State of the Environment of the Black Sea

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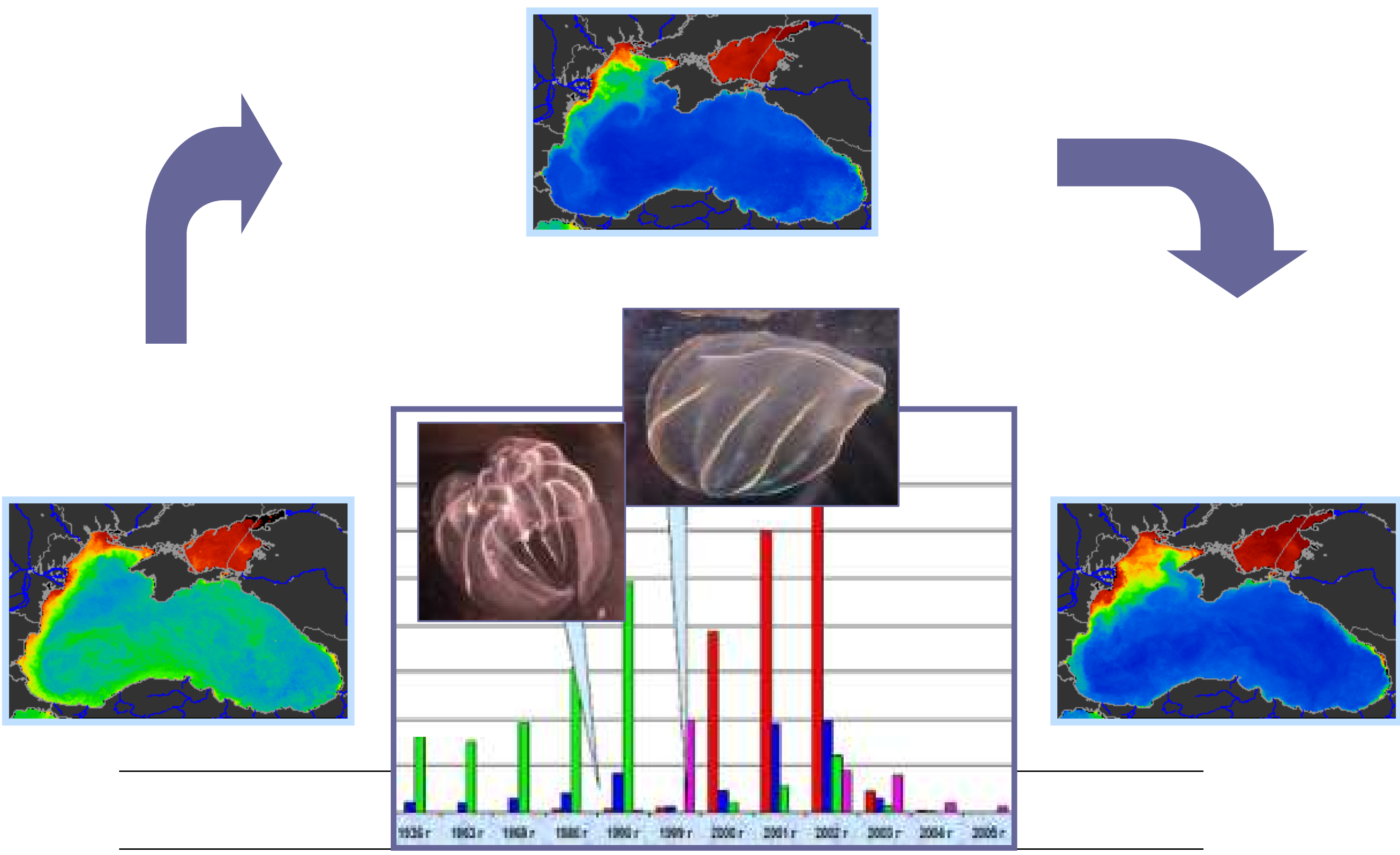

CHAPTER 8 THE STATE OF ZOOBENTHOS

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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 zoobethos community structure shifted to the dominance of smaller size hypoxia tolerant groups and opportunistic species that resulted in an increase in total zoobethos 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 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

8.2.1. Meiobenthos

Meiofauna are small benthic invertebrates larger than Microfauna but smaller than Macrofauna. The studies on community structure of meiobenthos in the northwestern shelf go back to the early 1960s (Kiseleva, 1965, 1981) when their qualitative composition and quantitative distribution were first described along the western and southern coast of Crimea. Later studies have shown significance of meiobenthos within the overall benthic community in terms of both abundance and biomass (Kiseleva, 1981). The analysis of long-term changes of its qualitative and quantitative characteristics is difficult due to regional heterogeneity and species diversity as well as their temporal changes. Many ecological factors possibly contributed to long-term changes in the biota. But, the major impact was attributed to anthropogenic eutrophication (Zaika, 1992).

Changes in meiobenthos structure of the northwestern shelf (NWS) have been first noted in the 1970s. Up to the mid-1970s, nematodes formed the largest eumeiobenthos group followed by harpacticoids (Kiseleva, 1992). Nematodes and harpacticoids dominated on loose sediments, harpacticoids and ostracods on seaweeds, and harpacticoids on the interstitial spray zone. High density and biomass of nematodes around 336000 ind·m^{-2} and 61117 mg·m^{-2} was observed in the Odessa area. The average density and biomass were 256000 ind·m^{-2}, 1941 mg·m^{-2}, respectively, in the Danube discharge area and 137000 ind·m^{-2} and 225 mg·m^{-2} in the Zhebriansky Bay.

After the 1970s, hyper-eutrophication and subsequent large-scale hypoxia markedly decreased abundance of phytophilous benthos and altered the relative share of taxonomic groups. The faunistic composition of foraminifers was impoverished from 39 species in 1973-1987 to 14 species in 1985-1990, of which only six (*Ammonia tepida*, *Ammonia compacta*, *Porosonian martcobi*, *Haynesina anglica*, *Nonion matogardanus* and *Canalifera parkerae*) were more frequently observed. In the Odesa Bay, out of the 11 species in the 1970s (Vorobyova and Yaroshenko, 1979), only 8 remained in 1995-2001 (Helmboldt 2001). In addition to the reduction in species diversity, meiobenthos groups showed morphological disorders with increasing number of anomalous species (Sergeeva, 2003). Nematode density decreased almost 3-folds (up to 76000 ind·m^{-2}) in the Danube discharge region and 4.5 folds in Zhebriansky Bay (Vorobyova and Kulakova, 1998; Kulakova 2001).

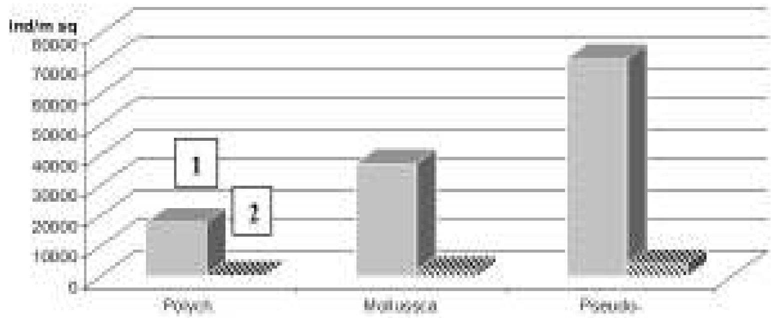

Fig. 8.1. Average density (ind.m^{-2}) of Polychaeta, Mollusca and total pseudomeiobenthos in (1) 1984 and (2) 1990 in the northwestern shelf.

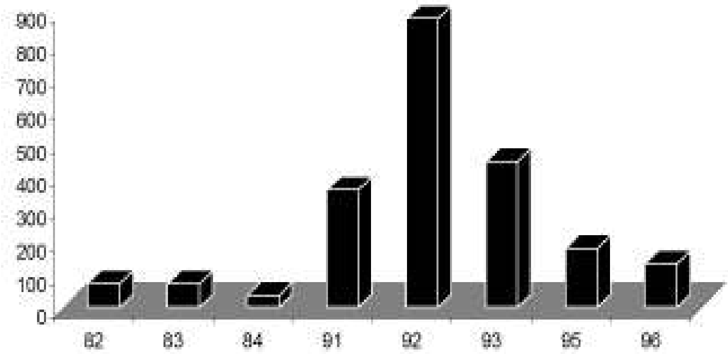

Fig. 8.2. Long-term change of the meiobenthos abundance to biomass ratio as an index for the assessment of environment conditions in the northwestern shelf (Vorobyova, 2000). The x-axis shows the last two digits of the years from the 1980-1990s.

From 1984 to 1990, meiobenthos in loose bottom sediments of the Zernov *Phyllophora* field continued to experience changes in their abundance and biomass under progressing eutrophication. As shown in Fig. 8.1, following an abrupt reduction in the density and biomass of pseudomeiobenthos (polychaetes, mollusks) the contribution of eumeiobenthos (prevailed by Foraminifera and Nematoda; small-sized organisms with a short life cycle) constituted 98.2% and 64.6% of total meiobenthos abundance and biomass, respectively. Their prevalence in hypertrophic areas has limited development of high-quality feeding bases for larvae and fry of near-bottom and bottom communities. In the NWS area, the average meiobenthos density increased from 16500 ind.m^{-2} in 1982–1983 to 885570 ind.m^{-2} in 1992 and 778434 ind.m^{-2} in 1996 (Vorobyova and Kulakova, 1998). Simultaneously, the index expressed by the ratio of total meiobenthos abundance to total biomass (i.e. number of individuals per one milligram of total biomass) increased from the range 37-73 in 1982-1984 to 357 in 1991 and 877 in 1992 in response to an increase in foraminifer density from less than 2% of total meiobenthos abundance in 1982-1983 to 89% in 1991-1992 and accompanying reductions in crustacea, polychaete and mollusk densities (Fig. 8.2, 8.3a).

