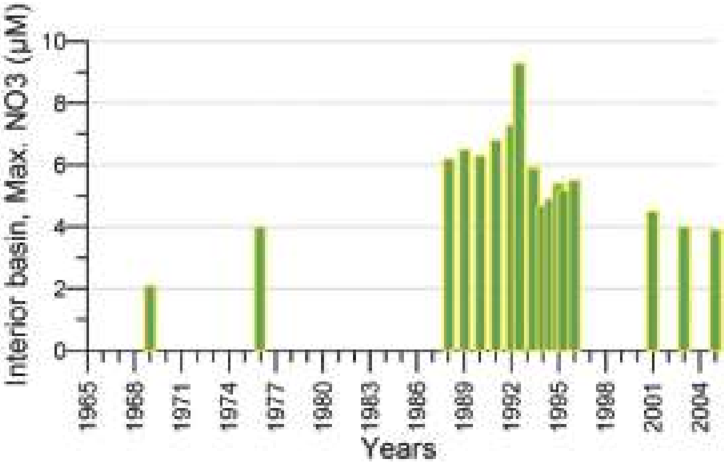

Fig. 12.8. Temporal variations of the subsurface peak nitrate concentration within the interior basin.

Available data suggest regionally and seasonally varying limiting nutrient conditions along the western shelf waters. In general terms, brackish coastal waters with salinity lower than 17 psu, most influenced by the river discharges, are predominantly P-limited as, for example, reported for the Sulina and Constanta measurement sites due to continuing high nitrogen enrichment. On the other hand, the amalgamated data formed by the N-NO_3 and P-PO_4 measurements in the Romanian and Ukrainian inner and outer shelf waters show weak N or P limitation (Fig. 12.9) whereas the interior basin is strongly N-limited system. The data also suggest an increasing Si limitation along the western coastal waters due to high N-NO_3 concentrations relative to SiO_4.

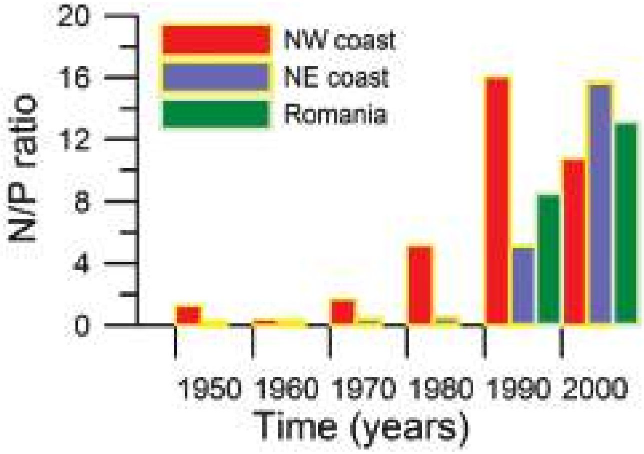

Fig. 12.9. Decadally-averaged changes of N-NO_3/P-PO_4 ratios in the Ukrainian and Romanian shelf based on the amalgamated data (see Chapter 2 of this report).

Chlorophyll concentration: According to the satellite ocean color data (Fig. 12.10), annual-mean surface chlorophyll concentration in 1998-2007 possesses three-fold higher values in the northwestern region (~3 mg m^{-3}) with respect to the western interior basin (~1 mg m^{-3}). Moreover, in-situ summer chlorophyll-a measurements near the Zmeiny Island reveal summer mean surface Chl-a concentration around 1.0-2.0 mg m^{-3} (Table 12.1) which are at least twice lower than the mean value of 4.5 mg m^{-3} for 1980-1995 (Kovalova et al., 2008), therefore supporting a decrease in primary production during the present decade. However, high chlorophyll values up to ~25 mg m^{-3} are still observed temporarily in spring-summer months. In the subsurface layer, summer mean Chl-a concentration is roughly half of the values measured in the surface mixed layer (Table 12.1). Highest monthly-mean surface chlorophyll concentrations around 2-3 mg m^{-3} are observed during April-June. The secondary maximum of 2 mg m^{-3} arises in October-November following the minimum concentration about 1 mg m^{-3} in August. Thereafter, Chl-a concentration rises from 1 mg m^{-3} in January up to 3 mg m^{-3} in April. The corresponding monthly-mean chlorophyll concentration variations provided by the SeaWiFS ocean colour data for the NWS shelf (Fig. 12.10) attains an increasing trend from 2.0 mg m^{-3} in March to 4.0 mg m^{-3} in July. Equally high peak concentrations also arise in November. The satellite data however do not show a well-defined spring peak as in the case of the Zmeiny island data.

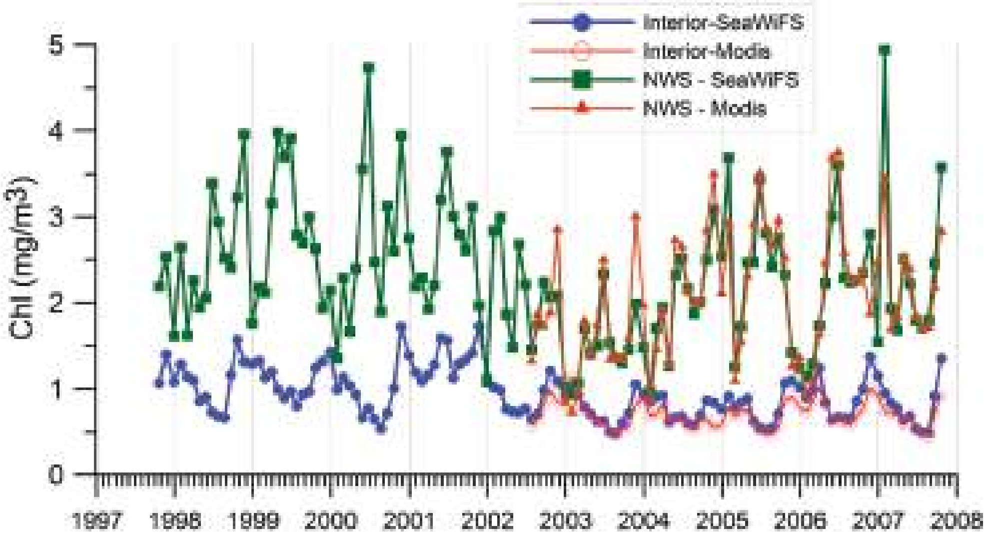

Figure 12.10. Average surface chlorophyll concentration for the northwestern shelf and the interior basin obtained from 8-daily 9 km resolution SeaWiFS and Modis ocean colour products after the original data is smoothed by 5 point moving average.

Table 12.1. Ranges and average values of Chl-a concentration (mg m^{-3}) near the Zmeiny Island of the northwestern shelf during summer months of 2003-2007 (after Kovalova et al., 2008).

	Surface Layer		Bottom Layer	
	Range	Average	Range	Average
V-IX 2003	0.28-7.75	1.25	0.25-1.26	0.76
VI-XI 2004	0.22-12.02	2.41	0.26-5.72	1.48
IV-XI 2005	0.19-28.03	2.90	0.18-2.93	1.03
IV-XI 2006	0.13-7.29	1.53	0.13-5.55	0.75
IV-XI 2007	0.13-16.80	1.33	0.15-1.44	0.78

The interior basin depicts a different annual chlorophyll structure (Fig. 12.10). Surface chlorophyll concentration decreases linearly from a peak in November (1.5 mg m^{-3} as an average of 1998-2007) to a minimum in July (0.75 mg m^{-3}), followed by an increase from August to November again. A weak chlorophyll peak may occasionally exist in spring. This structure implies that the phytoplankton production initiates in September, gradually intensifies and spreads over the basin in October, and finally reaches a basin-wide bloom stage in November. The autumn bloom episode generally terminates in January and is followed by a continuous decreasing trend during winter and spring months. The strong chlorophyll signal in February or March, which was the most robust feature of the annual structure in the 1980s, appears as a slight increase in concentrations by about 0.1-0.2 mg m^{-3} either in January or February, except no peak in 2002 and its shift to spring in 2001.

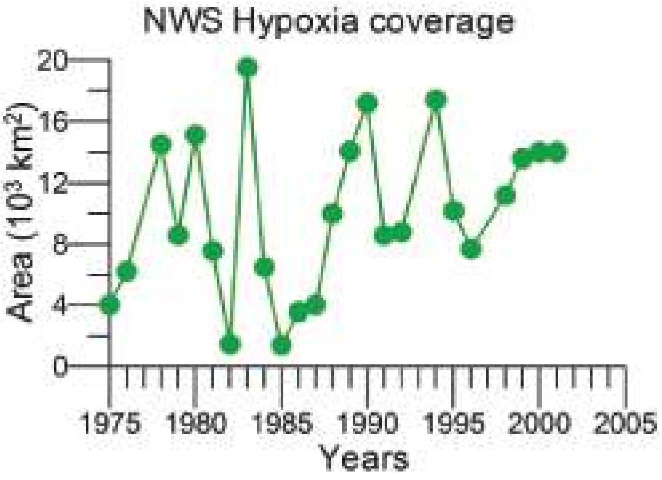

Fig.12.11. Long-term variations of spatial coverage of hypoxia in northwestern coastal waters. The data are taken from the Ukrainian National Reports, UkrNCEM.

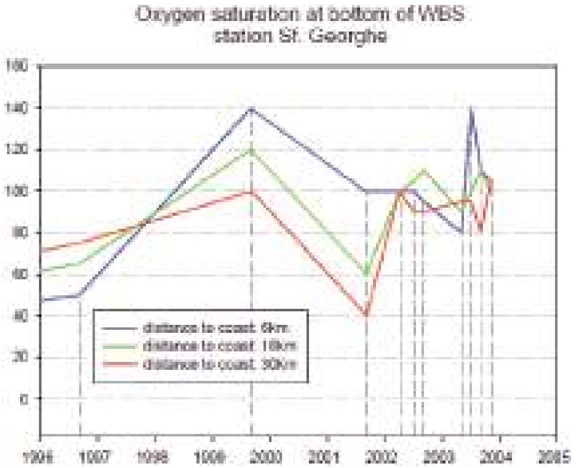

Fig. 12.12. Changes in summer oxygen saturation values of bottom waters at three locations along the Sf. Georghe transect immediately to the south of Danube discharge zone (after GEF-UNDP Project Report, 2006).

