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BIOLOGICAL DIVERSITY OF THE COASTAL ZONE OF THE CRIMEAN PENINSULA: PROBLEMS, PRESERVATION AND RESTORATION PATHWAYS

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The results of complex hydrochemical, hydrobiological and ichthyological investigations by IBSS, NAS of Ukraine, realized in 6 regions of the coastal zone of the Crimean peninsula in the Black Sea and the Sea of Azov are given. The main negative factors causing changes in structural and functional characteristics of hydrobiocenoses in the regions studied are analyzed and "hot ecological spots" are isolated. Variants of different methods of management of the coastal ecosystems, including construction of artificial reefs and usage of biological filters for water cleaning, protection and recreation of biological diversity are taken into consideration.
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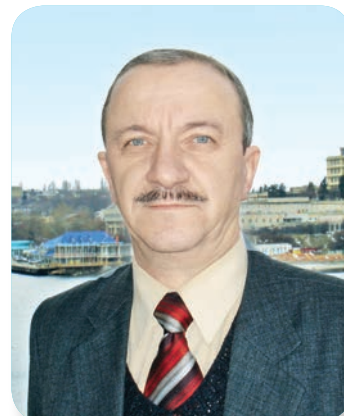
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INTRODUCTION

Environmental disturbances have become a serious challenge to the human race. In the overwhelming majority of countries the top authorities have made and are making steps towards biodiversity preservation, sensible exploitation of natural resources, be it living or inanimate, anthropogenic pressing minimization, environmental rehabilitation or conservation. After the global significance of saving flora and fauna has been fully realized, a series of pertinent international conventions were signed and a large number of international ecological programs proposed and implemented. Ukraine has also contributed to this through participation in the UNO Convention for the Protection of Biological Diversity (995 030), Pan-European Strategy for the Preservation of Biological and Landscape Diversity and in many others. Located amidst Europe, Ukraine has every reason to be involved because its nature and people have long been subject to severe harmful impacts from the national industry and man-caused national and continental disasters. Suffice it to remember the tragedy of Chernobyl, the excessively polluted air, water and soil in highly industrialized Ukrainian regions, the degradation of ecosystems in the Black Sea and the Sea of Azov. The importance of urgent nature-protection actions has been recognized and declared in the Constitution of Ukraine (254k/96-VR), some other legislative acts, the international obligations assumed by Ukraine determined the mainstream state policy in the field of environment protection, natural resource exploitation and environmental safety in conformity with the Statute of Verkhovnaya Rada (Supreme Council of Ukraine) of 05.04.98, № 188/98-VR and in some other relevant laws and regulations.

Highly dynamic coastal zone is a key factor in functioning of marine and shore biocenoses. Under rational nature use coastal zone management that implies protection, preservation and balanced resource exploitation acquires special importance in economical activity planning.

At present a critical problem exists: coastal ecosystems are getting less stable because of human activity; the variety of the threats includes continual inflow of pollutants, eutrophication, building of hydrotechnical constructions, dumping and mining operations that destruct biocenoses, bottom trawling and overexploitation of bioresources and also immigration of alien species aggressive for the native flora and fauna.

Uneasy situation has developed near the shores of the Black Sea and the Sea of Azov where the disturbances have noticeably changed coastal ecosystems. Until the mid-1970s the Black Sea shelf had been a biofilter composed of seston-eating mollusks which dominated by biomass in most bottom biocenoses.

At present, bottom biocenoses on the Crimean shelf and along most of Ukrainian coastline are depressed, thereby reducing natural biological self-purification rate and, correspondingly, the recreation potential of the entire coastal zone. Evidently, the macrobenthos communities have lost their significance as the influential link in food chain of the ecosystem. The problem should be solved as soon as possible otherwise the continually increasing influx of untreated industrial and domestic sewage will create a disaster area of the sea.

Regrettably, but natural restoration of the sea-bottom biocenoses to the original scope is not possible even if any economical activity was ceased there. Indeed, a complex of measures, preferably national programs, should be urgently taken to rehabilitate coastal ecosys-

tems in the Black Sea and the Sea of Azov. The first step would be an integral assessment of the environment, species diversity and ecological structure of coastal marine biocenoses in Ukraine to enable identification of disturbed seawater areas. Having set the priorities, the rehabilitation program that entails introduction of up-to-date methods for management of coastal marine ecosystems is launched. For this new original technologies should be designed based on natural seawater self-purification by biofouling communities intensified through enlargement of the surface of natural or artificial hard substrates (e.g., artificial reefs, modules for biological water purification, etc.).

The expediency of artificial reefs has been generally recognized; these constructions favor faster species diversity restoration and natural biological purification of sea water that enables dozen- and hundred-fold increase in the productivity of biota, commercial species in particular, and due functioning of the local marine communities.