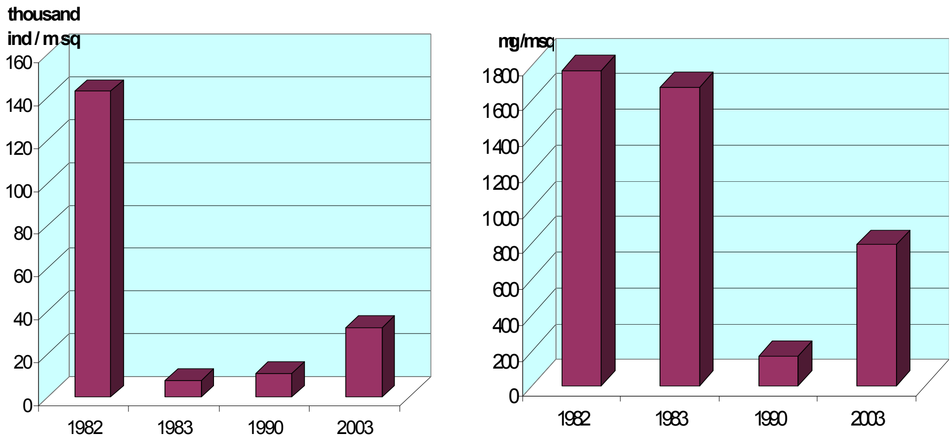

Fig. 8.3a. Long-term changes in density (10^3 ind. m^{-2}) and biomass (mg m^{-2}) of the fodder meiobenthos community (Harpacticoida, Ostracoda, Oligochaeta, Polychaeta and Bivalvia) in the NWS (after Vorobyova, 2006).

In the following years, the total meiobenthos abundance was subject to a reverse trend and decreased to 196191 ind.m^{-2} in 1996 due to decline in development of foraminifers (Vorobyova, 2006). The diversity index reduced to 180 in 1995, 133 in 1996 (Fig. 8.2), and 37 in 2003 due to lower abundance and higher biomass as shown in Fig. 8.3a for 2003. The trend after 1996 therefore indicated recovery of the forage meiobenthos community (Harpacticoida, Ostracoda, Oligochaeta, Polychaeta and juvenile mollusks) in the north-western Black Sea up to a level comparable to its pristine state. 2003 observations suggested a much better meiobenthic structure in the NWS that has become comparable to the early-1980s. For example, Polychaeta, that was almost extinct two decades ago, was able to develop an abundance of about 5000 ind. m^{-2} in the northern sector of Romanian shelf up to the shelf break zone (Fig. 8.3b). Its abundance as well as number of taxa improved only slightly towards south along the Ukrainian, Romanian, and northern half of the Bulgarian waters (up to the Varna transect). This feature was also valid for total meiobenthos abundance (see Fig. 8 in Mee et al., 2005). However, in the absence of additional data after 2003, it is too soon to claim a definitive improvement of meiobenthos.

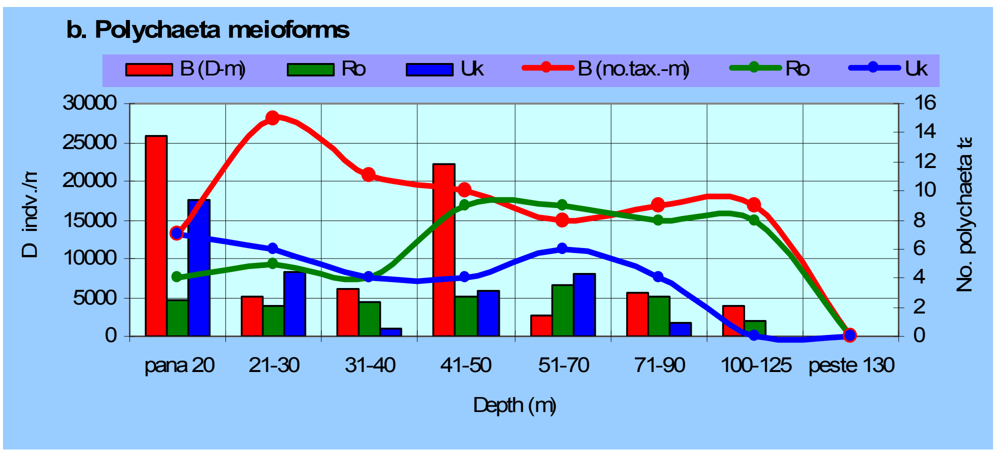

Fig. 8.3b. Changes in average density (vertical bars; ind.m^{-2}) and number of taxa (straight lines) of Polychaeta meioforms versus depth of the water column for Ukrainian, Romanian and Bulgarian littoral zone during autumn 2003. After Skolka et al. (2006).

8.2.2. Macrozoobenthos

During 1973-2005, nearly 4500 benthic stations had been executed in the NWS and along the coast of Crimea mostly in the shallow coastal zone with less sampling at the depths deeper than 40 m in the 2000s. The biocenotic structure, quantitative development and long-term changes of macrozoobenthos were studied using the database in the Benthos Ecology Department of IBSS (Sevastopol) based on the biomass determination approach for dominant species (Vorobyova, 1949).

Taxonomic composition: Bottom macrozoobenthos community of the northwestern shelf (NWS) and coastal zone of the Crimean Peninsula have experienced major population changes and morphological anomalies in the 1970s and 1980s. Most notable changes were encountered in its north-northwestern coastal zone including the Karkinitskii Gulf (Povchun, 1992) and to a lesser extent in the western and southern coasts of Crimean Peninsula (Zaika, 1990; Revkov et al., 1992; Zaika et al., 1992; Petrov, Zaika, 1993; Kisseleva et al., 1997; Revkov et al., 1999; Zaika, Sergeeva, 2001; Makarov, Kostylev, 2002).

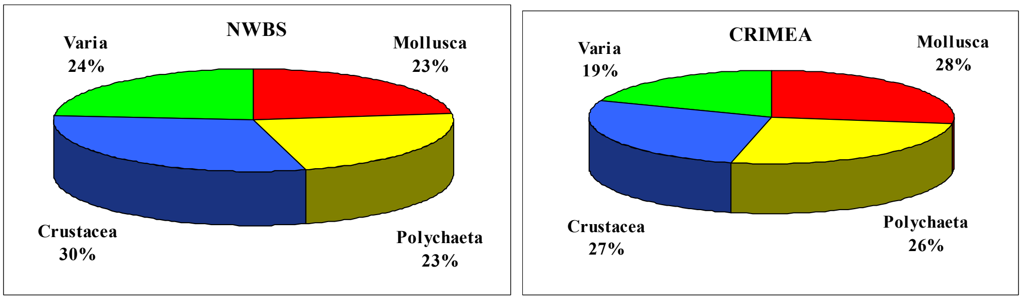

Fig. 8.4. Relative contribution of the basic zoobenthos groups in the NWBS and at the Crimea coast during 1967-2005 (without taking into account Oligohaeta and Turbellaria).

Bottom zoobethos fauna of the northern and northwestern coastal zone of the Black Sea has the Mediterranean-Atlantic origin (Mordukhay-Boltovskoy, 1972). It included 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. The recent investigations 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 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. 8.4). The Crimean coastal zone has richer bottom fauna involving 561 macrozoobenthos species (Table 8.1) that was formed by 28% Mollusca, 26% Polychaeta, 27% Crustacea, and 19% Varia (Fig. 8.4).

These regionally-averaged values, however, differ considerably in different parts of the NWS and the Crimean Peninsula (Fig. 8.5). 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 Karkinitsky gulf at 115 stations, 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 (Fig.8.5). The “Varia” group had the largest share (24 %) in the Sevastopol Bay.

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

Taxon	The Black Sea, before 1975*	NWBS**			Crimean coastal zone***		
		before 1967	1973–2003	1967-2003	before 1975	1980–2005	1975-2005
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
ECHINODERMATA	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.

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

So far, the group of Hydroids of Crimea was replenished by 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 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 molluscs; *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), *T. truncatula* (Draparnaud, 1805). The ‘enrichment’ of the gastropods took place mostly due to their taxonomical revision.

In addition to enrichment of the Crimean macrozoobenthos fauna, some species were not observed after the 1980s. This may be due to the low species populations and thus their inadequate sampling as well as difficulty of 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.