Hypoxia coverage: According to the data shown in Fig. 12.11, the Ukrainian sector of northwestern shelf continued to experience successive large scale hypoxia shocks (> 10,000 km^2) once every few years. Although no published data are available after 2001, the hypoxic areas were reported to decrease in the present decade except some short-term events in localized shallow regions upstream and downstream sides of the Danube delta region (e.g. summer 2005). No hypoxia was reported in Bulgarian waters as well as national waters of other Black Sea states. Fig. 12.12 displays the summer 2001hypoxia event in terms of variations of oxygen saturation values at different locations off the Sf. Georghe transect.

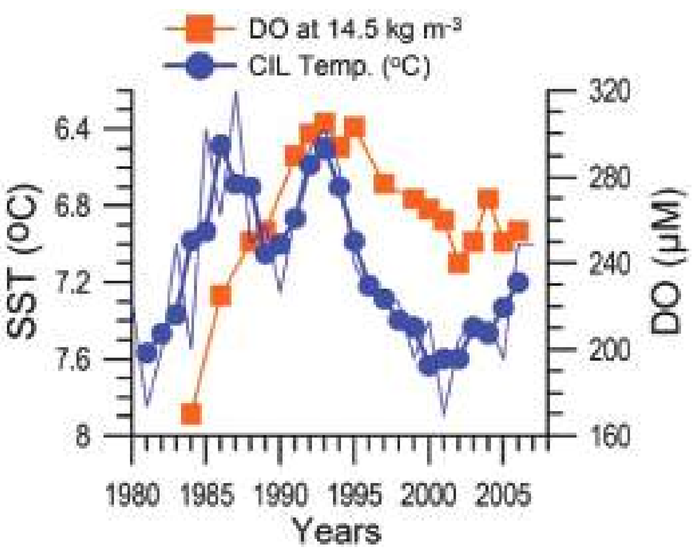

Fig. 12.13. Long-term variations of winter dissolved oxygen concentration within the layer of density surfaces σt ~14.45-14.6 kg m^{-3} in the offshore region the eastern coastal waters during 1984-2004 and summer-autumn mean CIL temperature of the interior basin. The oxygen data are provided by Yakushev *et al.* (2008).

Subsurface oxygen concentration in the interior basin: The level of sub-surface oxygen concentration in the deep region of eastern basin provides an independent assessment for the present state of basin-scale eutrophication. The long-term data of winter dissolved oxygen concentration within the layer of σt ~14.45-14.6 kg m^{-3} density surfaces (i.e. immediately below the euphotic zone) in the offshore region of the eastern basin during 1984-2004 reveal an increasing trend from 170 µM at 1984 to 300 µM during the early 1990s, and a reverse trend during the 1990s with the values varying in the 240-270 µM range during the present decade (Fig. 12.13). Lower values in the present decade with respect to the early 1990s can however be hardly explained by higher rate of oxygen utilization during the remineralization of organic matter provided the fact that the present decade is known to be less eutrophic and hence less productive than the 1980s. This structure therefore contradicts with a priori expectation from the eutrophication perspective. A more likely explanation is the degree of ventilation from the surface in response to climatic changes. The former process (i.e. the oxygen utilization) is particularly important during the warm and more productive period of the year and causes oxygen depletion whereas the latter (i.e. the surface ventilation) contributes to its enrichment in winter months. In the case of higher rate of ventilation, more oxygen stored within the oxycline reduces the rate of oxygen depletion in subsequent months and thus support more favourable oxygen conditions during summer months. This link is shown in Fig. 12.14 using the summer-autumn CIL temperature as a proxy variable of climatic changes. The decadal trend of increase of subsurface oxygen coincides with the cold climate period associated with higher rate of atmospheric oxygen flux at the surface. On the contrary, subsequent milder and warmer winter years of the 1990s (i.e. the warming trend of CIL temperature) with more limited atmospheric oxygen supply coincide with the decreasing trend of subsurface oxygen concentration. Cold years 2003-2004 coincide again with relatively higher subsurface oxygen concentrations.

Recalling that the 1985-1993 period was characterized by highest level of plankton production, the accompanying cold winter climatic conditions, on the one hand, pre-conditioned the system for more intense spring production and, on the other hand, prevented excessive oxygen depletion of subsurface levels by storing more oxygen below the euphotic layer, which otherwise would likely cause a broader suboxic layer. Conversely, relatively mild winters after the early 1990s set unfavourable conditions in terms of oxygen ventilation even though biological production was lower than the previous decade.

12.5. Chemical pollution

Discharge of insufficiently treated sewage introduced microbiological contaminants into the Black Sea and posed a threat to human health, development of sustainable tourism and aquaculture. The Black Sea was particularly vulnerable to solid wastes dumped into the sea from ships and coastal towns as any floating or half-submerged waste was inevitably washed ashore. Some beaches have had a high accumulation of garbage presenting a risk to marine animals and humans.

Ballast water and other types of illegal discharges continued to be an important source of petroleum pollution with a high level of spatial heterogeneity. Oil enters the sea as a result of operational discharges of vessels and accidents, as well as through land-based sources. The present level of oil pollution is not high in the open sea but is unacceptable in many coastal areas. The total amount of oil spilt into the Black Sea was generally less than 50 tonnes during 1996-2004 except 260 tonnes in 1997 and 530 tonnes in 2003 (Fig. 12.14). They were discharged by spill accidents of around 10-30 per year with the exception of 61 relatively low spill accidents reported in 2001.

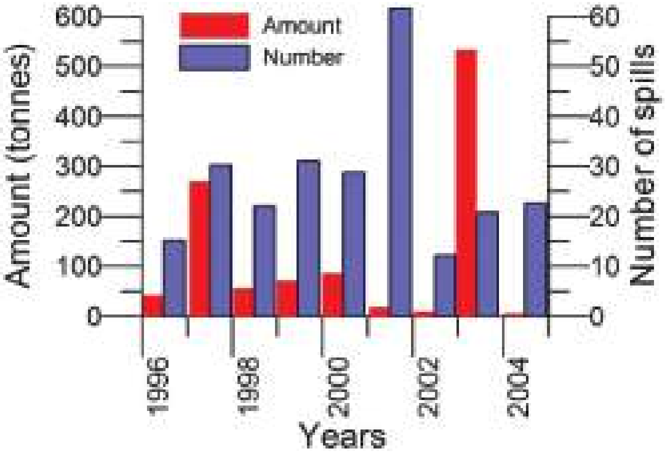

Fig. 12.14. Total of number of oil spills and amount of oil spilt during 1996-2006 on the basis of data reported by countries to the BSC.

The mean concentration of total petroleum hydrocarbons (TPHs) in general exceeded the Maximum Allowed Concentration limit (MAC~0.05 mg/l) almost everywhere in the sea, but increased up to 25.0 mg/l along tanker and shipping routes between Odessa, Novorossiysk and Istanbul, as it may be inferred from the composite satellite map shown in Fig. 12.15. The extremes in coastal shallow waters (Fig. 12.16) must be a result of local spills from ships calling at ports and bunkering and discharges from the waste water systems of large cities. The current monitoring network is not dense enough to monitor oil spills at a desired level. It will be useful to support field monitoring by routine satellite and/or aircraft images, as this is done in Europe.

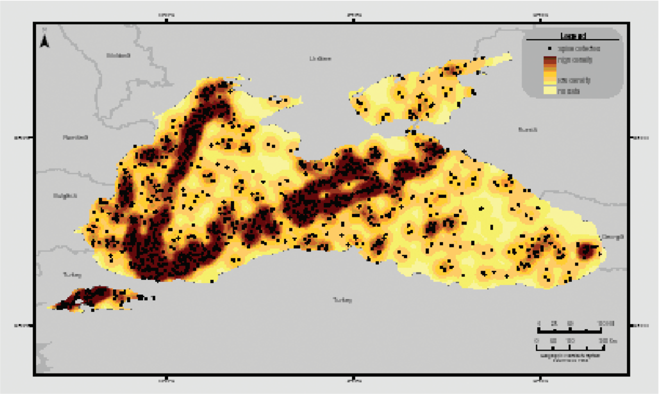

Fig. 12.15. Composite map of oil spill anomalies in the Black Sea during 2000-2002 and 2004 based on the images taken by Synthetic Aperture Radars (SARs) of European satellites ERS-2 and Envisat (http://serac.jrc.it/midiv/ maps/). The oil spill density has been spatially normalized to the spill widths. The darker areas signify the high anomaly regions.

Pesticides and heavy metals continue to pollute hot spots near certain well-identified sources. PCBs which are or have been produced for industrial use are now mostly restricted to closed systems, and the use of DDT has been banned or restricted in most countries of the Black Sea. For example, the use of organochlorine pesticides was controlled in the late 1970s in Turkey and Romania, but effective restrictions were not imposed in Turkey until the 1980s. Despite these restrictions, recent studies have shown high concentrations of DDT in Turkish rivers, streams, and domestic and industrial discharges, which indicate their illegal use. The use of these chemicals in other Black Sea countries is currently unclear. Nevertheless, on the basis of available data, pesticide (total DDT and HCH) concentrations in surface waters were typically below their detection limit (0.05 ng/l), except for some very dense patches being detected occasionally. Generally, the present pesticides pollution arises due to their huge amount stored in the agricultural fields or old dilapidated storage places in the past. Concentrations of DDTs, HCHs and PCBs in Black Sea fish and mammals are also high in comparison to those reported for some other regional seas.

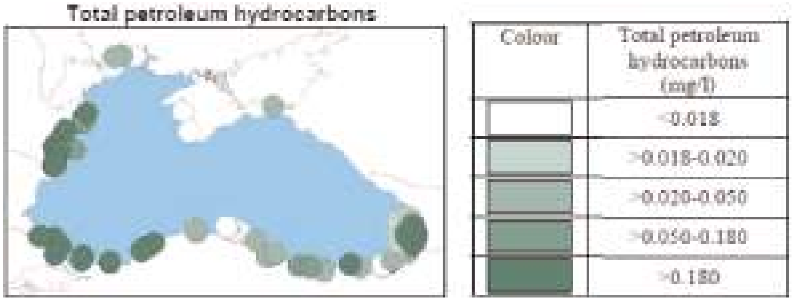

Fig.12.16. Mean concentration of total petroleum hydrocarbons in surface waters (0-10m depth) around the Black Sea periphery during 2000-2005 (after TDA, 2007).