1. MATERIAL AND METHODS

This research is based on results of the hydrological, hydrochemical and hydrobiological surveys made during 2010-2011 within the framework of the project of UNESCO participation Programme "Elaboration and use of modern environmental management methods in rehabilitation and protection of coastal zone of the sea" and on data of the earlier investigations having been conducted since 2000. Material was collected by specialists of the Institute of Biology of the Southern Seas (IBSS) during the complex expeditions to the coastal zone of the Crimean peninsula; four sampling sites (Karkinit Gulf, Tarkhankut peninsula, the coastal zone and some bays of Sevastopol, Cape Martyan) were located in the Black Sea and two (Cape Kazantip, Eastern Sivash Gulf) in the Sea of Azov, six altogether (Fig. 1.1).

Fig. 1.1. Geographic position of the investigation areas at the Crimean coastal zone

During the expeditions, at the fixed stations seawater temperature and salinity were measured and samples of bottom sediment were taken in which the content of oil products and heavy metals was determined. For the hydrobiological study samples of phyto – and zooplankton and macrozoobenthos were taken, and fishes caught.

All the hydrochemical and hydrobiological works were made at the Department of Marine sanitary hydrobiology and the Department of Plankton of IBSS, in the laboratories certified for making environmental control measurements within the State metrological control competence (Certificate of standardization PI – 072/10 of 14 December 2010, valid till 14.12.13, State Enterprise "Sevastopol research-and-production centre for standardization, metrology and certification"; Certificate of attestation Reg.№ PI – 051/09, of 01.12.09, valid till 01.12.12, State Enterprise "Sevastopol research-and-production centre for standardization, metrology and certification").

1. Material and methods

Table 1.1. The areas and dates of the complex expeditions carried out

Surveyed location	Time
Eastern part of the Karkinit Gulf	23 – 25 June 2008 7 – 17 August 2009
Coastal zone of the Tarkhankut peninsula	26 – 27 June 2008 16 – 17 August 2009 16 – 22 June 2011
Coastal zone and bays of Sevastopol	monitoring since 2006
Coastal waters of the Cape Martyan	8 – 15 September 2010 31 August – 4 September 2011
Coastal and adjacent waters of the Cape Kazantip	monitoring since 2006
Eastern Sivash Gulf	18 – 23 June 2008 12 – 13 July 2009 6 – 7 August 2010 16 – 26 May 2011

Phytoplankton. Samples of sea water were taken from the surface layer and condensed to 50-70 ml in the inverse filtering funnel with 1-μm nuclear filters (Dubna, Russia) (Sukhanova, 1983); the concentrated product was fixed with 37% formaldehyde. Condensed samples were handled under the light microscope Amplival "CARL ZEISS" (×125, 250 and 500) in the Laboratory of microplankton, IBSS. Nanophytoplankton cells (2-16 μm large) were counted in the 0.01-ml drop on the glass and microphytoplankton (larger than 16 μm) in a 0.75-ml Naumann chamber. Taxonomically different cells were counted, their morphometric parameters determined and individual cell volumes computed (Senichkina, 1978) as well as the abundance and biomass.

Zooplankton. Zooplankton samples from different coastal seawater areas of the Black Sea and the Sea of Azov were collected during 2010-2011. The stations were positioned at different depths, a boat was not always available therefore two sampling techniques were used. At shallow, to 1-m depth, stations usually a 100-l sample of seawater was filtered through a sieve with the mesh not larger than 140 μm set between two rings of the filtering bowl. Sea water above the filter was poured out into a laboratory vial and fixed with 40% formaldehyde (4% final formaldehyde concentration); the used sieve was placed into the vial. In depths, a boat was not always available therefore two sampling techniques were used. At shallow, to 1-m depth, stations usually a 100-l sample of seawater was filtered through a sieve with the mesh not larger than 140 μm set between two rings of the filtering bowl. Sea water above the filter was poured out into a laboratory vial and fixed with 40% formaldehyde (4% final formaldehyde concentration); the used sieve was placed into the vial. In the laboratory the sample was handled and the retained zooplankton washed off from the sieve. Above the deep-water sites zooplankton was collected with Juday net equipped with the sieve (140-μm mesh size); the sample was condensed using a rubber syringe or a filtering bowl equipped with the sieve with smaller mesh size. Further treatment was as the first technique states.

Plankton samples were handled in the Laboratory of zooplankton, IBSS, in conformity with the routine procedure. Pelagic forms were identified to species and to developmental stage and benthic larvae to higher taxa. All these organisms were measured for further biomass calcula-

Fig. 1.2. Sampling and sample handling in the expeditions

Fig. 1.3. Sampling and sample handling in the expeditions

tions. Biomass was calculated depending upon species, developmental stage and individual dimensions using the standardized weight key.