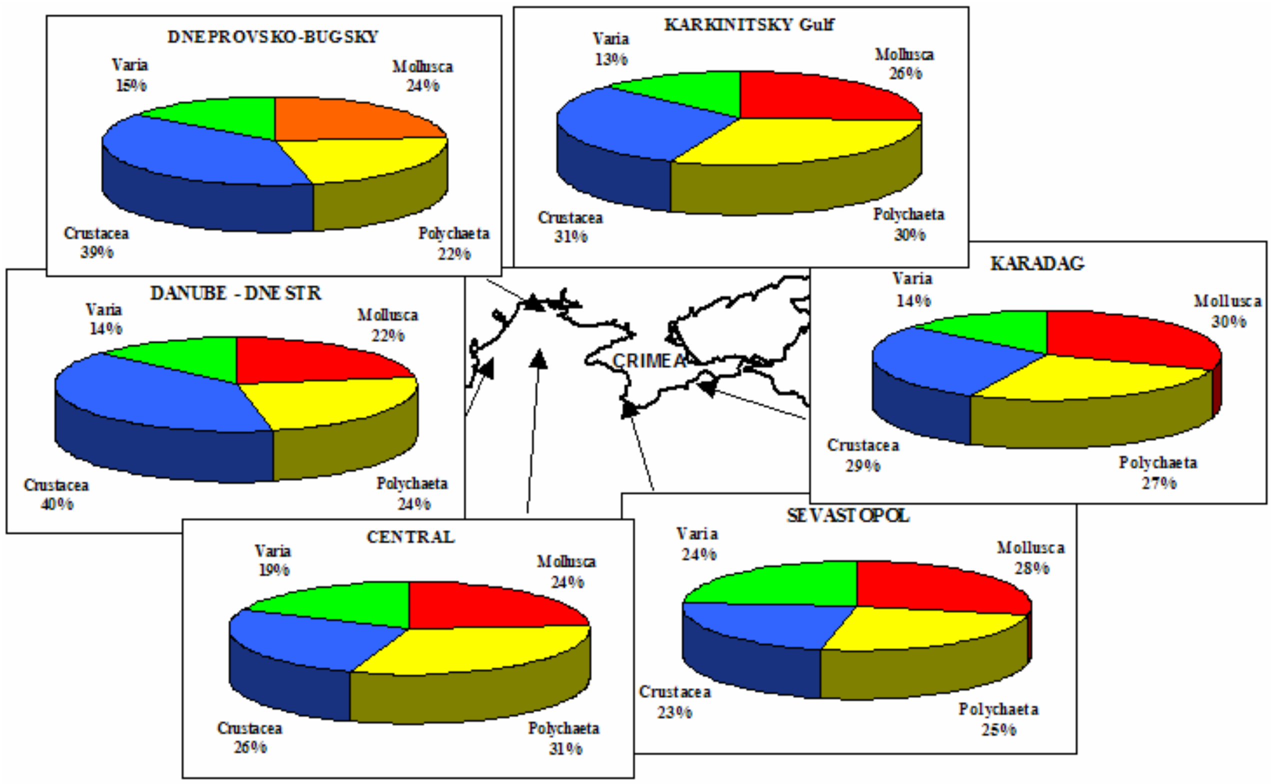

Fig. 8.5. Species numbers (in %) of basic zoobenthos groups in different regions of the Ukrainian sector of the Black Sea. The data used for the NWBS correspond to 1973-2003. For Sevastopol and Karadag, the measurement period covered observations prior to 1973.

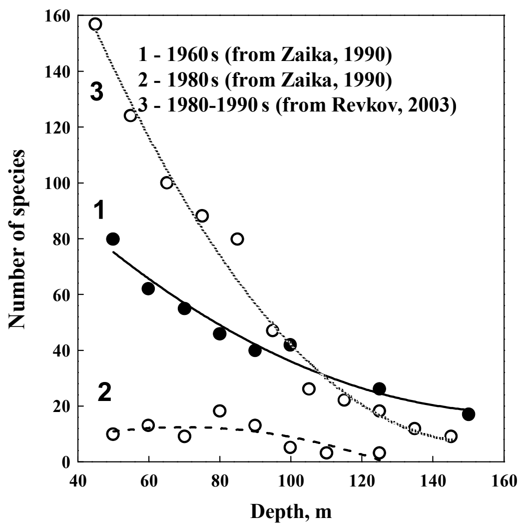

Fig. 8.6. The changes in macrozoobenthos species diversity on the soft bottoms along the coast of Crimea during different periods.

Along the coast of Crimea, species diversity declined with depth at different rates after the 1960s (Revkov, 2003b). The highest species diversity (242 species) was placed at coastal and relatively shallow depths of 11 – 20 m during 1980 – 1990s where the most diverse group (81 species) was the Molluscs fauna, whereas 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 21 – 30 m depth range. These results reflect the presence of different bottom fauna in shallow coastal zone. In deeper waters, at 50-120 depth range, 3-5 fold reduction in macrozoobenthos species diversity was noted in the 1980s as compared to the 1960s (compare the cutves 1 and 3 in Fig. 8.6). In the 1990s, the species diversity increased within the 50-100 m depth range but reduced by half at depths greater than 100 m. This reduction was explained by the decrease of population density of some species (rare chance to find them in the samples) instead of their disappearance from the local fauna (Zaitsev, 2006).

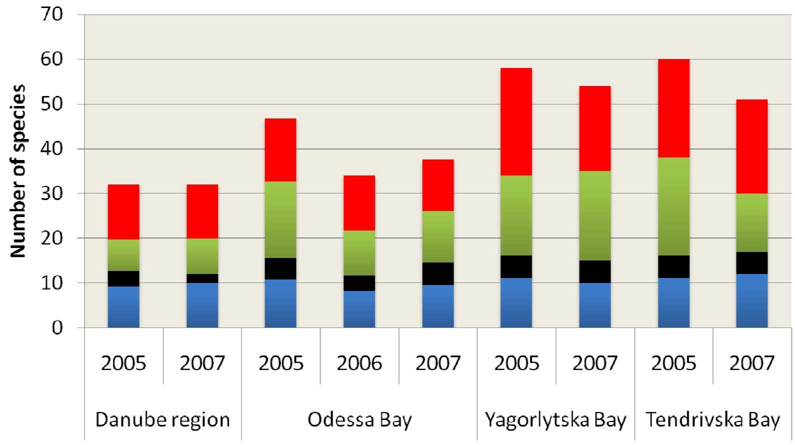

Fig. 8.7. Total number of macrozoobenthos species in different areas of the NW Black Sea: blue – Bivalvia, black – Gastropoda, green – Crustacea, red – Polychaeta (from Ukrainian National Report, 2007).

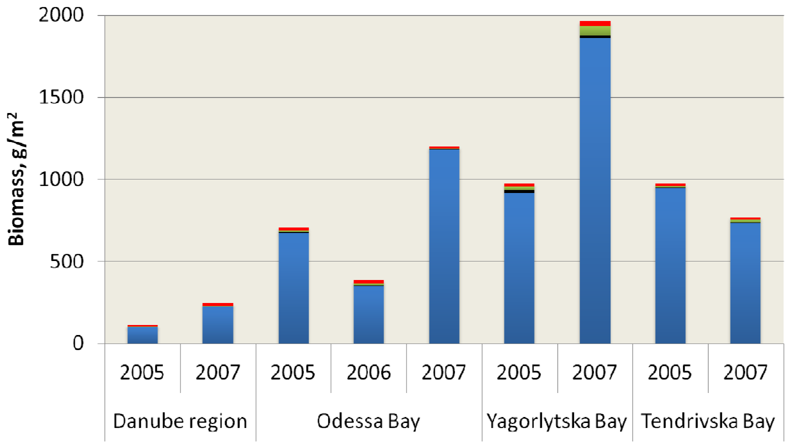

Fig. 8.8. Macrozoobenthos biomass (g m^{-2}) in different areas of the NW Black Sea: blue – Bivalvia, black – Gastropoda, green – Crustacea, red – Polychaeta (from Ukrainian National Report, 2007).

At present (2005-2007), total number of species in shallow waters of the NWS region varied in the range 30-60; the lowest values were found in the Danube delta and Odessa Bay regions, but they were twice higher in Yagorlystka and Tedrivska Bays (along the northwestern Crimean coast) (Fig. 8.7). Crustacea and Polychaeta have almost equal and highest contributions, Bivalvia comes the second, and the Gastropoda group is represented by least number of species at all four sites. However, in terms of biomass, Bivalvia group dominates entirely total macrozoobethos biomass that amounts to less than 500 g m^{-2} in the Danube delta and Odessa Bay and around 1000 g m^{-2} in two northwestern Crimean Bays and even reached at 2000 g m^{-2} in Yagorlystka Bay during 2007 (Fig. 8.8).

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). Rather new biocenoses were *Heteromastus filiformis*, *Pontogammarus maeoticus, Paphia aurea, Orchestia cavimana, Anadara inaequivalvis, Irus irus* and *Donacilla cornea.* Biocenoses of *Mya arenaria* Linnaeus, 1758 and *A. inaequivalvis* were formed by introduced species, and biocenoses of *Neanthes succinea* and *H. filiformis* were formed temporarily as a result of near-bottom suffocation and (Sinegub, 2006).

Using the results of benthos survey in 1980 – 2004 along the coast of Crimea, about 50 bottom biocenoses can be described. According to 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 more local origin occupying small areas in the region. The belt-community of *M. phaseolina* extended from the mid-shelf (~50 m depth) to the shelfbreak (at 120–135 m depths) where mollusks were found in the form of fine spots (Zaika et al., 1992). *M. phaseolina* at depths more than 100 m is represented mainly by juvenile forms and their presence was even extended to 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 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. 8.9) (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 periazoic community forms ring-belt around the entire sea.

The belt of silt mussel *Mytilus* was limited by the depth range from 30 – 40 m to 50 – 60. The *Ch. gallina* belt community is located at depths shallower than 30 – 40 m where the benthic habitat is more heterogenous and patchy due to various factors impacting their distribution. Each of these benthic belt is a habitat for different local communities (Zaika, 1998).

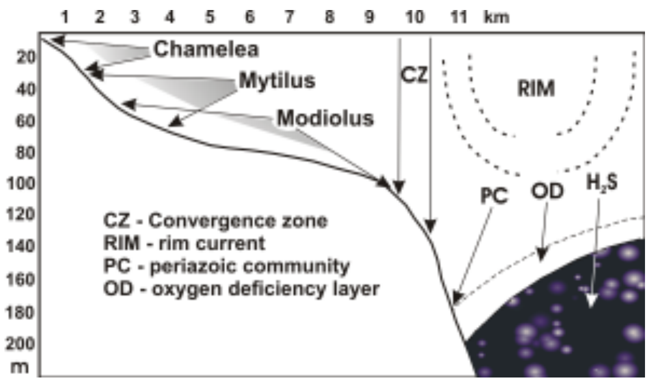

Fig. 8.9. Benthic belts of the Black Sea shelf (from Zaika, 1998, with additions).