Except some hot spot regions with clear anthropogenic influence from the main land-base sources, heavy metal concentrations are generally lower than their Maximum Allowed Concentration (MAC) levels in coastal waters, and close to their natural background values in offshore waters. In particular, the copper and chromium pollutions were wide-spread over the NWS. High chromium concentration was also found along the Crimea coast. A tendency of decreasing maximum mercury and cadmium concentrations in the Danube Delta region has been noted during last 10 years.

The rather sparse data set makes it difficult to realistically assess the long-term trends of either TPHs or total DDT and HCH concentrations in sediments. Nevertheless, it may be stated that bottom sediments of almost the entire coastal waters around the sea presently contain high levels of total DDT and HCH pollutions without any clear indication of reduction over the last 13 years of measurements. Sediments in many hot spots contain total DDT and HCH concentrations 5 times higher than their MAC levels, but most serious of them are limited to the NWS. Highest concentrations of DDTs are traced in lipid rich sediments in the Romanian and Ukrainian coastal waters that are under the influence of River Danube discharge. Elevated concentrations are also reported for sediments in the vicinity of Odessa and Port Constanta. Other pesticides were close to their detection limits except rather high concentrations of hexachlorobenzene in sediments along the Romanian and Bulgarian coasts.

Selected chlorinated compounds in sediments and organisms are ranked as DDTs > HCHs ≥ PCBs > HCBs. As with hydrocarbons, highest concentrations are situated in the Danube delta region and the port Constanta. Among the PCBs, the toxic di-ortho and mono-ortho compounds predominate. The pattern as well as the major sources of PCBs in other countries surrounding the Black Sea are unclear. Concentrations of lindane and other HCH isomers are low in samples from the Ukrainian coastline, Russian Federation and Turkey. Elevated concentrations in samples from Romanian coast stations, under the influence of the River Danube, indicate substantial usage of HCH as a pesticide in the River Danube watershed. The values found at Odessa, the Bosporus entrance region, and Sochi suggest HCH contamination. HCB were found in sediments at much lower concentrations than the other compounds. Its highest values were recorded along the Romanian and Ukrainian coastlines adjacent to the River Danube.

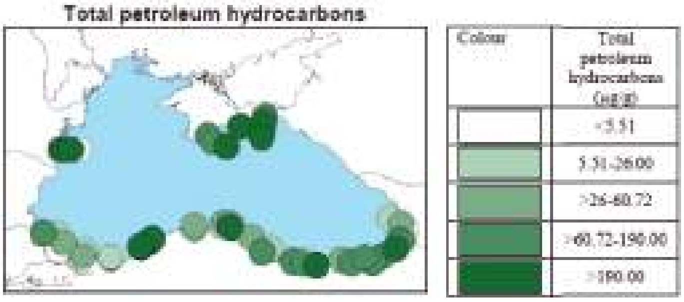

Fig. 12.17. Mean concentrations of total petroleum hydrocarbons in sediments around the periphery of the Black Sea during 1996-2006 (after TDA, 2007).

During the last 10 years, mean concentration of TPHs in bottom sediments of coastal regions was about 1 MAC (50 µg/g), but much higher concentrations were recorded in sediments collected from large ports, oil refinery and terminals in Romanian, Turkish and

Russian waters (Fig. 12.17). They generally decreased offshore. Irregular and often patchy sampling in many parts of the sea greatly limited a better evaluation of the TPH pollution. A more systematic monitoring program is desired for a better description of petroleum hydrocarbons pollution in bottom sediments especially in the vicinity of main oil sources.

Radioactive substances which have been introduced to the Black Sea by the Chernobyl accident in 1986 do not pose a risk any more.

12.6. Biodiversity change, habitat destruction, alien species invasions

Phytoplankton: The annual-mean phytoplankton biomass over the Ukrainian, Romanian and Bulgarian shelf waters (Fig. 12.18a) experienced a decreasing trend from ~10 gm-3 during the late 1980s and the early 1990s to less than 4 g m^{-3} during the 2000s. Relatively high values greater than 20 g m^{-3}, however, occasionally measured in hot spot regions along the entire coast, an example of which is shown in Fig. 12.18a near Batumi (Georgia) in 2005. A decreasing trend of phytoplankton biomass from 20 g m^{-2} to 4 g m^{-2} was also observed in interior basin up to 2002 followed by an increase to more than 10 g m^{-2} in the subsequent years (Fig. 12.18b). Assuming that phytoplankton biomass in western coastal waters is homogeneous over 10-15 m layer, its integrated biomass of 40-60 g m^{-2} is roughly five-folds higher than the interior waters biomass that imply extensive ongoing phytoplankton production within the inner shelf waters of the western basin. On the other hand, a two-fold increase in species diversity from roughly 20 to 40 (Fig. 12.19a), decreasing phytoplankton:zooplankton biomass ratio (Fig. 12.19b) together with diminishing bloom frequency and tendency of shift of annual maximum algal development from summer to the classical spring and autumn forms during the present decade indicate a tendency of algal community towards its normal status. In fact, the shifts in phytoplankton taxonomic composition have become more and more evident since 2000. The blooms of non-traditional species (*Dactylosolen fragilissimum, Pseudosolenia calcar-avis, Akashiwo sanguinea, Emiliana huxleyi,* microflagellates) are more frequently observed and a high number of new species have successfully adapted to the Black Sea environment, some of them however potentially toxic.

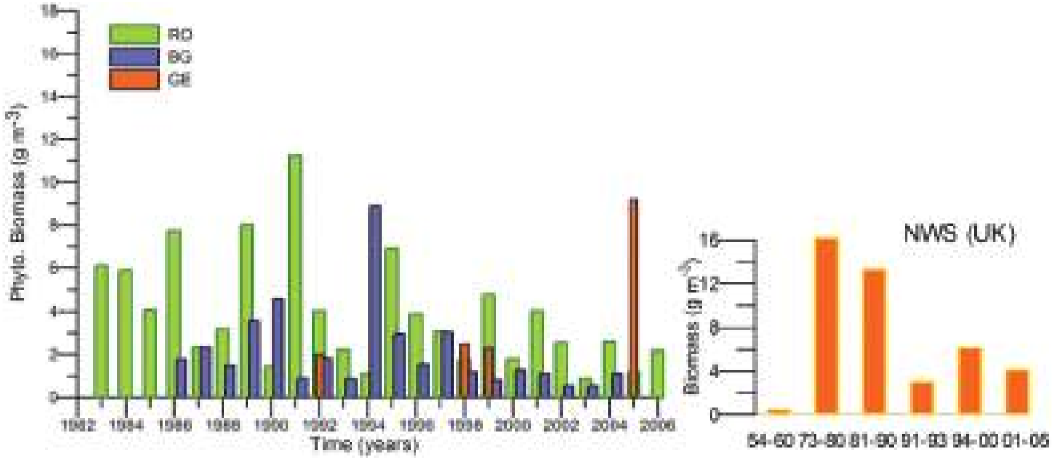

Fig.12.18a. Long-term variations of annual-mean phytoplankton biomass (g m^{-3}) averaged over all stations in the Romanian (RO), Bulgarian (BG), Georgian (GE) shelves as well as the coastal northwestern sector of Ukrainian shelf (NWS-UA, after Nesterova, 1987, see Chapter 5 of this report).

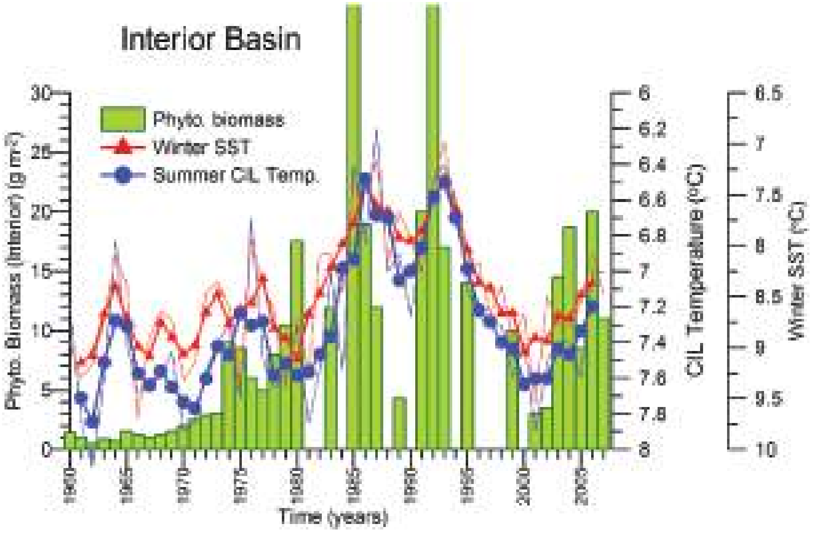

Fig. 12.18b. Long-term variations of summer-autumn mean phytoplankton biomass (g m^{-2}) (vertical bars; after Mikaelyan, 2005), the mean CIL temperature (°C) (blue dots; after Belikopitov, 2005) averaged over all stations within interior basin and mean winter (December-March) sea surface temperature (SST) as an average of Hadley2, NCEP-Reynolds and Pathfinder5 data sets. The phytoplankton biomass is expressed in terms of euphotic zone integrated values.

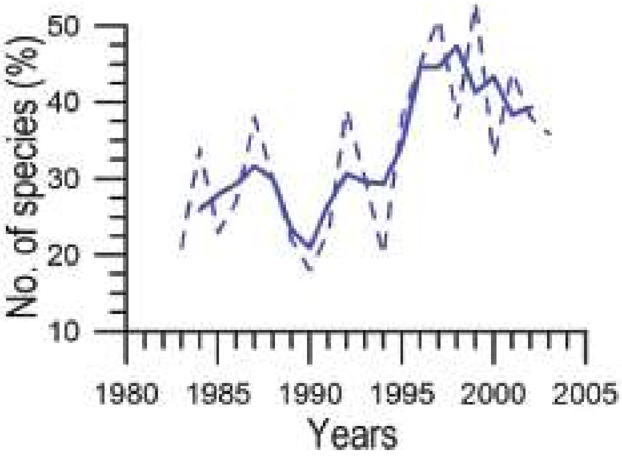

Fig. 12.19a. Long-term changes in species number contributing to annual phytoplankton biomass along the Bulgarian coastal waters (after Moncheva, 2005).