Macrozoobenthos. In the Sevastopol bay the year-round macrozoobenthos monitoring over the standard station grid from 2-18 m depths has been carried out for more than three decades. (Fig. 1.4). During 2011 the surveys were made at 7 coastal stations near the Kazantip peninsula (Fig. 2.6). Samples of macrozoobenthos were taken in two replications from 3-11 m depths by a Petersen dredge with the 0.038 m^2 capture area and from 1 m depth by a hand bottom sampler with the 0.08 m^2 capture area. The samples were cleansed through a sieve (1-mm mesh size) and fixed with ethanol. Species composition, numbers and fresh weight of the fixed organisms were determined in the laboratory. Organisms belonging to macrofauna, except for Oligochaeta, Nemertina and Platyhelminthes, were identified to species according to (Vodyanitsky, 1968; 1969; 1972). Bivalve mollusks were dissected and weighed after fixing solution had been removed from the mantle cavity.

Fig. 1.4. Map of sampling locations in the Sevastopol Bay

Shannon diversity index H' (by biomass and abundance, 2 base logarithm) and Pielou evenness index J' were computed using program DIVERSE, package PRIMER–5. To define ecological status of the seawater areas under the examination, AMBI (M-AMBI) (Borja et al., 2000) indices were calculated applying the software product accessible on the Technological Centre AZTI Tecnalia website (http://www.azti.es); the values of Black Sea boundary indices suggested by an intercalibration expert team were taken into account. (WFD intercalibration..., 2009).

Ichthyofauna. In the surveyed seawater areas, except for the nature reserves Cape Martyan and Kazantip, we used gill nets with the mesh size 12, 16, 18 and 20 mm, a towed scoopnet netting bag with the semicircular mouth 1.6 × 0.8 m (1 м^2 capture area) equipped with a 6.5-mm mesh and a variety of hand scoop nets with 2-5-mm mesh. Towed scoopnet netting bag trawling for 50-m distances was made in three replications. The hand scoops 30-35 cm in diameter were used when diving to 8 m deep.

In the Karkinit Gulf the upper 1.8-m seawater layer 50-400 m off the shore was fished at 8 stations located along the gulf's coastline from the western extremity of isle Dzharylgach to the Tarkhankut peninsula.

1. Material and methods

Fig. 1.5. Geographic position of the Sevastopol bays

In the coastal sea of the Tarkhankut peninsula fishing was made at 7 stations. At Cape Martyan only visual identification and count were performed, fish were caught in the 10-m water column on three stations out of the nature reserve.

Most of the material for the investigation was collected during 1996-2011 in the vicinity of Sevastopol, SW Crimea: from the coastal zone between Cape Tolsty, half-kilometer northward of the outerpart of the Sevastopol bay, and Cape Aya, and from Sevastopol, Quarantine, Streletskaya, Kruglaya, Kazachiya and Balaklava bays.

Fishing gear used year through in the open-sea coastal zone and in Kazachiya bay in the depth range from 2 to 10-30 or, infrequently, to 60 m consisted of gill nets with 10-200-mm mesh size and hooked fishing tackle. In warm season of a year small bottom-dwelling fishes were caught to 5-m depths by divers with a hand net scoop (25-30 cm in diameter, 1-mm mesh); occasionally, just the same way of fishing was practiced in the Sevastopol, Kruglaya and Quarantine bays. Since 2006 the near-mouth part of Sevastopol bay and since 2008 of the Streletskaya and Kruglaya bays have been monthly trawled with the towed scoopnet netting bag year round. At the fixed stations spatial position of which was under GSP-navigator control a series of touch-the-bottom sac trawling were carried out at 0.8 to 3m depths. In the entrances of the Sevastopol and Quarantine bays standard bottom trap nets BS-3 (mesh size 12 mm) were set. At times, commercial catches of the pound nets in the mouths of the Streletskaya, Kazachiya and Balaklava bays were scanned and fishes brought by the local amateur fishermen and fishing divers were examined.

Visual underwater observations were included in the schedule of ichthyological surveys in the water reservoir of Kazantip nature reserve; in the neighboring Arabatskiy and Kazantip gulfs standard fishing gear was used and commercial hauls of the pound nets were studied.

In the Eastern Sivash Gulf fish were caught at 9 sampling stations; besides, commercial hauls of the pound nets were examined.

Submarine visual observations, photo- and video works were performed at *in situ* studying species composition, behavior and distribution of fish.

All caught fishes were identified to species and pertinent biological tests made in conformity with the generally accepted techniques. Overall morphometric analysis was made and newly found, rare and unidentified species photographed. The fishes were fixed with 4% formaldehyde, labelled and included to the collection of Black Sea-and-Sea of Azov fishes, the property of IBSS; specimens available in duplicate have been passed to the National Museum of Natural History, NAS of Ukraine (Kiev). Altogether more than 8000 fish juvenile and adults were the objects of the research.