The number of stations, falling to each of the biocenoses, defines the area occupied by these particular biocenoses and can testify their regional importance. The leading species occupy the belt-shaped biocenoses are *M. galloprovincialis, M. arenaria, N. succinea* in the NWS (Table 8.2), and *Ch. gallina, M. galloprovincialis* and *M. phaseolina* in the Crimean shelf (Table 8.3). In the biocenosis of *M. galloprovincialis,* occupying large areas in the NWS, the greatest number of species (163) was registered. Significant part of sampling stations in the Dnepr-Bug and the Danube-Dnestr marine areas belonging to the biocenosis of *M. galloprovincialis* were 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 *M. galloprovincialis* of the central NWS where the maximal length of mussels did not exceed 40 mm.

Transformation of NWS mussel settlements during the 1980s and 1990s was caused by periodic suffocation of bottom fauna, destruction of bottom zoocenoses, and silting of substrata under the impact of large-scale trawling (Shurova, 2003). This led to development of a more simplified population structure of mussel settlements in the present decade (Shurova, Stadnichenko, 2002). In summary, the present status of NWS bottom fauna exhinited radical changes in species composition, abundance and biomass both in species level and community level (Sinegub, 2006). The benthos trophic structure was simplified by sharp reduction in carnivorous and phytophage abundances and domination of detrivorous species by abundance and of sestonophages by biomass in the freshwater areas of the NWS shelf that experienced strongest damage by suffocation.

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 abundance, 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 (E)
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.

Along the Crimea coast, maximal average macrozoobenthos biomass was registered in the biocenoses of *Ch. gallina* (~500 g m^{-2}) within 0-10 m (Fig. 8.10a) and *M. galloprovincialis* (~900 g m^{-2}) within 10-20 m (Fig. 8.11a) during the 1980s-1990s. The location of maximum macrozoobenthos biomass in the biocenosis of *Ch. gallina* and *M. galloprovincialis* was however at 25 m and 40-45 m during the 1960-1970s (Kiseleva, 1981). The maximum biomass of *Ch. gallina* and *M. galloprovincialis* were found at depths 0-10 m and 20-40 m during the 1980s-1990s (Fig. 8.10b, 8.11b).

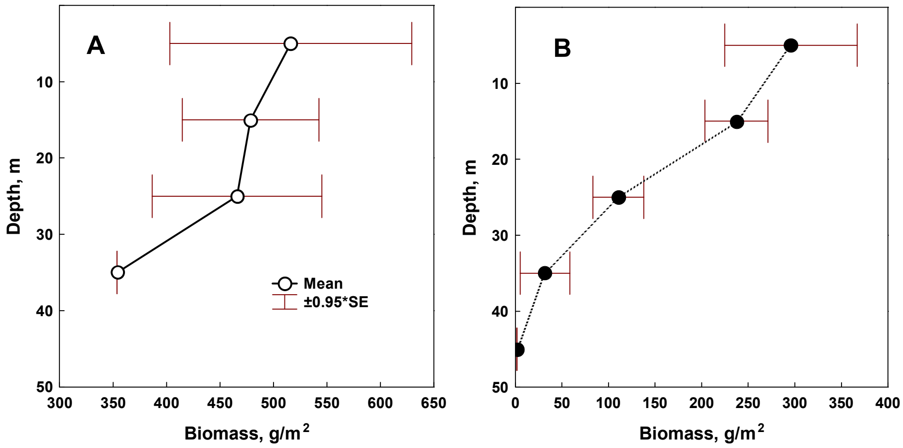

Fig. 8.10. Vertical profiles of the total zoobenthos biomass in the biocenosis *Ch. gallina* (A) (according to 157 stations) and the biomass *Ch. gallina* (B) (310 stations) at the coast of Crimea for the period 1980-1990s.

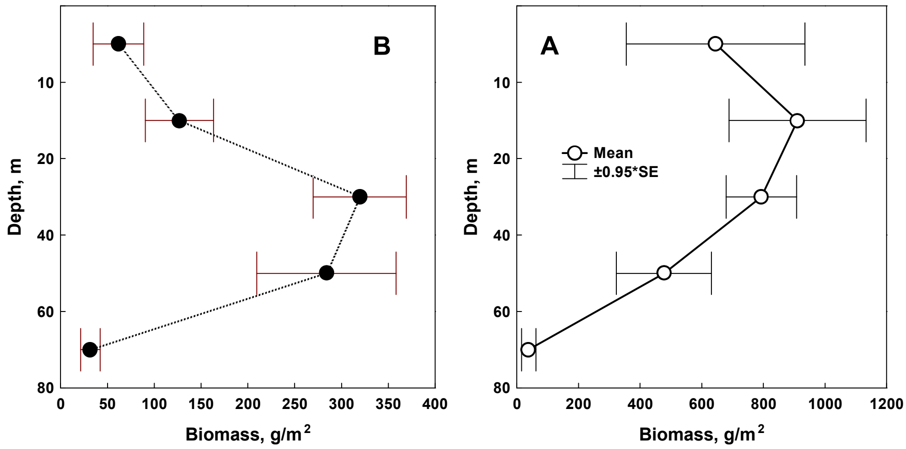

Fig. 8.11. Vertical profiles of the total zoobenthos biomass in biocenosis *M. galloprovincialis* (A) (according to 86 stations) and the biomass *M. galloprovincialis* (B) (370 stations) at the coast of Crimea for the period 1980-1990s.

Long-term changes: On the basis of long-term data comprising the period 1930s - 2000s, (Kisseleva, 1981; Zaika, 1990; Zaika et al., 1992; Kisseleva et al., 1997; Revkov and Nikolaenko, 2002; Mironov et al., 2003; Mazlumyan et al., 2003; Sinegub, 2006), bottom fauna in the Ukrainian Black Sea has improved slightly (or, at least, has not been worsened) during the last two decades with respect to the 1970s. Below 'open coastal waters' and the 'Sevastopol Bay' of the western Crimea were used as examples to delineate the changes in the zoobenthos characteristics.

Sevastopol Bay*:* The data from 1920s and 2000s reveal pronounced changes in the development and occurrence of certain benthic forms (Revkov et al., 2005). For example, the most common forms of macrozoobenthos carnivorous *Nassarius reticulatus* and *Nephtys cirrosa* (Ehlers, 1868) in 1920s with the occurrences 92% and 89%, respectively, were replaced in 2001 by the detritus-feeders *Heteromastus filiformis* (91%) and *Cerastoderma glaucum* (85%) with *N. reticulatus* remaining as a sub-dominant form observed only at several near-shore bottom sites. The alteration of dominant forms indicates qualitative changes in flow of matter in the benthic ecosystem. Moreover, a pronounced increase in the share of seston-feeders was also noted in the 1980s (Mironov et al., 2003).

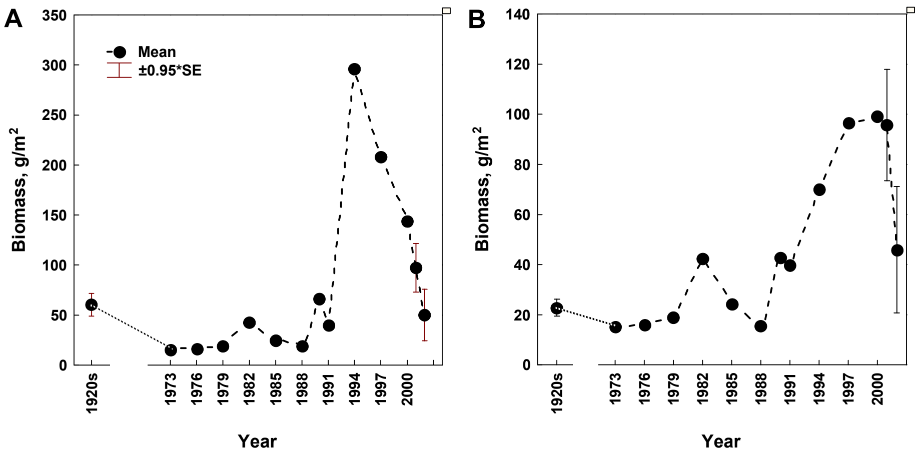

Fig. 8.12. Long-term dynamics of zoobenthos biomass in Sevastopol Bay – with the account of all macrozoobenthos (A), and without *M. galloprovincialis* which is not a typical soft bottom species of the Sevastopol Bay (B).

As shown in Fig. 8.12a, 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 that was then followed by a decrease towards the background values in 2000s (Mironov et al., 2003; Revkov et al., 2005). When *M. galloprovincialis* biomass was excluded from the total biomass data since it is not a typical species for soft bottom fauna of the Sevastopol Bay, zoobenthos biomass tends 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. 8.12b).

Open coastal waters of the western Crimea: Similar long-term structural changes in the zoobenthos biomass and abundance were also observed at open coastal waters of the western Crimea. In terms of 'Density index', *Ch. gallina* abundance at 1-12 m depth range remained constant (about 25) up to 1980s and then experienced a sharp increase to 300 in the 1990 and decline afterwards to 60 in 2000 (Fig. 8.13). *Ch. gallina* abundance also dominating 13-25 m depth range, changed from 50 at 1980 to 175 at 1990 and dropped to 40 at 2000. Similarly, *M. galloprovincialis* density index rose abruptly from less than 5 to 150 during the same phase at 26-50 m depth range, but its subsequent trend is not known due to the lack of data. Thus, *Chamelea gallina* and *M. galloprovincialis* became most optimal zoobethos forms in the 1990s. On the contrary, the density index of *Modiolula phaseolina* which was the dominant species at 51-103 m range in the 1950s decreased from 125 to 20 at 1970 and then remained at this level since was replaced by *T. stroemi* in the 1970s-1990s.