Diatiom/dinoflagellate biomass ratio is normally considered as an indicator for the change in phytoplankton taxonomic structure. Its classical spring-summer value of 10:1 for an undisturbed system was used to be maintained in the Romanian coastal waters during the 1960s and 1970s by 92% and 75% contribution of diatoms, respectively. This ratio then altered in favor of dinoflagellates during the 1980s when its biomass constituted almost 60-70% of total phytoplankton (Fig. 12.20). The diatom constituted more than 50% of the total phytoplankton during the 1990s whereas dinoflagellates became the dominant group again during the recent decade. Similar changes were also observed in the Bulgarian coastal waters and within the interior basin.

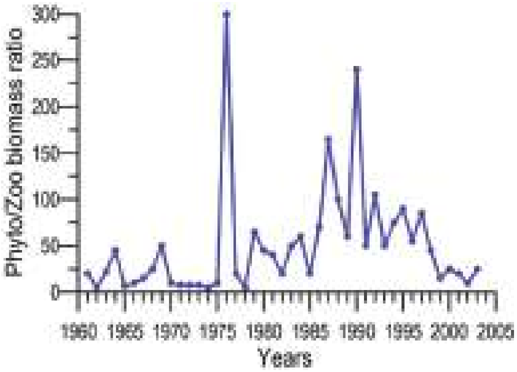

Fig. 12.19b. Long-term changes annual-mean phytoplankton to edible zooplankton biomass ratio along the Bulgarian coastal waters (after Moncheva, 2005).

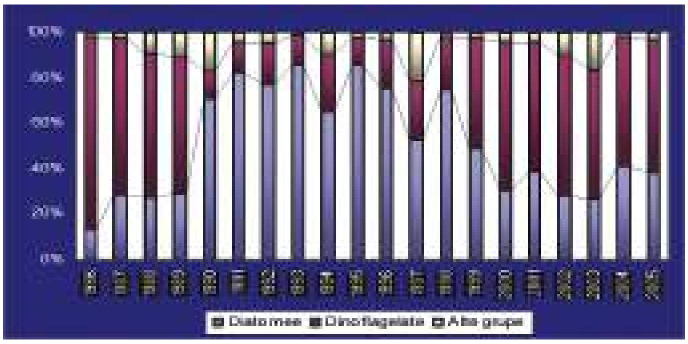

Fig. 12.20. Long-term change in percentage of biomass of main algal groups in Constanta monitoring station during 1986-2005 (after Boicenco, see Chapter 5 of this report).

The shift in phytoplankton species composition from diatom (siliceous) to dinoflagellates (non-siliceous) during the 1980s is consistent with the decreasing silicate concentration and thus reduction in Si:N ratio of the Danube nutrient load during the 1980s. As the Danube SiO4 load increased in the 1990s, diatoms were no longer limited and started dominating the community structure against dinoflagellates. In the present decade, decreasing SiO4 load (except 2005) led to domination of the community structure by dinoflagellates again. Furthermore, cooler (warmer) spring-summer conditions in the 1980s (1990s) provide growth advantage for dinoflagellates (diatoms) (Stelmakh, 2008).

The phytoplankton data from the interior basin indicate domination of phytoflagellates and coccolithophores in the annual bloom structure during the present decade. The species shift towards carbonate-producing coccolithophores in coastal waters during May-June has significantly affected sea water chemistry in terms of alkalinity and pH. Predominance of small-sized flagellates during the recent years may be a major reason for the proliferation of gelatinous zooplankton (e.g. *Noctiluca scintillans*) at the expense of edible mesozooplankton and fish eggs and larvae.

Trends in phytoplankton biomass may not always be a firm indicator for the state of eutrophication due to strong modulation of bloom intensity and species structure by climate-induced changes. For example, anthropogenic-based nutrients that were accumulated into the subsurface waters of the interior basin and/or sediments of the shelf waters are brought into the surface layer more effectively in cold winters that then promote more intense new production-based spring blooms and subsequently stronger regenerated production in summer months. This is clearly shown by the correlation between increasing and decreasing trends of interior basin phytoplankton biomass and the cooling and warming phases of the mean May-November CIL temperature during the 1980s and 1990s, respectively (Fig. 12.18b). The subsequent increase of phytoplankton biomass in 2003-2007 may also be explained by the recent climatic cooling trend. Moreover, the phosphorus limitation constitutes as an additional factor for the decrease of phytoplankton biomass along the western coastal zone during the 1990s and the present decade.

Even if the phytoplankton biomass has been improved recently, it does not indicate a stable structure; instead it implies a transitional phase with fragile ecological conditions under relatively high nutrient concentrations.

Bacterioplankton: The annual-mean bacterioplankton abundance within the northwestern shelf during 1979-2008 (Fig. 12.21a) resembles closely the long-term changes in phytoplankton biomass. It reveals an increasing abundance from the average value of 1.2 million cells ml^{-1} during the late 1970s and the early 1980s (the range: 0.3-2.6 million cells ml^{-1}) to 3.3 million cells ml^{-1} (the range 1.0-7.3 million cells ml^{-1}) in 1990-1991. It was followed by an abrupt drop to ~2.5 million cells ml^{-1} in 1993-1994 and a steady decreasing trend to 1.5 million cells ml^{-1} up to 2008. The average bacterioplankton abundance was therefore reduced during 2003-2008 by more than twice with respect to 1990-1992. This reduction was most likely caused by the decrease in total concentration of autochthonous and allochthonous organic matter that are more easily assimilated by bacteria; thus implying a reduction in organic pollution in the northwestern Black Sea. This should be connected to the decrease in the intensity of algal blooms and lower mortality rates in bottom fauna. Higher abundance was particularly observed in the vicinity of Danube delta. The measurements in the Bulgarian coastal zone also showed a stable annual abundance remained around 1.0 million cells ml^{-1} since 1994.

The NWS bacterioplankton abundance (Fig. 12.21b) attains lowest values in winter (January-February) and highest in summer under high organic matter accumulation in water column. During the intense eutrophication phase (1983-1997), abundance greater than 2 million cells ml^{-1} prevailed from March to October with the highest population close to 3 million cells ml^{-1} in August. During 2004-2007, maximum abundance reduced to 1.5 million cells ml^{-1} and summer abundances varied around 1 million cells ml^{-1} from April-to-September.

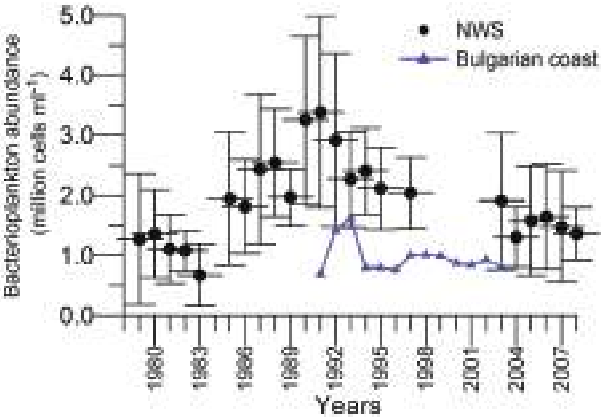

Fig. 12.21a. Long term annual-mean changes of bacterioplankton abundance in the surface layer of northwestern and Bulgarian coastal waters (redrawn from Kovalova *et al.,* 2008).

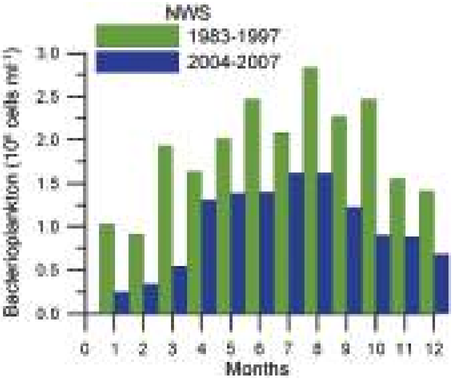

Fig. 12.21b. Long term monthly-mean changes of bacterioplankton abundance in the surface layer of northwestern coastal waters in the Black Sea (redrawn from Kovalova *et al.,* 2008).

Edible Zooplankton: The annual-mean edible zooplankton biomass formed by averaging of the Ukrainian, Romanian and Bulgarian data sets exhibited a declining trend from ~300 mg m^{-3} in 1960 to 20 mg m^{-3} in 1990, persisted this level up to 1995, and then fluctuated interannually within 50-200 mg m^{-3} range during 1996-2004 (Fig. 12.22). These fluctuations were mostly provided by the intermittent recovery of edible zooplankton (up to ~300 mg m^{-3}) within the Romanian shelf contrary to only a slight improvement (~100 mg m^{-3}) in the Ukrainian NWS and the Bulgarian shelf. According to this amalgamated data, the highest biomass registered within 1996-2004 was almost half of the biomass attained prior to the 1970s.

On the other hand, edible zooplankton biomass followed a different track of changes in the northeastern basin; it fluctuated around 10±5 g m^{-2} during 1960-1990, maintained its minimum level (2.0 g m^{-2}) during 1991-1993, and then experienced a pronounced rising trend to 20 g m^{-2} in 2000-2004 and 25.0 g m^{-2} in 2005-2008 (Fig. 12.22). Its values during the present decade were the highest ever registered since the 1960s. Assuming that zooplankton population is uniformly distributed within the upper 50 m layer, integrated biomass of the western coast during 1996-2004 varied between 2.5 and 7.5 g m^{-2} that were comparable with the Cape Sinop but substantially lower than the northeastern basin (Fig. 12.22).