2. DESCRIPTION OF THE SURVEYED SEAWATER AREAS

Karkinit Gulf. Lying between the continent and the NW coast of the Crimea, the Karkinit Gulf, 118 km long and to 80 km wide, is the largest in the Black Sea and the Sea of Azov. Because of its special physical-geographical, hydrological, biological and fishing characteristics the gulf has been acknowledged as one of the five native zones distinguished along the Crimean coast of the Black Sea (Vodyanitsky, 1949). Bakal sandy spit and Bakal shoal divide the Karkinit Gulf into two parts – the deep-water (to 36 m depths) in the west and the relatively isolated, not deeper than 10 m, in the east; the first is characterized by free water exchange with the sea and the latter by the coastline indented by numerous small and shallow bays and coves and the extensive sand banks (Fig. 2.2).

These features have predetermined the marked difference in the hydrological and hydrochemical conditions of the two areas. Considerable variation of the parameters is typical of the eastern part of the gulf. Temperature of the sea surface there changes from – 1°C in winter to 26.9°C in summer and to 30°C on the shoals (Pukhtyar et al., 2003). The expedition records show that in June the sea water warmed to 24.5 – 26.0°C and in August to 17.0 – 18.2°C at the sunrise and 22.0 – 25.5°C in the afternoon with daily gradients reaching 6.5°C. As stated elsewhere, average seawater salinity in the gulf is within 17.3 – 18.6 ‰, increasing during summer to 20.8 ‰ in the east owing to the high-rate evaporation on the shallows (Arnoldi, 1949, Pukhtyar, 2003). In the western part of the Karkinit Gulf salinity decreased to 13 – 14 ‰ only when the western wind brought about brackish river discharge (Bolshakov, 1970). For the three recent decades the patches of low salinity (to 6.9 ‰) caused by freshwater outflow from the irrigation works have been registered in the eastern part near the Swan isles and in the Dzharylgach Gulf (Aleksandrov et al., 2009).

As our data indicate, in summer in the shallow area of the gulf seawater salinity distributes rather unevenly (Fig. 2.1). In the bays Shirokiy, Chatyrlyk and Samarchik (sts. 6 and 7, 10–12) desalinated owing to the freshwater outflow from the fish ponds, rice fields and irrigation canals it varied within the range of 0.8 – 2.7 ‰. Near the shore and in the shallow bays and coves, where the rate of evaporation from the surface was especially high, salinity estimates increased. For instance, in the Dzharylgach Gulf (st. 2) salinity of the seawater was 22.1 ‰, near the Khorly peninsula (sts. 4, 5) 23.9 – 28.0 ‰ and in the Perekop Gulf (st. 8) as high as 34.79 ‰. Depending upon the wind, the surface and limits of abnormal salinity lenses can considerably change. In the open sector of the Kazantip Gulf near the Tarkhankut peninsula salinity of the sea water approximated that in the Black Sea and varied between 17.5 and 18.8 ‰.
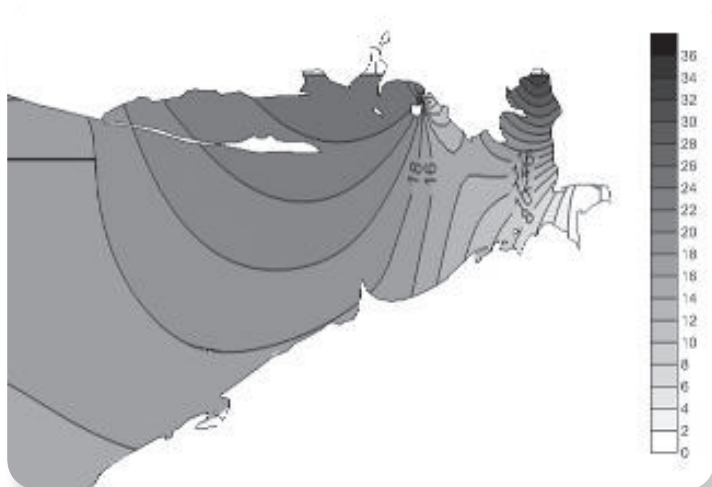

Fig. 2.1. Distribution of salinity in the water upper layer in the Karkinit Gulf

Fig. 2.2. The scheme of the stations location and characteristic landscapes at the Karkinit Gulf coast

Biological productivity in the Karkinit Gulf is remarkably high and marine life, primarily, phyto- and zoobenthos very abundant (Arnoldi, 1949). From the times of antiquity to the mid-20th century sturgeon, mullet, turbot, oyster and mussel fishery prospered there (Zernov, 1913; Vodyanitsky, 1949). Since the 1970s the gulf has been eutrophicated and the sea water and bottom sediments severely polluted with industrial and agricultural discharges and oil and gas extraction; as a result, unique biocenoses have undergone ruinous changes.