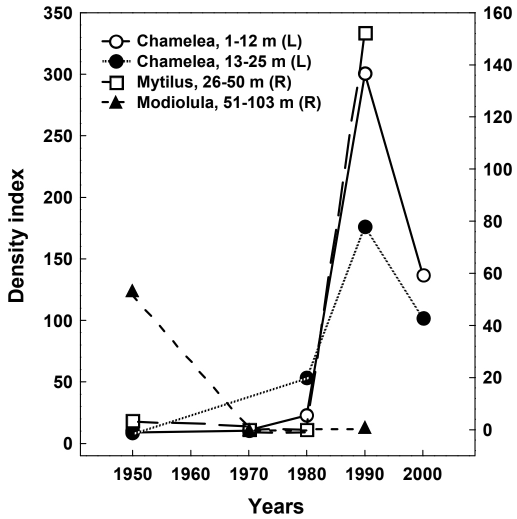

Fig. 8.13. Long-term changes of 'Density index' values with respect to populations of *Ch. gallina*, *M. galloprovincialis* and *M. phaseolina* at the western coast of Crimea. The 'Density index' axes on the left and right are marked by L and R, respectively, in the figure.

At the Lisya Bay, located about 3 km to the west of Karadag (southeastern coast of Crimea), number of species of all dominant trophic groups increased from 1973 to 1998, and total species number changed from 56 to 93. Consequently, the average benthos abundance increased from 395 to 7066 ind. m^{-2} and 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. The filter-feeders group increased markedly due to the domination of mollusc *Ch. gallina* in bottom communities. Based on the survey conducted in summer 2008, preliminary results suggested the total biomass of the Lisya Bay fauna approaching to the 1970s.

Thus, the tendency of sharp benthos biomass increase during the 1990s appears to be a common feature for many coastal water of the northwestern Black Sea and related to adaptation of the benthic ecosystem to increasing organic pollution. So, filter-feeding molluscs *Ch. gallina* and *M. galloprovincialis* (in open coast) and *C. glaucum* (in the internal part of estuarine water areas) became the most abundant forms and altered the benthic assemblages structure along the Ukrainian coastal zone. The more recent data from the 2000s testify a reduction in the total zoobenthos biomass towards the level of the 1980s due possibly to the 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 spreaded 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.

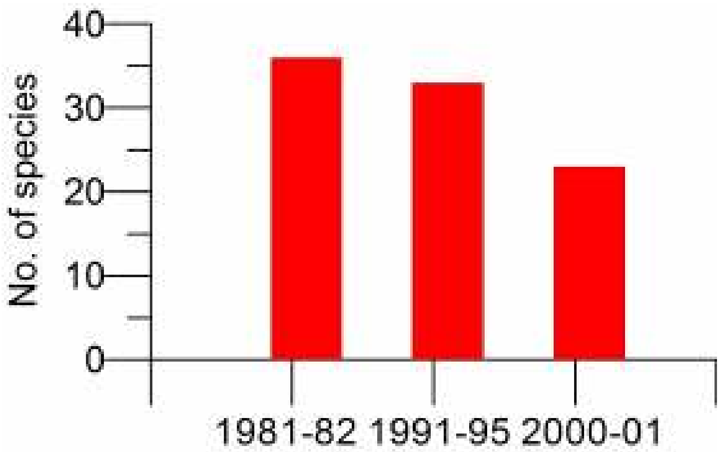

Fig. 8.14. Change in species diversity in the muddy bottom biocoenosis of *Modiolus phaseolinus* during 1981–2001 that was the most characteristic biocoenosis along the Romanian coast from 55m to 120 m.

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).

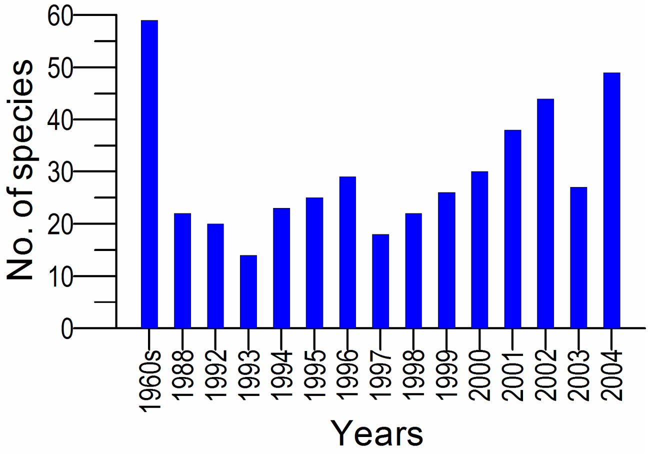

Fig. 8.15. The change in species diversity of the macrobenthic fauna in the pre-Danubian sector of Romanian coastline during 1993-2005.

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 molluscs due to their well-developed populations. Among the molluscs, *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.

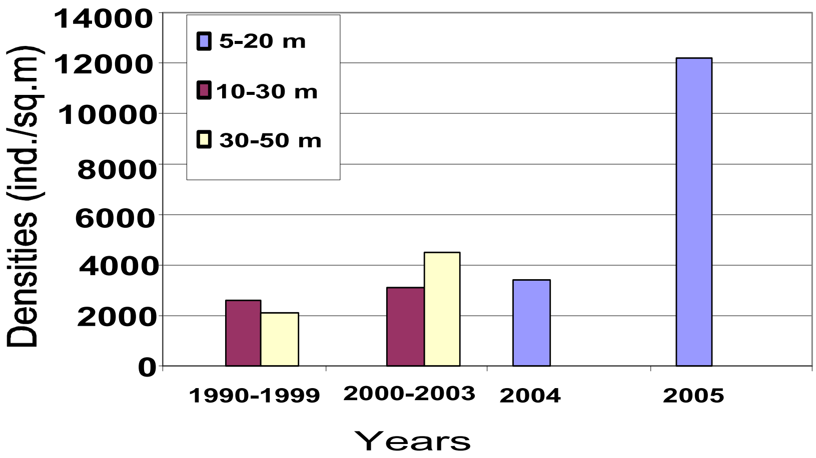

Fig. 8.16. Changes in the average abundances of macrozoobenthos at different depths in the pre-Danubian sector.

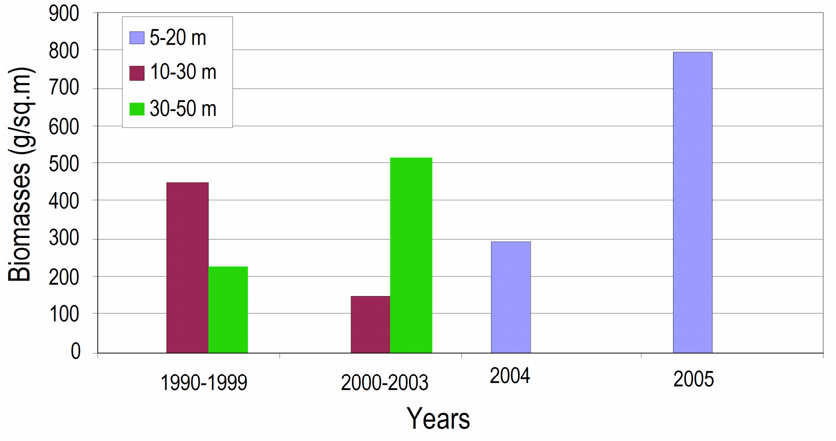

Fig. 8.17 – Changes in zoobenthic average biomass at different depths in the pre-Danubian sector.

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).

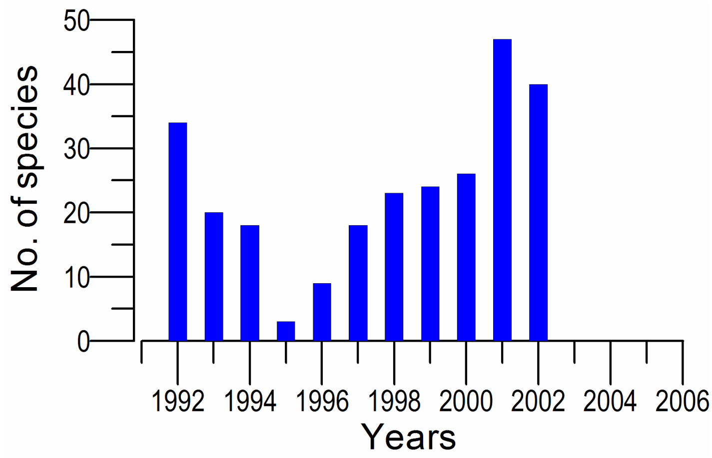

Fig. 8.18. Change of species diversity in the Constanta marine sector between 1993 and 2002.

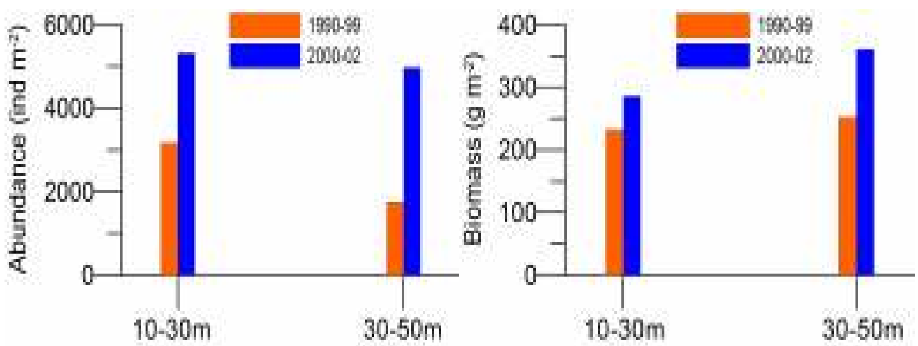

Fig. 8.19. Average zoobenthos abundance (ind. m^{-2}, left) and biomass (g m^{-2}, right) at 10-30m and 30-50m depth ranges in the Constanta sector of the Romanian shelf waters during 1990-99 and 2000-02.