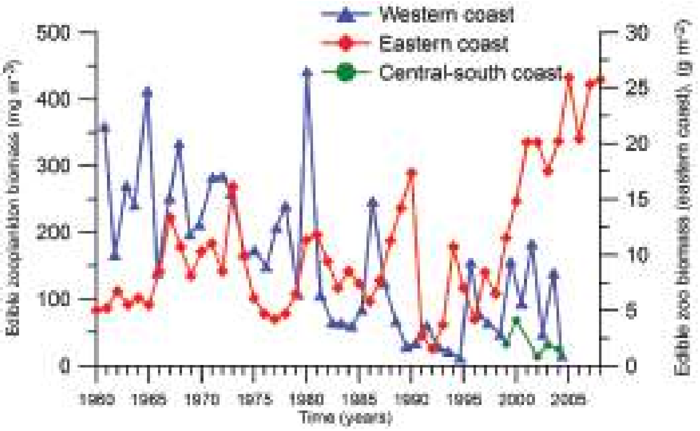

Fig.12.22. Long-term variations of the annual-mean edible zooplankton biomass in the northeastern basin (g m^{-2}) and the western coast (mg m^{-3}) obtained by averaging the Romanian, Bulgarian, and the northwestern Ukrainian data sets. Also included for comparison is the edible zooplankton biomass (g m^{-2}) measured near the Cape Sinop in central part of the Turkish coast (after Shiganova *et al.*, see Chapter 6 of this report).

Although fodder zooplankton biomass has not yet increased to a level observed in the 1970s in the NWS and western coastal waters, its community was partially recovered in terms of species diversity. The community structure was re-organized by an increase in abundance and biomass of copepods and cladocerans, such as *A. tonsa*, *P. mediterranea, C. euxinus* and *A. patersoni* which were almost absent during 1980s-1990s. The extinct species *P. mediterranea*, being an indicator of non-eutrophic waters, has re-appeared since 2000 as a sign of positive ecosystem changes. Similar changes were also noted within the northeastern basin.

Fig. 12.23 depicts distribution of the summer edible zooplankton biomass over the basin based on the compilation of all the available data during 1954-1995. It reveals considerable patchiness in accord with the meso-scale circulation structure (Fig. 12.2). Biomass variations follow closely meanders of the Rim Current with higher biomass within coastal anticyclonic eddies at onshore side of meanders. Its most distinctive example is shown near the southeastern corner of the sea occupied by the well-known quasi-permanent Batumi gyre.

Gelatinous zooplankton: According to recent observations (1998-2004), *Mnemiopsis* biomass had a decreasing trend following its population control by *Beroe* after 1998. Nonetheless, *M. leidyi* can occasionally be abundant in the northwestern and western coastal waters (Figs. 12.24), in contrast to deeper part of the western shelf and the northeastern basin where the share of *A.aurita* was increased due to its competitive advantage under low *Mnemiopsis* populations. As one of the worst cases, edible zooplankton biomass in the Danube delta region constituted only 10% of the total zooplankton structure during 2003-2007; the rest was dominated by the combination of *Mnemiopsis, Aurelia* and the opportunistic species *N. scintillans*. On the premise of low edible zooplankton and high gelatinous and opportunistic species, the western-northwestern inner shelf waters therefore do not show a stable zooplankton structure within the present decade, but a sign of recovery of mesozooplankton community structure is well-marked within the northeastern basin.

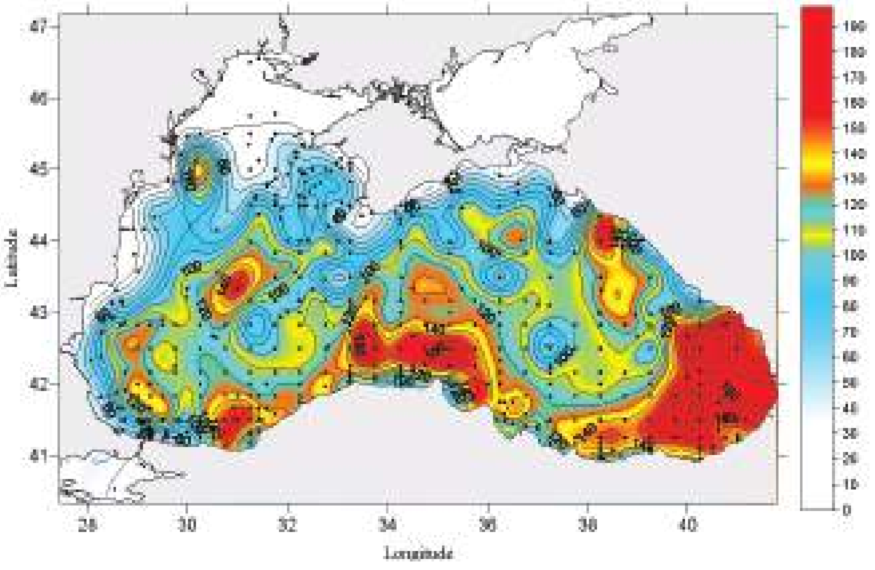

Fig. 12.23. Distribution of summer edible zooplankton biomass (mg m^{-3}) during 1954-1995 (after Temnykh, 2006).

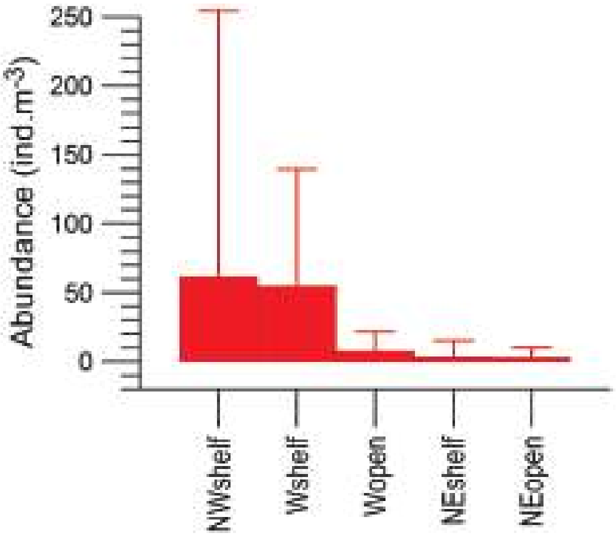

Fig. 12.24. Mean Mnemiopsis leidyi abundance (ind.m^{-3}) in the Northeastern (NE), North-Western (NW), and Western (W) Black Sea inshore and offshore waters during the summer 1998-2004 (redrawn from Kamburska et al. 2006).

As for the long-term variations of phytoplankton, zooplankton biomass and community structure also appear to be strongly regulated by climatic variations. Relatively mild years with warmer winter temperatures favour more efficient *Mnemiopsis* and edible zooplankton growth, whereas severe years with colder winter temperatures limit edible zooplankton production albeit producing stronger spring phytoplankton blooms and promote more favourable *N. scintillans* and *A. aurita* development. The spring temperature conditions are particularly critical for the intensity and species succession of zooplankton production. *Mnemiopsis* attained higher biomass when August surface temperature was relatively high as in the case of 2000-2001 and 2005 or lower biomass as in the case of relatively cold August temperatures during 1996-1998 and 2003-2004.

Macrophytobenthos: The red algae *Phyllophora* field in the northwestern shelf was known to be one of the most extensive macrophytobenthos habitats in the world. It was not only an important generator of oxygen but also the nucleus of benthic community involving more than 100 species of invertebrates and more than 40 species of fish. Following the deterioration of environmental conditions since the early 1970s as a combination of reduced transparency, lifting of mud particles in the water column during bottom trawling and hypoxia, the settlement size and stock of *phyllophora* field reduced from about 9 million tons to 8 thousand tons in 2000. *Phyllophora* harvesting therefore ceased practically after 1996. The recent observations indicated a sign of their re-establishment within the outer shelf whereas no apparent recovery has yet been evident close to the mouths of Danube and Dniester Rivers in particular and shallow coastal zone of the NWS in general. Its total harvesting of 0.5 thousand tons during the recent years had no significant commercial value, but suggests their ongoing degradation. A similar deterioration of *Phyllophora* biomass also continues along the northeastern coastal zone. For example, its biomass of 1.4 kg m^{-2} along 20 m isobath during the 1970s reduced to 0.5 kg m^{-2} during 1998 and disappeared during 2005. The same also holds in shallower regions.

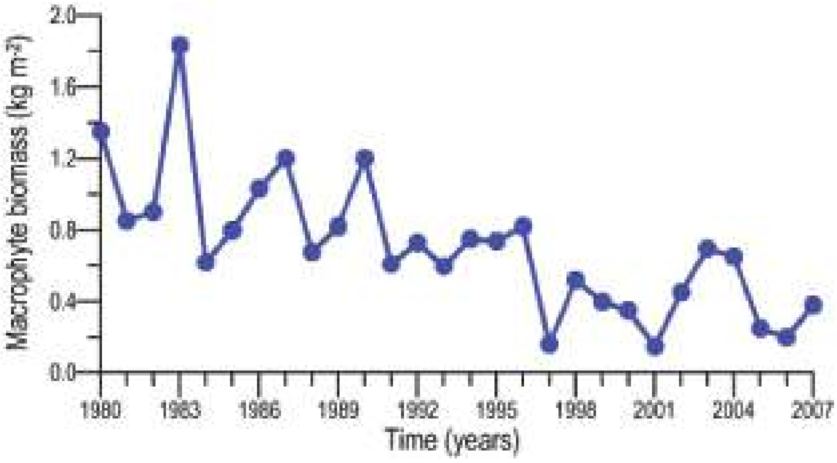

Fig. 12.25a. Long-term change of total macrophyte biomass (kg m^{-2}) in the northwestern shelf dominated by small, opportunistic species (after Minicheva, see Chapter 7 of this report).