Trawling, water turbidity increase, sea bed silting in the western part of the gulf led to destruction of Mytilus, Chara and some other biocenoses concentrated on the sand and shell rock substrate and has been the feeding area for trade fishes (Zaitsev et al., 1992). Besides, the fish stock has been devastated by poaching fishing.

For the recent twenty years the gulf biocenoses, in particular those dwelling in its eastern part, have been only fragmentary studied, therefore little can be said about their current state.

Tarkhankut peninsula. Situated in the western part of the Karkinit Gulf, the Tarkhankut peninsula emerged as Sarmatian limestone elevation; abrasive-terraced and land-slide deposits have shaped its coast (Fig. 2.3).

A variety of hard substrates such as steep submarine rocks with Cystoseira growth and chaotically piled blocks, boulders and stones compose the coastal sea bed. At 8-10-m depths hard substrate gives place to sand and shell debris. The southern coastal zone of the peninsula is well protected from anthropogenic impact. Three-mile belt along the shore is the fishery protection zone in which nature management is specially regulated. Being relatively unpopular for residence and tourism, the region has been sustaining its environmental safety as yet.

Coastal zone and bays of Sevastopol. Stretching all along the coastline of the SW Crimea, coastal zone of Sevastopol with its diverse natural environments occupies special position in Black Sea ecosystem. The nearly 45-km long coastal strip harbors a variety of biotopes characteristic for the open-sea area and numerous bays and coves, morphological and biocenotic peculiarities of which considerably differ (Fig. 2.4). The environment in the inspected area of the sea is typically maritime, with moderate seasonal variations of seawater temperature and relatively steady salinity if compared to the northward. The semi-closed bays in which seasonal temperature variations are different, and some have quasi-stationary desalinated water lenses formed owing to river and submarine freshwater inflow make an exception. The geographic position of the Crimea, extended far southward to nearly the mid-sea is also a factor of influence. Cape Sarych, the southernmost point, lies at only 258-km distance from the Anatolian peninsula; here in the sea surface the seasonal meridional current from Turkey flows that drifts westward from Phoros and streams on along the SW Crimea coastline. Hypothetically, the current can transfer Mediterranean species to the coastal zone and bays of Sevastopol.

The shelter, spawning and fattening grounds available in plenty favor species diversity of the regional ichthyofauna, primarily going for spawning and feeding in spring and for wintering in autumn, their route traditionally bottom and bottom dwelling non-migrant marine fishes. Pelagic migratory fish appear usually when passes along the SW extremity of the Crimea. In warm winters some of the pelagic fishes concentrate

Fig. 2.3. The scheme of the stations location and characteristic landscapes at the Tarkhankut peninsula coast

Fig. 2.4. The scheme of stations location and characteristic landscapes of the coastal zone and bays of Sevastopol

in the coastal zone and in the bays. Along with the marine non-migratory and migratory fishes keeping off desalinated and cold seawater localities, anadromous and brackish-water species from the NW Black Sea and the Sea of Azov also come to winter there (Zernov, 1902; Vodyanitsky, 1949).

The mildly sloping beach and hence mildly increasing depth of the sea, the stony sea floor with sparse boulders and extensive limestone platforms with thick Cystoseira growth are characteristic of the open coastal zone stretching from Sevastopol bay to Cape Khersones. The locality between Capes Khersones and Aya is characterized with a sharp depth increase, the rocky and rock-and-stone submarine relief with cliffs, scattered stones and huge boulders on which Cystoseira grow. Deeper than 8-15 m the hard substrate changes for soft, mainly sandy with a portion of shell debris, and muddy-sandy. Temperature of the sea water usually changes from 7°C in winter to 26°C in summer. During warm season of a year thermocline lies 8 to 35 m deep. In summer months strong southwestern wind gives rise to upwelling when cold near-bottom sea water lifts up to the surface, decreasing the temperature by 10-16°C for several hours. Seawater salinity is about 18 ‰ on the average, inconsiderably fluctuating.

In the examined series of bays five largest – Sevastopol, Quarantinnaya, Streletskaya, Kruglaya and Kazachiya – open into the sea along the 10 km coastal length; Balaklava bay keeps apart, being located 22 km southeast of Cape Khersones. Sevastopol bay stretches for 7 km and is the largest in the Black Sea; the rest of the bays are 1.4 to 3.3 km long. Depths measured in the mid-part and in the entrance of the bays are 5-18 and 17-21 m, respectively.