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 mollusc 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 molluscs community dominated by *Mya arenaria* and *Scapharca inaequivalvis* (Abaza *et al.*, 2006a, 2006b).

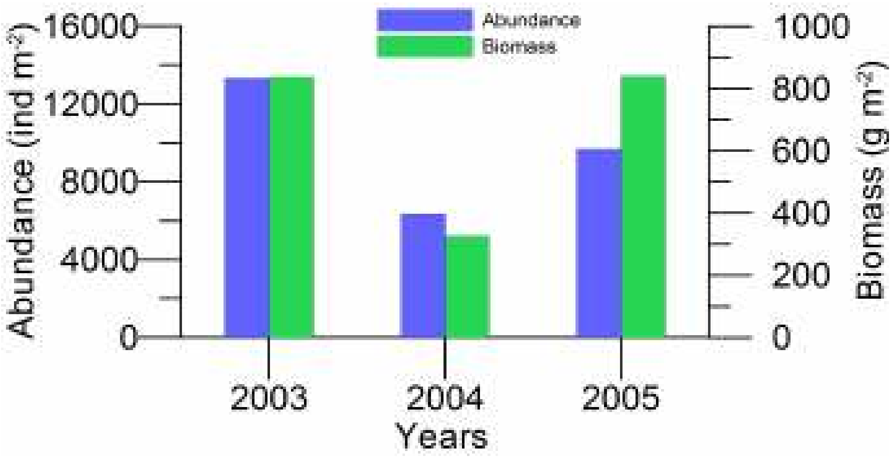

Fig. 8.20. Changes in the average abundance (ind m^{-2}) and biomass (g m^{-2}) of macrozoobenthic populations in the central (Constanta) sector at 5-20 m depth range.

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 has 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*.

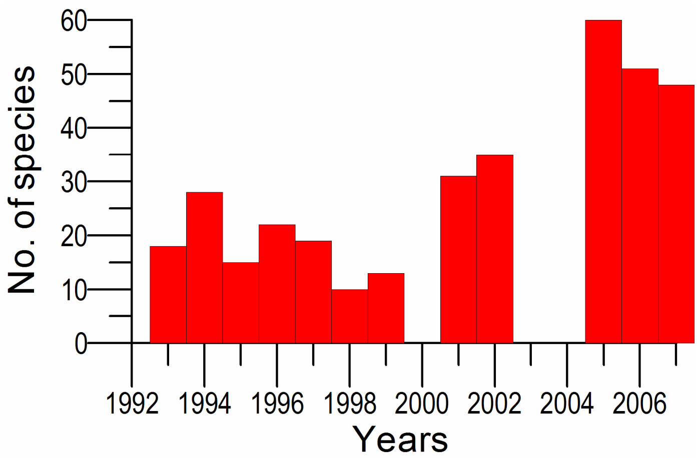

Fig. 8.21. Change of species diversity in the Southern (Mangalia) marine sector between 1993 and 2007.

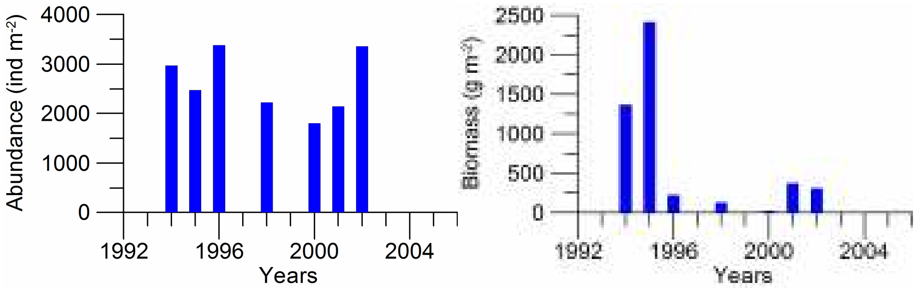

Fig. 8.22. Average zoobenthos abundance (ind. m^{-2}, left) and biomass (g m^{-2}, right) at 30-50m depth range in the Mangalia sector of the Romanian shelf waters during 1994-2002.

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 molluscs and crustaceans. The molluscs 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 14113 ind.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.

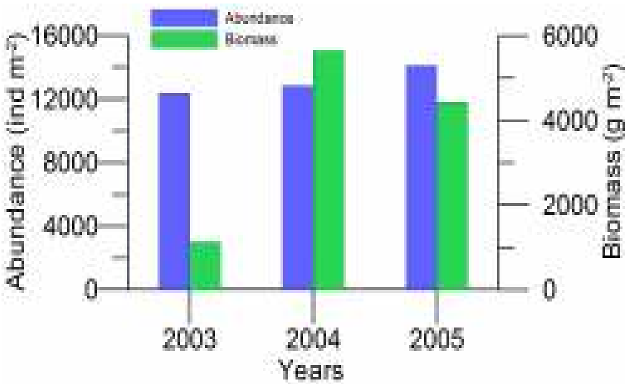

Fig. 8.23. Average abundance (ind. m^{-2}) and biomass (g m^{-2}) of macrozoobenthic populations in the southern sector at 0-20 m depth range.

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.

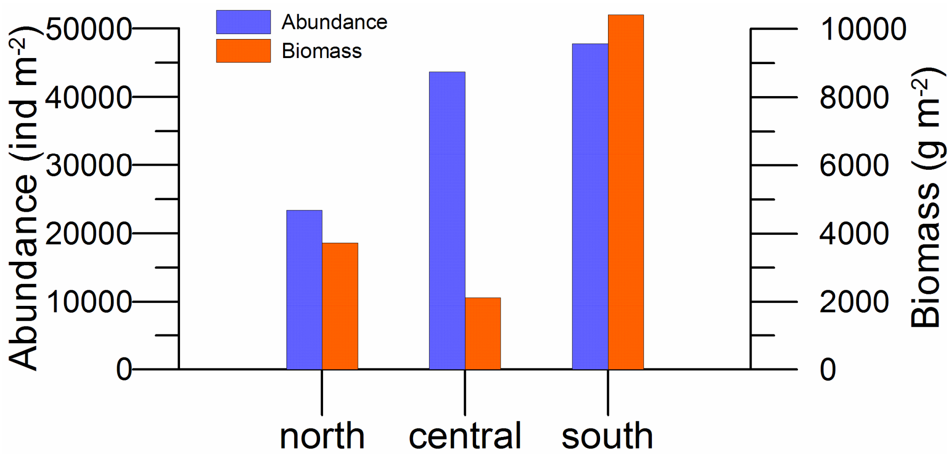

Fig. 8.24a. Average abundance (ind. m^{-2}) and biomass (g m^{-2}) of macrozoobenthic populations during 2002-2006 at 0-20 m depth range of the northern, central, southern sectors of Romanian litteral zone.

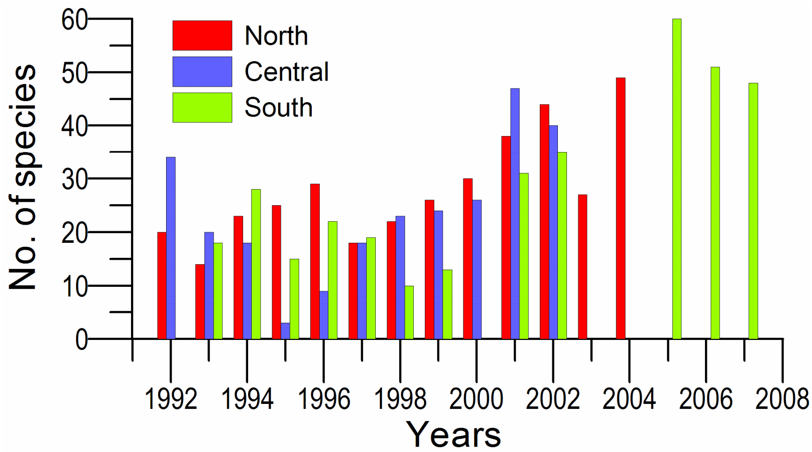

Fig. 8.24b. Change in number of macrozoobenthic species during 1992-2007 in the northern, central, southern sectors of Romanian litteral zone.

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.

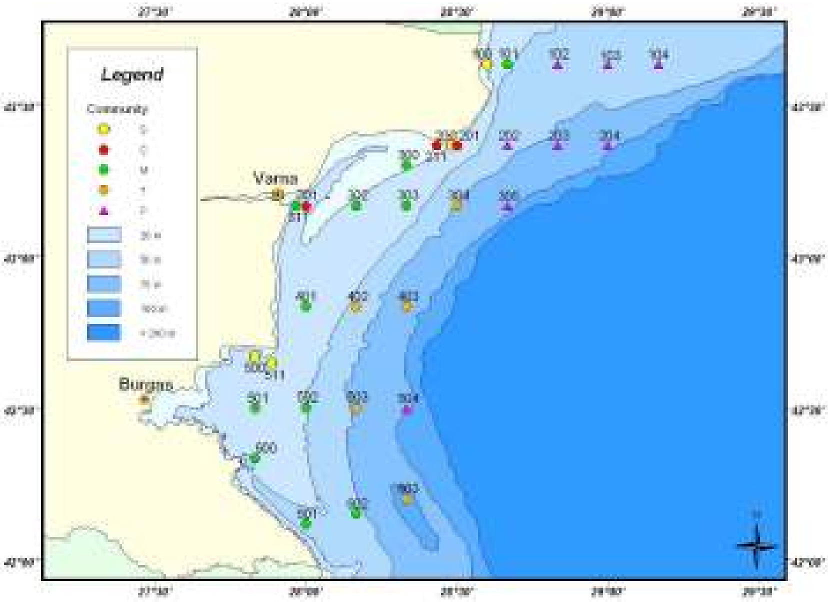

Fig. 8.25. Map of the studied area with sampling locations and communities as differentiated according to the cluster analysis: S – infralittoral sand community, C – infralittoral silt community, M – upper circalittoral silt community with *Melinna palmata*, T – impoverished circalittoral silt community,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

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 “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 H_2S (Tatishvili et al., 1968).