Due to intense eutrophication, *Cystoseireta* phytal zone has been reduced to a narrow inshore strip shallower than 10 m due to the lack of sufficient light for photosynthesis in deeper regions. Beyond 10 m depth zone, large perennial macrophytes with a thick talus and longer life cycle were replaced with a few small branchy, filamentous, opportunistic-type algae species having rapid growth but relatively short life cycle. Nevertheless, the overall biomass of opportunistic species group had a declining trend by the beginning of 1990s and their present level suggested a three-fold reduction (Fig. 12.25a). Similarly, along the northeastern coast, *Cystoseira* fields that were used to stretch up to 20-30 m in the 1970s with biomass >3.0 kg m^{-2} were limited into the innermost 5 m zone during the 1980s (Fig. 12.25b). The present status shows a slight recovery at depths shallower than 10m zone (Fig. 12.25b). Floristic diversity of macrophyte communities in Zernov's *Phyllophora* field started increasing even though the tendency of increase in Ochrophyta species is minor with respect to ongoing intensive development of ecologically active filamentous algae in relation to the increase of transparency and availability of high nutrient content in the bottom sediments (Fig. 12. 25c). In spite of such positive signs, it is still difficult to assert an appreciable basin scale restoration. Full recovery of historical *Phyllphora* field is still not evident. Its coverage both in winter and summer is less than 10% with respect to the pristine state, and its role as habitat was taken over by filamentous algae.

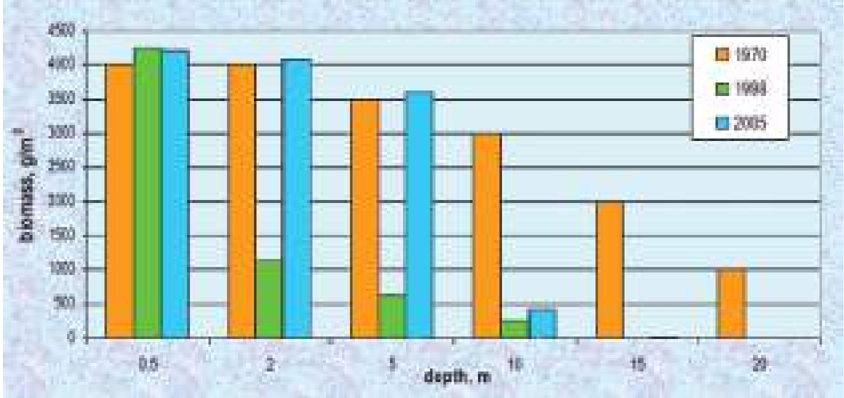

Fig.12.25b. *Cystoseira* spp. biomass at different depths along the northeastern coastal zone during 1970, 1988 and 2005 (after Kucheruk, 2006).

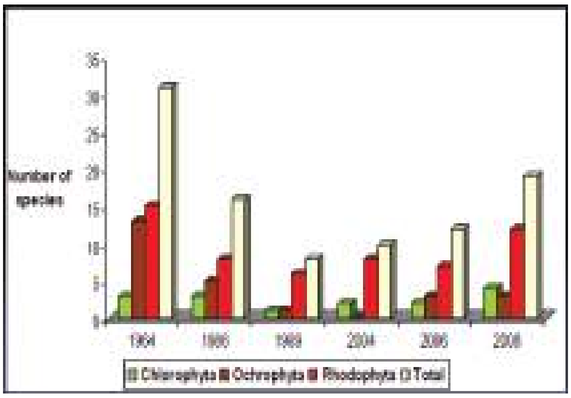

Fig.12.25c. Changes in floristic diversity of macrophyte communities in Zernov's *Phyllophora* field (after Friedrich et al., 2008).

Macrozoobenthos: The most notable changes in zoobenthos community of the 1980s and 1990s in response to intensifying eutrophication and sustained organic enrichment of sediments were lower species diversity, reduced abundance and biomass of benthic populations, and thus a more simplified community structure dominated mostly by opportunistic and invasive species with high total abundance but low total biomass, increasing role of hypoxia-tolerant groups (bivalve molluscs), high fluctuations of populations. Despite such severe changes, observational studies since the mid-1990s were limited and were based on random samplings with irregular periodicity. The measurements suffered from deficiencies in sampling quality and processing, organism identification, lack of general consensus on benthic biodiversity methodology, and insufficient experts. Therefore, the current state of knowledge on the existing state of zoobenthos structure involves many uncertainties to make a reliable assessment.

Available data for the western shelf suggest a slight improvement of zoobenthos community structure in terms of species number during the last 10 years (Fig. 12.26). Some species sensitive to hypoxia which became almost extinct started re-appearing. But, the recovery of the crustaceans is incomplete despite their population increase. The mussel *Mytilus galloprovincialis* population seems to grow under more favourable conditions as they can sustain more than one year life cycle. The current abundance level of opportunistic molluscs' species, the predatory gastropod *Rapana venosa,* the bivalves *Anadara inequivalvis* and *Mya arenaria,* however continue to dominate the macroobenthos system due to rich trophic resources and their hypoxia tolerance.

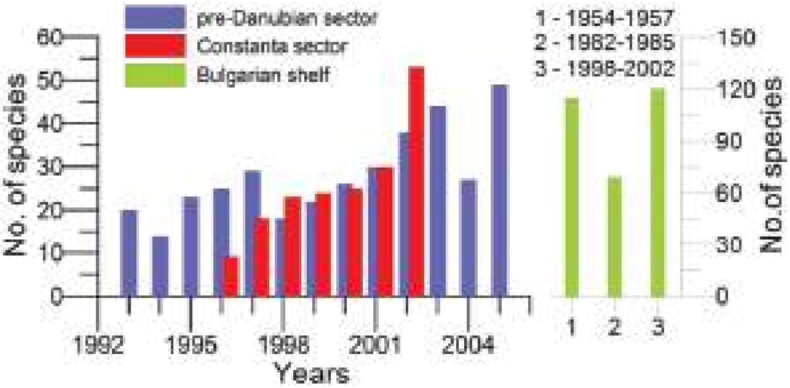

Fig. 12.26. Temporal changes in species diversity of total macrozoobenthos community in the Romanian pre-Danubian and Constanta sectors (left) and the Bulgarian shelf (right) (after Abaza, Todorova *et al.,* see Chapter 8 of this report).

As these modifications signaled beginning of the rehabilitation trend, the general state of this biotic component of the marine ecosystem is still fragile over large areas of the Ukrainian and Romanian shelves and represents clear symptoms of undesirable disturbances, such as patchiness, domination of the zoobenthos system by opportunistic and hypoxia tolerant species as indicators of organic pollution. Shallow, coastal regions remain to be vulnerable to anthropogenic disturbances as compared to offshore areas deeper than 30-50m. The muddy bottom biocoenoses of *Modilus phaseolinus* at deeper than 50 m has not yet recovered due to impact of hypoxia, opportunistic species, and degradation of bottom by dredging and trawling. Therefore, there are great deals of uncertainty to claim the recovery. On the other hand, the classification algorithm based on the empirical AMBI model (Fig. 12.27) suggests a rather optimistic view that even the Danube delta region has rather moderate pollution level and most part of the NWS is in ecologically good conditions. The conditions gradually progress to the south along the western coast and to the east away from the source region of the pollution and eutrophication.

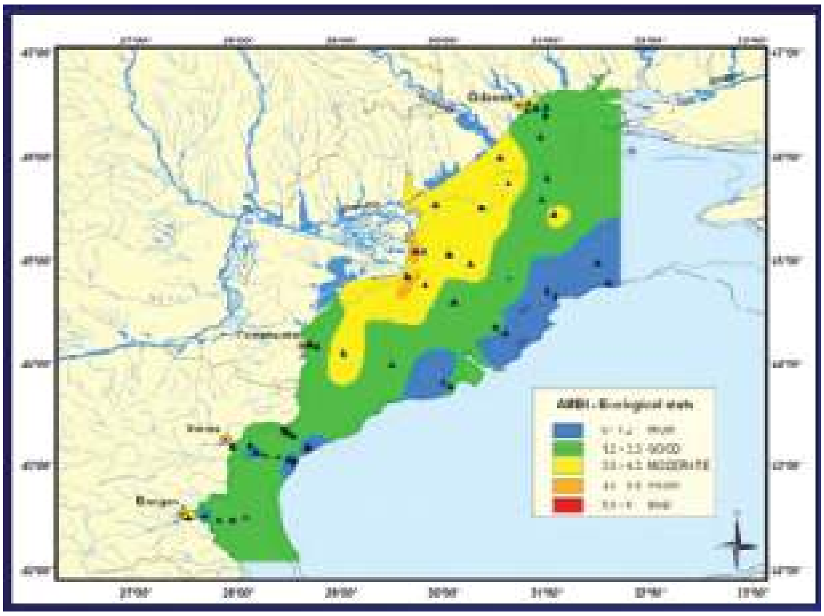

Fig. 12.27. Recent ecological state of he northwestern and western shelves according to the AMBI classification. Yellow and green colours signify moderate and good ecological state, whereas the brown spots are degraded regions of macrozoobenthos (after GEF-UNDP Project Report, 2006).

Introduction of *Beroe* and its predation on *Mnemiopsis* introduced a major transition in macrozoobentic populations. As shown in Fig. 12.28a for the northeastern coastal zone, over-comsumption of bivalve larvae and the subsequent reduction in the settlement of young bivalves observed during the 1990s were ended after the weakening of *Mnemiopsis* population. This led to mass settlement of opportunistic alien Bivalvia species *Anadara inequivalvis* larvae that is a major competitor of the native species *Chamelea gallina*. Simultaneously, the niche emptied by *Mnemiopsis* was immediately occupied by the opportunistic invasive predator Gastropod species *Rapana venosa.* Starvation due to food shortage for such high populations and their predation by *Rapana venosa* concomitantly led to their population decline which was followed by the population decline of *Rapana* due to food shortage. The opportunistic polychaeta group took advantage of these conditions in the absence of *Rapana* and increased at a significant level. It is not clear whether this transient system observed during 2000-2005 is gradually stabilizing in recent years or still continuing to persist.