Geomorphologic characteristics of the sea bed in the bays have much in common. In the shallow along-the-coast sea the bottom are sandy patches interspersed between limestone rocks. On 4-6 m depths hard substrate gives place to sandy and sandy-muddy grounds with occasional shell debris spots; deeper than 8 m silty sediment prevails. The sea floor in the upper part of the bays is more or less silted sand with a minor portion of shell debris; rich patchy seagrass beds of Zostera and Ruppia occur there. Human activity has considerably changed the native coastal relief in Sevastopol and Balaklava bays, and to less extent in Streletskaya bay; in other bays different hydroconstructionss, breakwaters and piers occupy not much of the coastline.

As in the coastal sea zone, the outermost section of the bays cools to 6.9°C (rare less then 4°C) in winter and warms to 26.8°C in summer, the salinity changes from 16.9 to 18.2 ‰, correspondingly. During severe winters large or small extent of the surface is covered with ice. In summer the sea water on the shallows warms to 30°C and even to 32°C. In the sites receiving subterranean or submarine freshwater inflow temperature fluctuates only slightly while seawater salinity drops to 1.8 – 3.2 ‰.

Cape Martyan. This is a typical coastal site of the Crimean Southern shore. The hard-substrate submarine relief begins with the near-shore pebble-and-boulder strip changing deeper for conglomerations of huge seaweed-covered blocks and the underwater rocks towering above the sea surface (Fig. 2.5). Soft sediments are coarse sand and shell debris which become coated with mud with increasing depth. Hydrological conditions are much as in the sea between capes Khersones and Aya.

Fig. 2.5. The scheme of stations location and characteristic landscapes of the Cape Martyan coast

2. Description of the surveyed seawater areas

Cape Kazantip. The Cape Kazantip represents a peninsula, situated in the southern part of the Sea of Azov at the Kerch peninsula. Its coastal water by its characteristics relates to the central region of the sea. The Cape Kazantip has oval form and it is elongated from the north-east to the south-west; mount Kazantip (106 m) is located in the eastern part; there is low part in the centre, precipitous rocky coast is indented with sheltered small bays (Fig. 2.6). The Kazantip nature reserve occupies the shore to the width of 150 – 1000 m and 300 m inshore waters along all the peninsula perimeter; oil mining takes place in it's a low central part.

Depth gently increasing from the water edge, the sea gets 7–8 m deep at a distance of 200 – 300 m off the shore. The hard sea floor in the narrow coastal strip is formed by rocks, large boulders and stones composed of the fossilized siliceous skeletons of Bryozoa; at depths greater than 2–3 m the bottom is sandy and muddy-sandy. In winter the sea is covered with ice and in summer warms to 24 – 25°C; in July and August, the hottest months, the temperature can rise to 28.5 – 32.5°C. Salinity in the sea surface fluctuates as inconsiderable as 9.4 – 10.7 ‰. Wind, sometimes reaching full strength in 2 hours, is the main factor inducing seawater turbulence. Strong northeastern winds can rise waves to 2.1 – 3.0 m high.

Eastern Sivash Gulf. The 120-km long shallow (less than 1 m depths prevail) gulf separates the NW Crimea and Arabatskaya strelka spit; in the northeast the Tonky strait, 3.2 km long, to 150 m wide and to 2 – 4 m deep, connects it with the Sea of Azov (Zenkevich, 1963) (Fig. 2.6). The coastline is deeply indented, with many relatively isolated creeks, four largest are interconnected with the small sounds. In as shallow gulf as the Eastern Sivash seawater temperature dramatically changes from – 1°C in winter to 30 – 35°C in summer (Zenkevich, 1963). Until the middle of 1960-th seawater salinity estimates increased from the Tonky strait towards the Eastern Sivash southern part, fluctuating between 13.3 and 35.5 ‰ in the first creek, 38.3 – 83.9 ‰ in the second, 119.8 – 129.2 ‰ in the third and 139.0 – 155.9 ‰ in the fourth (Almazov, 1960). According to Pritchard's classification, Sivash was a hypersaline estuary, where the higher water evaporation rate and hence the typical salinity increased with remoteness from the strait towards the upper reaches locality (Pritchard, 1967).

Though construction of the North-Crimean canal (NCC) has considerably changed hydrochemical regime in the Eastern Sivash, complex investigations of the ecosystem were made only in summer months of 2003-2004, after about half-a-century time-out. It was found that all over the gulf the water has been markedly desalinated and the salinity has been quite differently distributed, being the lowest – a few ppm (‰) – in the coastal sites harboring freshwater discharge outlets. In the tested large creeks the average water salinity was within 12.7 – 14.4; 17.9 – 19.2; 13.8 – 18.3 and 21.7 – 26.0 ‰ in the 1st, 2nd, 3rd and 4th, correspondingly (Zagorodnyaya, 2006); close to the Tonky sound it was 10.6 – 12.6‰, the maximum of 29.1‰ was registered in the fourth creek.