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.

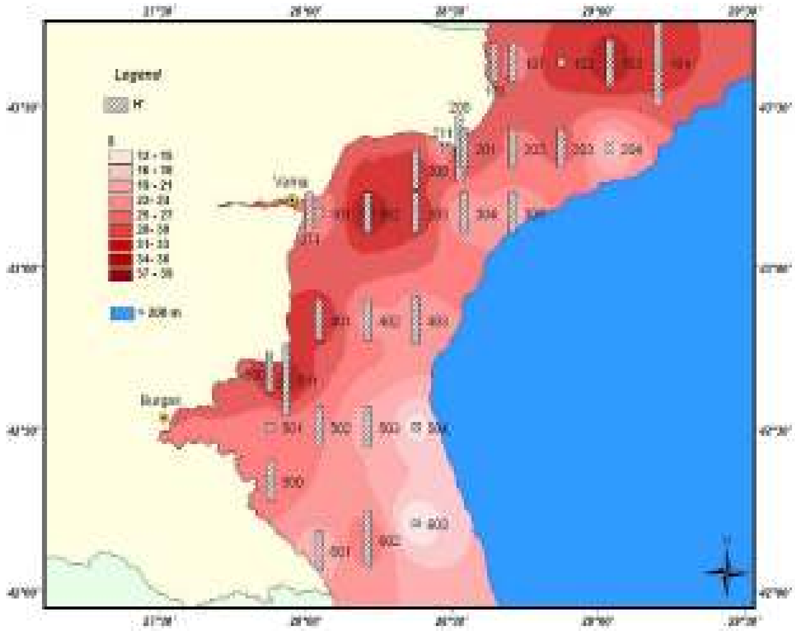

Fig. 8.26. Distribution of the average number of macrozoobenthos species (S) on the Bulgarian shelf and average Shannon-Wiener community diversity (H') index at sampling stations, summer 1998-2002.

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 molluscs, except for the "impoverished circalittoral silt community", which is dominated by the polychaetes due to almost complete absence of molluscs in the community composition.

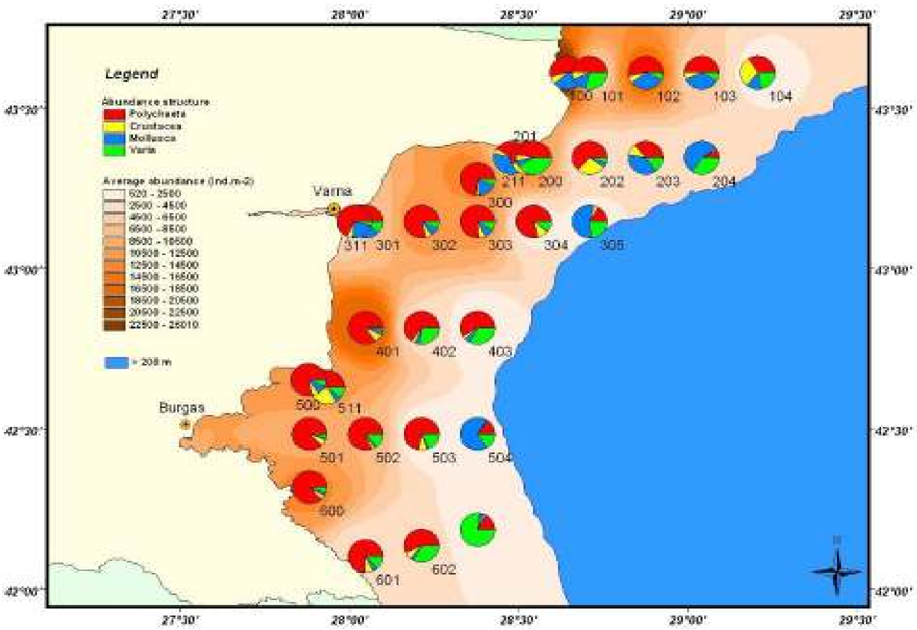

Fig. 8.27. Distribution of average macrozoobenthos abundance on the Bulgarian Black Sea shelf and abundance structure at sampling stations, summer 1998-2002.

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.

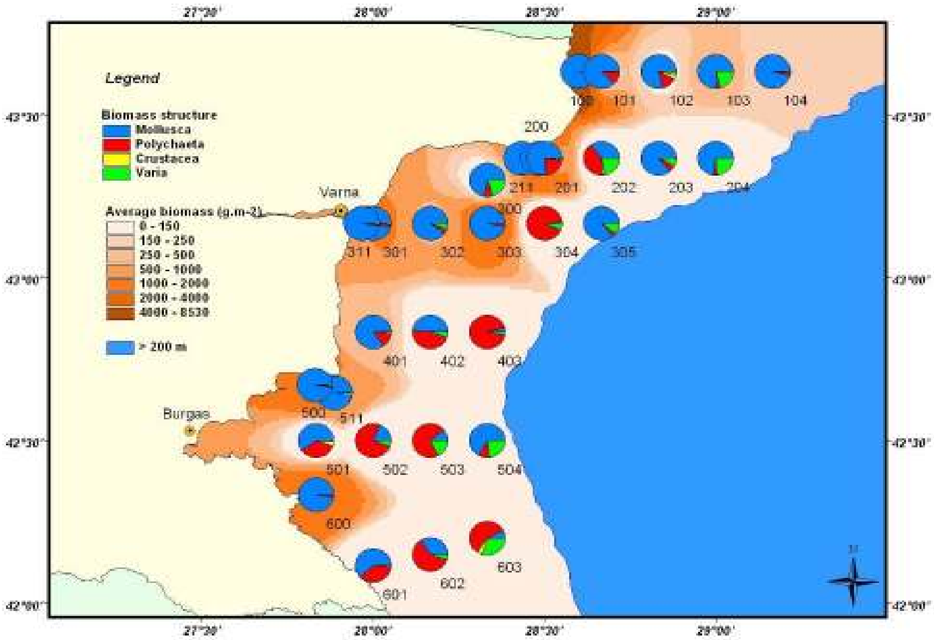

Fig. 8.28. Distribution of average macrozoobenthos biomas on the Bulgarian Black Sea shelf and biomass structure at sampling stations, summer 1998-2002.

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.

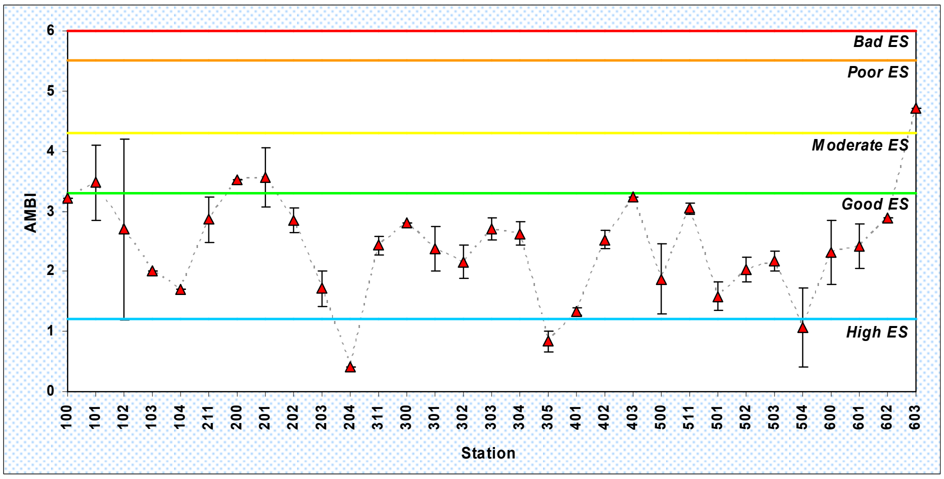

Fig. 8.29. AMBI values (mean ± st. error) at sampling stations (according to Fig. 8.26) on the Bulgarian Black Sea shelf, summer 1998-2002 and thresholds for five ecological state categories.

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 dominat 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 molluscs' 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 molluscs' 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 molluscs 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 molluscs 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 molluscs 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).

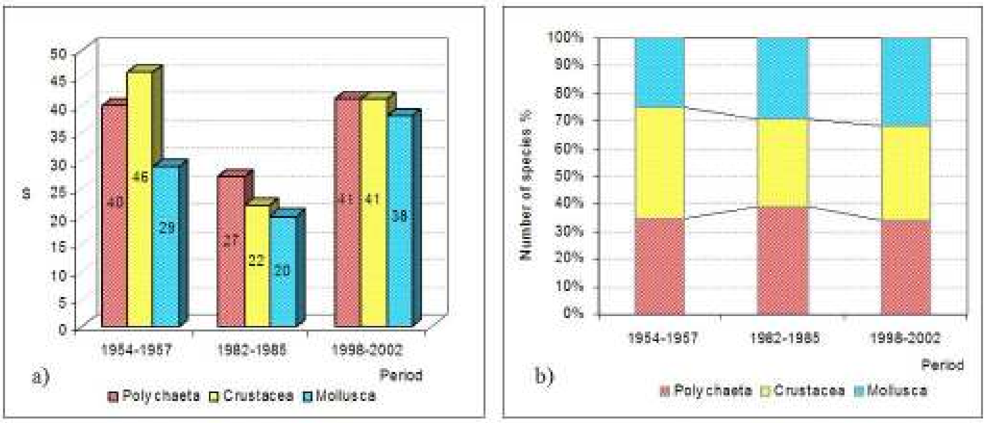

Fig. 8.30. Alterations in (a) total number of species (S) and (b) taxonomic structure of benthic macrofauna over the "pristine" period 1954-1957, the intensive anthropogenic eutrophication period 1982-1985, and the recent period 1998-2002.