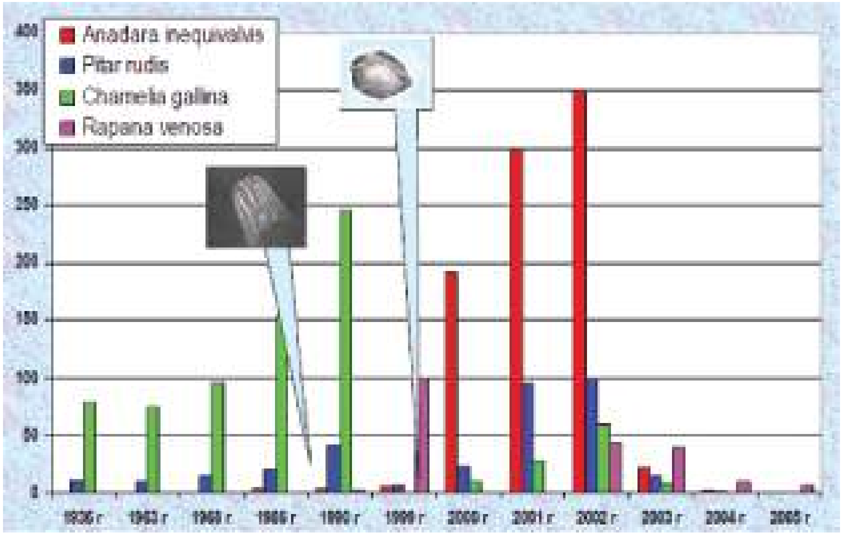

Fig. 12.28a. Changes in dominant zoobenthos species biomass (g m^{-2}) at the 10-30 m depth range of north-eastern Black Sea coast during 1936-2005 period (after Kuchreruk, 2006).

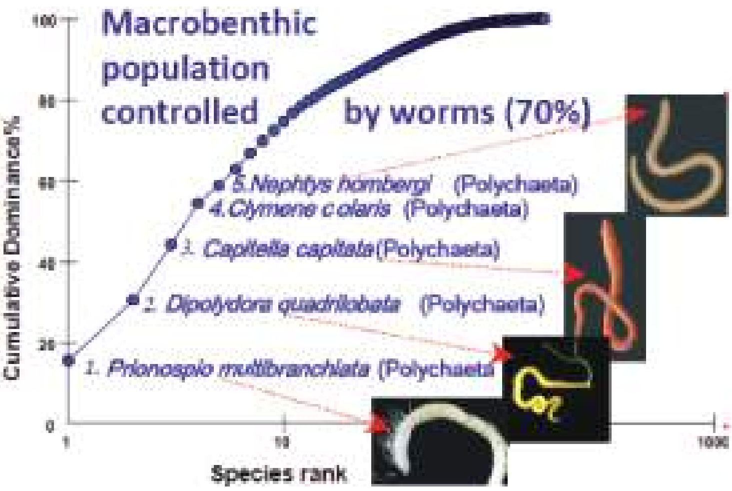

Fig. 12.28b. Species rank of macrozoobenthic population indicating its overwhelming domination by worms in the northwestern shelf (after Friedrich et al., 2008).

The 2008 Poseidon cruise in the NWS indicated a similar spectacular population development of Polychaeta species on soft sedimentary and hard substrate (Friedrich et al., 2008). As they formed 70% of the benthic population, filter feeders constituted only 9% that is a typical indication for eutrophication (Fig. 12.28b). Overall findings of the cruise were small recovery of macrozoobenthos community, strong biomass perturbations, high ecological pressure in coastal areas especially the vicinity of Danube and Dniestr discharge regions, ongoing high pressure from *Mya arenaria, Anadara inaequivalvis, Rapana venosa* survivors, and domination of the macrozoobenthos community by Polychaeta species.

12.7. Status of marine living resources

Pelagic fishes in general and their small-sized plankton-eating types in particular are most abundant species in the Black Sea ichthyocenosis. The total catch main target species European anchovy (*Engraulis encrasicolus*) constituted 31-75% of the total Marine Living Resources (MLR) during the last 15 years. European sprat (*Sprattus sprattus*), Mediterranean horse mackerel (*Trachurus mediterraneus*), Atlantic bonito (*Sarda sarda*) and bluefish (*Pomatomus saltatrix*) are the other pelagic fishes in terms of fishing value. The latter three species are large-sized predators which migrate into the Black Sea from the Marmara and Aegean Seas for feeding and spawning in spring and return their native places for wintering in late autumn. The catch around 350,000 ± 100,000 tons suggest partial recovery of major pelagic species after the fishery collapse at 1991 (Fig. 12.29).

From the fisheries perspective, the most important demersal fish species in the Black Sea are whiting (*Merlangius merlangus*), picked dogfish (*Squalus acanthias*), turbot (*Psetta maxima*), striped and red mullets (*Mullus barbatus, M. surmuletus*), four species of the family *Mugilidae*, including so-iuy mullet (*Mugil soiuy*). The total catch of these demersal fish species had a tendency of reduction after 2000. Its present catch size is approximately half of the 1990s (Fig. 12.29).

Among fishes by capture volume, the anadromous fish species pontic shad (*Alosa pontica*) and three sturgeon species *Acipenser gueldenstaedtii, Acipenser stellatus, Huso huso* take the last place, but their high consuming and economical value determines their specific role in the structure of the MLR. Stocks of anadromous fishes are formed mainly by the Danube populations. The catch data (Fig. 12.29) suggested their order of magnitude decline from about 5000 tons in 1994 to 500 tons in 1999-2001. A slight increasing trend of their annual catch after 2000 was due particularly to the recovery of Pontic shad.

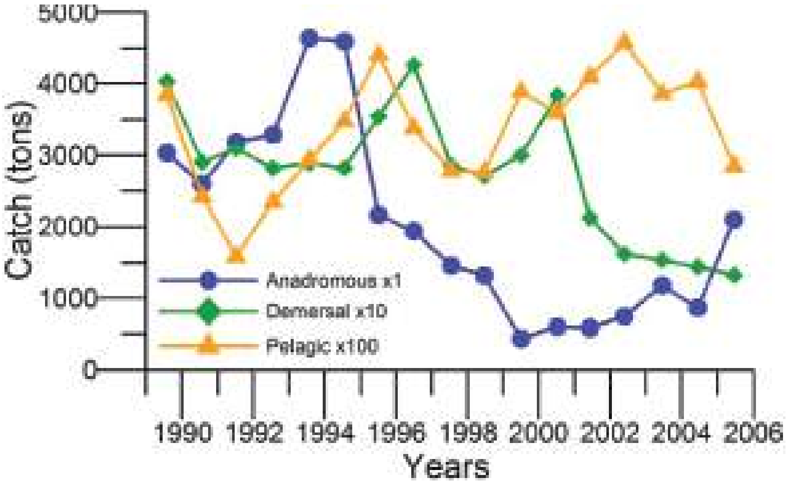

Fig. 12.29. Total catches of main anadromous, demersal and small pelagic fishes in the Black Sea during 1989-2005. The demarsal and pelagic fish catch values need to be multiplied by 10 and 100 to get the observed magnitudes, respectively (after Shlyakhov and Daskalov, see Chapter 9 of this report)

During 2000-2005, the most significant threats for fish resources appear to be the illegal fishing and use of destructive harvest techniques as well as the lack of regional cooperative management of fisheries, in addition to eutrophication-induced instability in the food web structure. At present, no recovery of sturgeons spawning and nursery habitat occurred, restocking size of the Dnieper sturgeon populations reduced considerably and the state of sturgeon stocks deteriorated definitely after 1999 with the possibility of collapse not being excluded. The state of Danube shad stocks did not improve; nevertheless the situation is less disastrous as compared to sturgeons. The sprat, anchovy, picked dogfish, and mullet stocks partially recovered in 1995-2005, but the current level of relatively high fishing efforts and catches impose a risk of deterioration of their stocks. The horse mackerel stock continues to be in a depressed state with low stock size and there is no sign of its recovery. The whiting and turbot stocks are exploited rather intensively and declining.

Among the mollusks, the clams (*Chamelea gallina, Tapes spp.*), the Mediterranean mussel (*Mytilus galloprovincialis*), and the sea snail (*Rapana venosa*) have the greatest commercial value. The former two species are harvested only by Turkey and the latter species by all countries of the region except Romania. In 2000-2005, mussel harvesting has had a decreasing trend in the Ukrainian sector but as a whole the state of mussels improved in the Black Sea (Fig. 12.30).

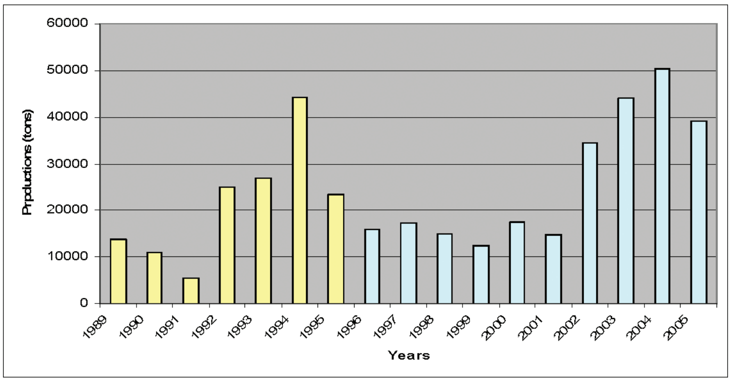

Fig. 12.30. Total catch of main mollusks in the Black Sea in 1989 -2005 (after Shlyakhov and Daskalov, see Chapter 9 of this report).

The current status (2000-2005) of the MLRs, in general, suggests an improvement with respect to the collapse period (1989-1992), but the overall situation is inferior when compared with the baseline state (1970-1988). The highly variable stock dynamics and lack of effective control measures may quite likely lead to sharp stocks decline in the future. In order to avoid this risk and to achieve sustainable fishery development, implementation of a regional management strategy is essential.

The harbour porpoises (*Phocoena phocoena relicta*), common dolphins (*Delphinus delphis ponticus*) and bottlenose dolphins (*Tursiops truncatus ponticus*) are the top predators without any natural enemies in the Black Sea except humans. Their populations were badly damaged during the last four decades due to anthropogenic-induced habitat degradation, depletion of food resources and commercial and intentional killing until the early 1980s. They are supposedly protected by the international agreements, but in practice their conservation status has not been adequately assured yet.