During summer surveys of the Eastern Sivash, conducted in 2008-2011, water salinity measured in the four-creeks series was 17.7; 21.5; 18.4 – 26.7 and 34.6 – 38.2 ‰, respectively, while within the 100-300-m distance off the canal outlets it dropped to 1 – 8 ‰. The discontinued desalination of the Eastern Sivash can be owing to the substantially decreased flux through the NCC once designed for massive irrigated crop-farming and rice-growing.

Fig. 2.6. The scheme of stations location and characteristic landscapes of the Cape Kazantip coast and Tatarskaya bay (below)
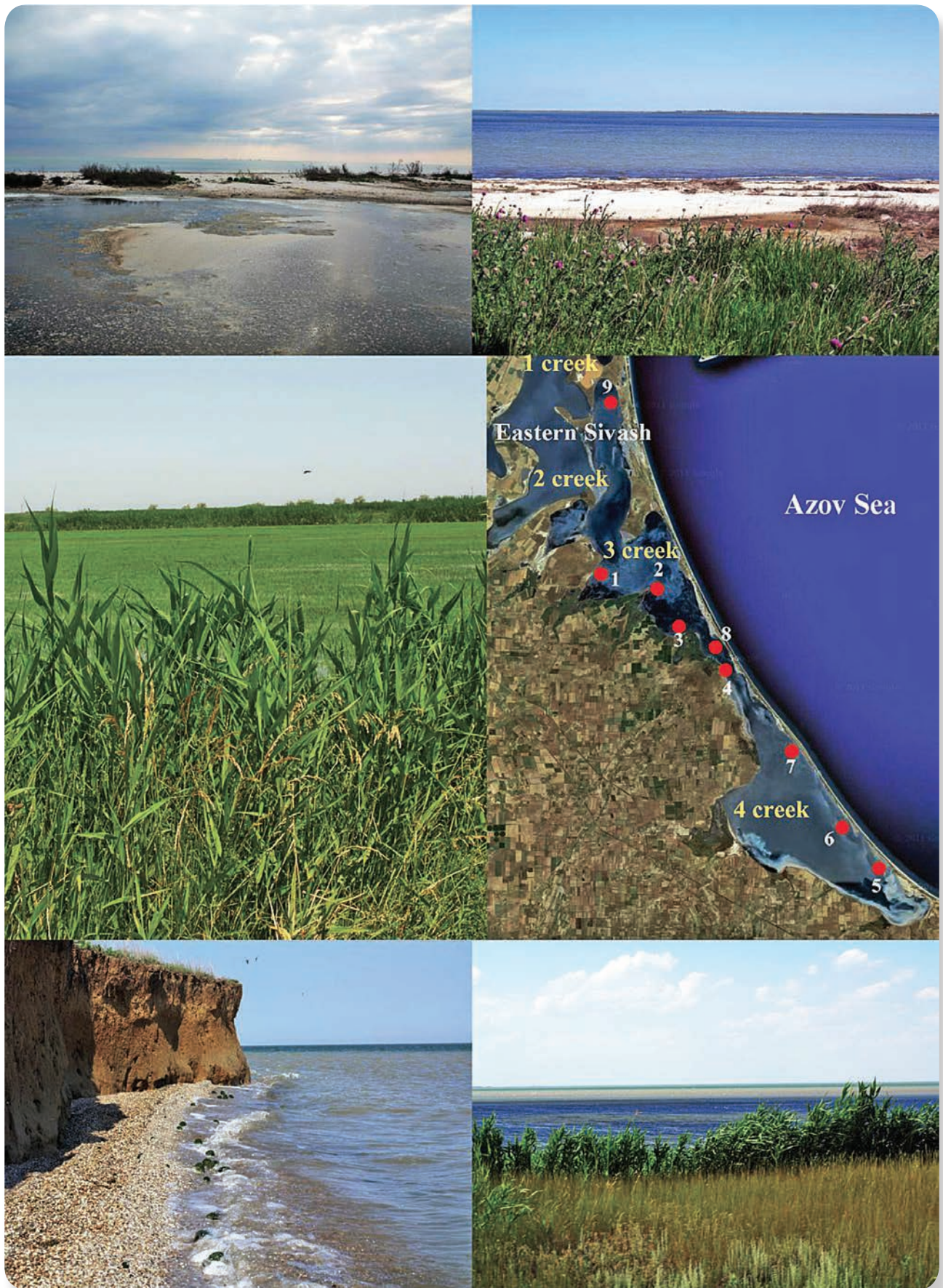
Fig. 2.7. The scheme of stations location and characteristic landscapes of the Eastern Sivash Gulf coast.