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 predominat 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.*

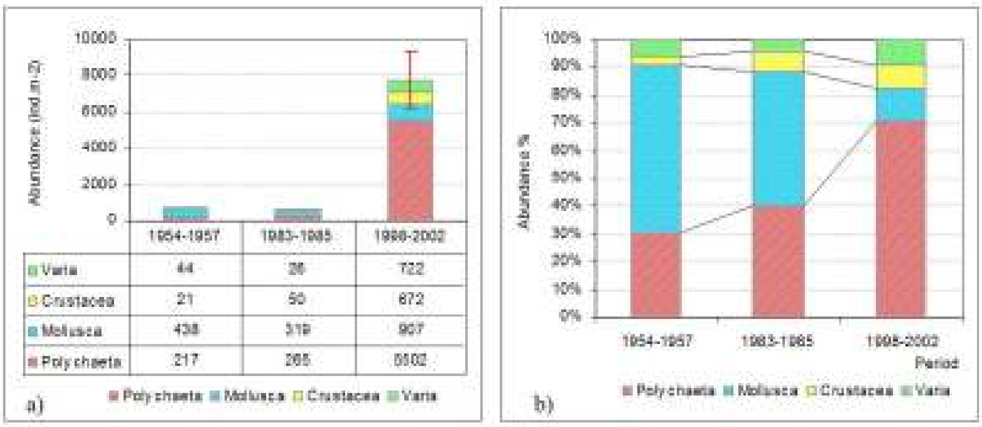

Fig. 8.31. Alterations in (a) total abundance and (b) percent abundance structure for the "pristine" period 1954-1957, the intensive anthropogenic eutrophication period 1982-1985, and the recent period 1998-2002.

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 radiply. 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-Beroe* 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 molluscs 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).

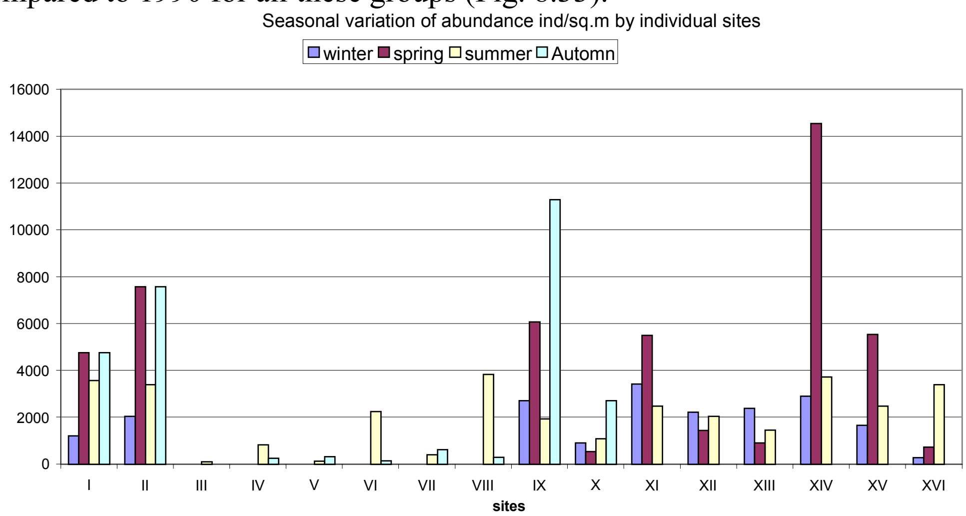

Fig. 8.33. Seasonal changes of macrozoobenthos abundance (ind·m^{-2}) at 16 coastal stations along the Georgian shelf waters in 2003-2004.

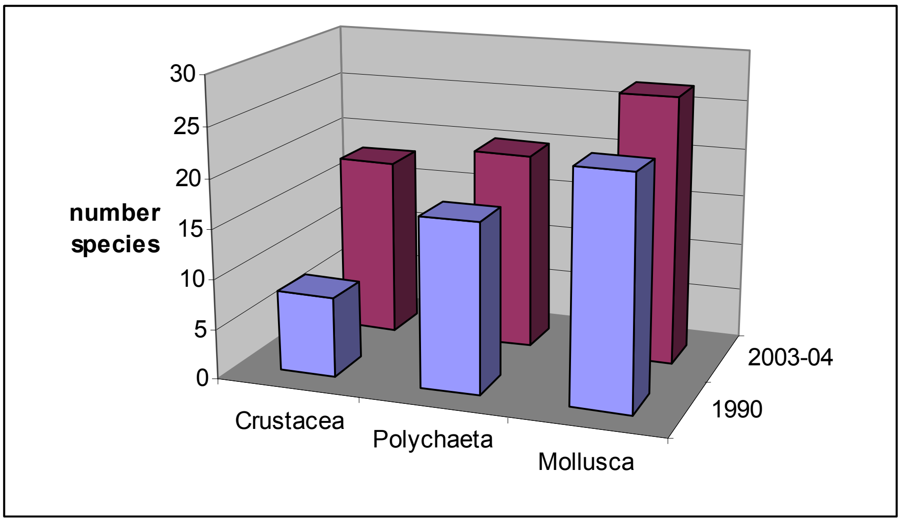

Fig. 8.33. Species number of main macrozoobentic group registered in 1990 and 2003-04 observations along the Georgian coast.

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 clay1	110	1.1	0	Heteromastus filirormis,
	yellow sand	260-820	3.45-87.1	0.8	Rapana thomasiana1,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	Chamellea gallina
	Black silt with smell	300-3840	0.2-5.4	0.1-0.2	Ceritidium pusillum, Melinna palmate

[1] 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. 8.35). The previous studies (Chikina and Kucheruk, 2004; 2005) indicated that the northeast Black Sea coastal waters are 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

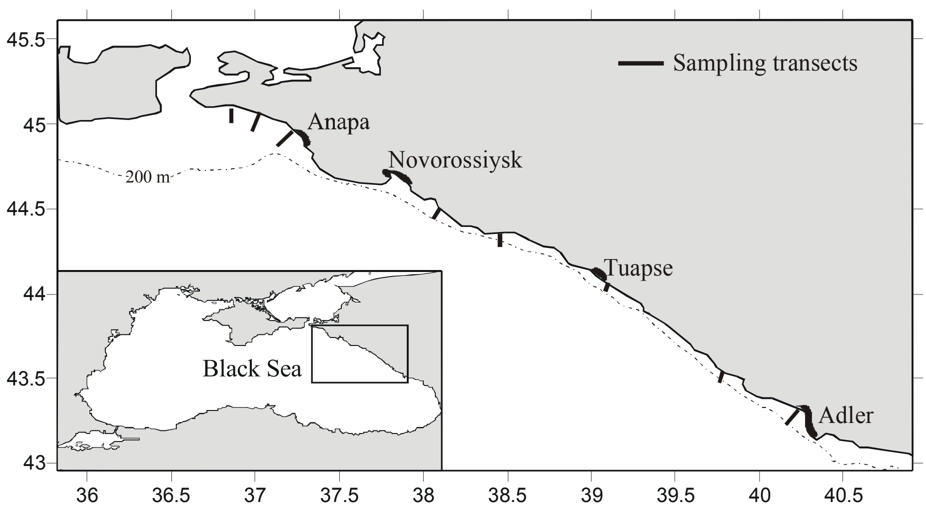

Fig. 8.35 Location of sampling transects in 2001-2007.

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 *Mythilus 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 *Mythilus 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. 8.36). 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.

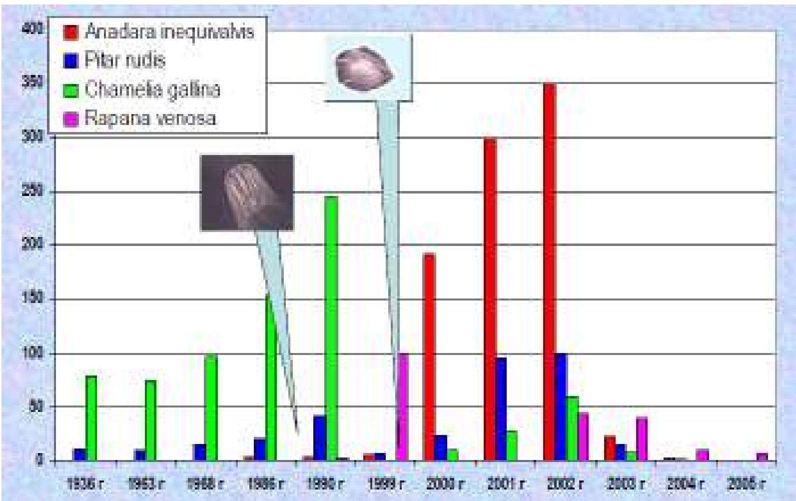

Fig. 8.35. Long-term changes in biomass of dominant macrozoobenthic species at 10-30 m depth range in the southern Caucasian coastal zone.

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 *Cystoseria* 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 *Mythilus 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 attacted by 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 on 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 engouraging 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 zoobethos 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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