12.8. Conclusions

Briefly, our assessments indicate a tendency of improvement and rehabilitation of coastal ecosystems of the Black Sea after 1995 under constraints for implementation of environment politics and restructured economic activities. The trends of improvement are visible both for water quality parameters and structural and functional properties of biota, when compared with conditions observed from the mid 1970s to the early 1990s. On the other hand, oil pollution still appears to be an ongoing concern along major shipping routes and in coastal areas around river mouths, sewerage outfalls, industrial installations and ports. There is no evidence of significant heavy metal, pesticides and other persistent organic pollutants (such as polychlorinated biphenyls, PCBs, or polyaromatic hydrocarbons, PAHs) in surface waters although elevated levels of these substances in hotspots around industrial centres and ports suggest their continuous monitoring. Following the 1986 Chernobyl accident, the present level of radioactivity does not pose a health hazard to humans and environment but it is important to monitor its changes. Bottom sediments in many coastal regions around the sea continue to possess high levels of TPHs, DDT and HCH pollutions without any major reduction over the last 10 years. Nevertheless, conditions gradually progress to the south along the western coast and to the east away from the source region of the pollution and eutrophication.

The pelagic ecosystem of western Black Sea coastal waters improved noticeably due to weakening of anthropogenic pressures. It is inferred by reduced nutrient inputs and fewer algal blooms, lower algal biomass, recovery of some algal populations, increasing plankton biodiversity, decreasing opportunistic and gelatinous pressures, and re-appearance of some native fodder zooplankton and fish species and increasing edible zooplankton biomass. The current relatively low nutrient inputs, especially phosphorus, were mainly due to the economic recession after the collapse of the former Soviet Union. The phosphorus limitation prevails most notably along the coastal zone whereas the nitrogen limitation dominates within the outer shelf and deep basin. The climatic warming during the 1990s and the early 2000s also played an important role for the limitation of primary production. Its relative contribution to the overall improvement of the pelagic system of the western coastal and shelf waters remains to be substantiated by the modeling studies. A switch to the cold climatic conditions in the future (as in the 1980s) may promote more intense phytoplankton production and thus disturb the present quasi-stable pelagic ecosystem structure.

The prominent changes were encountered in the structure of benthic communities of the Romanian and Ukrainian coastal waters. However, recovery of the benthic ecosystem appears to be less certain although an improvement on regeneration of macrophytobenthos and macrozoobenthos is suggested by the available data. In the western Black Sea, large areas of the seabed that had been suffering from anaerobic conditions - a clear symptom of eutrophication - started now returning to conditions prior to the 1970s. Hypoxic events are now less severe and less frequent than they were used to be in the past. The available data also show some unavoidable indications that the present status of benthic ecosystem is highly fragile and susceptible to further anthropogenic and environmental impacts. The regions shallower than 30-40 m depths still show symptoms of some undesirable disturbances, the most important of which is exerted by the alien opportunistic species such as bivalve species *Mya* *arenaria,* soft-clam species *Anadara inequivalvis,* gastropod species *Rapana*. Once again, higher organic load to the benthic community which likely develops during cold-climatic conditions may further disturb the benthic structure.

Fish stocks over the basin are still out of balance, mainly as a result of overfishing but also due to eutrophication. For example, eutrophication-induced unfavourable conditions reduced sharply catches of demersal fish with high commercial value such as flounder and turbot and replaced them with large quantities of small pelagics such as sprat in the western shelf. As a consequence, the Ukrainian and Romanian fishing fleet in the Black Sea almost collapsed. The additional impact of overfishing exacerbated the decline of high trophic level fishes relative to low trophic level fishes and multispecies fishery is unsustainable during the present decade. Anchovy remains to be the top predator species of the Black Sea ecosystem together with sprat along the western coast. Illegal fishing and destructive harvest techniques, lack of regional cooperative fishery management, eutrophication-induced instability of the food web structure constitute ongoing major threats for fish resources.

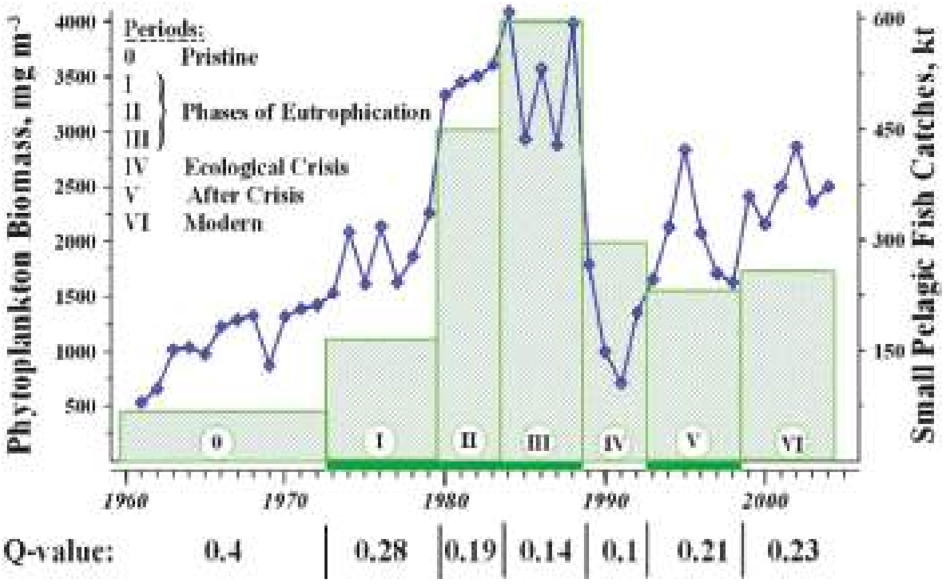

Fig. 12.31. Long-term changes of Q-value defined as the ratio of pelagic fish catch (in ktons y^{-1}) to phytoplankton biomass (in mg m^{-3}) as a measure of ecosystem vulnerability to the changes by external stressors (after Yunev *et al.,* 2008).

Recently, Yunev et al (2008) proposed a diagnostic method to assess the long-term improvement of pelagic ecosystem. It was based on the ratio of pelagic fish catch (in ktons y^{-1}) to phytoplankton biomass (in mg m^{-3}) referred to as Q-value to measure efficiency of the high energy food web chain (phytoplankton-zooplankton-small pelagic fish) since the 1960s. Phytoplankton biomass was constructed from the station network of all available measurements from the Bug River region in the north to the Cape Kaliakra region in the south. The Q-value (=0.4) was highest during the pristine state and deteriorated gradually up to 0.10 during the early 1990s of anchovy collapse and *Mnemiopsis* population outburst. Thereafter, it increased to 0.21 during the 1990s and 0.23 during the present decade in response to decrease in phytoplankton biomass and increase in small pelagic stock recovery. The current Q-value of 0.23 was still roughly half of its pristine value and indicated low resilience of the Black Sea ecosystem and high vulnerability to external stressors.

The present ecosystem structure is still different from that documented during the 1960s, and most likely it will never revert back to the pristine state. A more likely scenario is adaptation of the system to new conditions where it will eventually be stabilized. However, it is too soon to assert its stabilization today due to prevailing relatively high nitrogen concentration in the water column and sediment. The complexity and inherent nonlinear response of the ecosystem to external drivers and their internal feedbacks make unclear how the pelagic and benthic systems will respond to further stresses that may likely be introduced by climate changes, future agricultural and industrial development as economies of the riparian states recover. Its stabilization partly depends on natural evolution of the system under the concurrent impacts of climate change; eutrophication level, invasive species populations, and sustainable consumption of fishery resources. But it may partly be controlled by a carefully designed and implemented integrated and adaptive management strategy that ultimately needs to take firm decisions by policy-makers in the riparian countries.

Restoration of ecosystems is generally a long-lasting process that depends on the accomplishment of the conservation, protection and management measures both at national and regional level. In this respect, stress reduction interventions should be implemented in order to achieve improvement of environmental conditions in the coastal zone of the Black Sea and the sea itself. The most critical ones are the reduction of the terrestrial nutrient load from the catchment basin by investing in high technology waste-reduction projects and intensive agricultural practices, firm control on commercial fishery by effective regulation of trawls and dredges.

Moreover, the present assessment study indicates some gaps in our knowledge due to the absence of sufficiently comprehensive monitoring data. For the success of ecosystem restoration, routine monitoring of the key ecosystem indicators, e.g. set by EEA within the DSPIR framework, should be effectively implemented. This approach will further set a basis for the policy-relevant assessment of the state of the Black Sea environment in the EU context. The DSPIR protocol, however, may require some adaptations to the Black Sea conditions in terms of network of coastal stations, sampling frequency, and sampling depths in order to allow detection of temporal trends and inter- comparison of different areas. To this end, measurements of nutrients, oxygen, chlorophyll concentrations, as well as phytoplankton and zooplankton biomass, abundance and diversity need to be measured on monthly basis at some selected critical sites around of the basin. Also of critical importance is to monitor them not only in surface waters but also below the seasonal thermocline, and close to the bottom. Because majority of processes governing the pelagic ecosystem take place at time scales less than a month either in the surface layer or different parts of sub-surface layer, such high temporal resolution in observational strategy is indeed necessary. Either temporally, spatially and/or vertically coarse resolution measurements may be adequate for a stable ecosystem but will indeed carry a high risk of false assessments for the unstable Black Sea ecosystem.

Monitoring benthic communities needs to be designed to detect subtle changes in community structure through some indices and environmental conditions that drive these changes (e.g. sinking organic carbon flux, organic carbon content in sediments, deep-water oxygen concentration). The most practical approach is to choose some indicator species among the groups known to be opportunistic, disturbance-sensitive or insensitive. Great natural variability of the benthos requires seasonal monitoring at critical sections with many replicate samples. Monitoring chemical pollution level in sediments may be sufficient once a year. Large uncertainty exists on the amount of nutrients entering from the atmosphere and sediments, which therefore need to be monitored regularly around the basin. For example, the continuous measurement on the Zmeiny Island located 40 km away from the Danube Delta and therefore isolated from the local sources of atmospheric pollution indicated approximately 240 ktons y^{-1} and 16 ktons y^{-1} of atmospheric nitrogen and phosphorus fluxes when extrapolated over the Black Sea (Medinets and Medinets, 2008). Similar measurements during 2004-2005 in Sevastopol revealed 240 ktons y^{-1} nitrogen load (Chaykina et al., 2006). These figures are comparable with the loads supplied by the River Danube in recent years.

Ecosystems damaged by human actions for long periods of time show very slow recovery rate later despite of rehabilitation efforts. For example, after all efforts and progressive implementation of EU Directives, so far there has been only limited reduction in eutrophication of the Baltic and North Seas.

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