3. THE SPECIES DIVERSITY, ECOLOGICAL STRUCTURE AND CONDITION OF HYDROBIONTS COMMUNITIES OF THE CRIMEAN COASTAL ZONE

3.1. Phytoplankton

Phytoplankton in the Crimean coastal zone was under studies since the early 20th century, especially its micro- and nanoplankton forms were studied quite well (Morozova-Vodyanitskaya, 1948; Kovaleva, 1969; Georgieva, Senichkina, 1996). Yet it is essential to carry investigations on because phytoplankton is an important component of marine ecosystems and makes the base for trophic pyramid. Microalgae reliably indicate productive seawater areas; the degree of anthropogenic load upon aquatic biocenoses is assessed from their species composition and abundance. Exotic phytoplankton species invasions, adaptation and influence on native phytocenoses in the Black Sea and the Sea of Azov have been a serious challenge. Our recent surveys provided the insight into the species composition, quantitative structure and spatial distribution of phytoplankton in the Crimean coastal zone and into the effects that human activity in this zone produces on the phytoplankton community.

Phytoplankton in the Karkinit Gulf. During 2007 the total diversity of phytoplankton in the gulf was determined as 41 phytoplankton species and varieties, attributed to 4 divisions and 2 taxonomic groups (Table 3.1.1).

Table 3.1.1. Phytoplankton species quantity in different parts of the Crimean coastal zone in 2007–2010 years

Ordo	Cape Kazantip			Karkinit Gulf			Eastern Sivash Gulf		
	2007	2009	2010	2007	2008	2009	2008	2009	2010
Bacillariophyta	12	12	10	26	20	29	19	6	10
Dinophyta	10	15	8	7	11	14	15	12	8
Haptophyta	2	6	2	0	0	9	0	4	0
Chrysophyta	0	2	0	0	1	2	1	0	0
Chlorophyta	1	3	0	4	5	4	2	0	1
Cyanobacteria	4	5	1	4	4	4	3	1	0
Cryptophyta	0	1	0	0	1	0	0	0	0
Xantophyta	0	0	1	0	0	0	0	0	0
Euglenophyta	0	0	0	0	0	1	0	0	1
TOTAL	**29**	**44**	**22**	**41**	**42**	**63**	**40**	**23**	**20**

Bacillariophyta prevailed: 26 species, i.e., 63%; Dinophyta, Cyanophyta and Chlorophyta were represented by 7, 4 and 4 species, contributing 17, 20 and 20%, respectively. *Cylindrotheca closterium* and *Navicula sp.* dominated in the Bacillariophyta, *Gymnodinium sp.* in the Dinophyta, *Merismopedia punctata* in the Cyanophyta, and *Gloeotila sp.* in the Chlorophyta. A large number of freshwater microalgae were also found in the samples. Similar estimates were obtained in 2008; in 2009 the number of species increased to 63. As during 2007-2008, the diversity of Bacillariophyta was highest – 29 species and varieties, and the number of Dinophyta species increased to 14. Different from the earlier investigations, that time in the collected samples Prymnesiophyta, Cyanophyta and Chlorophyta, Chrysophyta and Euglenophyta (9, 4, 4, 2 and 1 species, correspond-

ingly) were registered. At the sampling stations solitary findings of *Apedinella spinifera*, the alien Chrysophyta, were made. Phytoplankton abundance was within the range of 17 – 322 million cells/m³ and biomass 25 – 625 mg/m³. In the shallow waters of the Karkinit Gulf, Bacillariophyta, that are usually associated with substratum (benthic, epiphytic *Cocconeis scutellum, Gyrosigma sp., Licmophora gracilis, Pleurosigma elongatum, Synedra tabulate, Syn. tabulate var. obtuse* and *Achnanthes longipes, Amphora insecta, Entomoneis paludosa*, correspondingly) were numerous. In the seawater localities receiving freshwater effluent from the rice fields, freshwater *Gloeocapsa sp., Formidium sp., Chlorosacculus sp., Scenedesmus quadricauda* and *Eutreptia lanowii* added to the phytoplankton diversity and abundance.

Phytoplankton of the Sevastopol bay and coastal sea water of Sevastopol. In a sizeable quantity of phytoplankton samples collected in this area during 2009-2011 (Fig. 3.1.1) 149 species and varieties of 8 divisions and 2 taxonomic groups were found. Dinophyta, Bacillariophyta and Haptophyta contributed largest shares to the total number of species – 61, 51 and 14 species, or 41, 34 and 9%, respectively; the diversity of Chrysophyta, Cyanophyta, Chlorophyta, Cryptophyta and Euglenophyta was incommensurably poorer. This proportion approximates that derived by N.V. Morozova-Vodyanitskaya (1948) for the main taxonomic groups of phytoplankton all through the Black Sea. In 2011, for the first time in the recent decade, Dinophyta regained the diversity championship, with genera *Protoperidinium, Gymnodinium, Dinophysis* and *Prorocentrum* represented by 12, 6, 6 and 5 species, correspondingly. Relatively diverse were diatom genera *Chaetoceros, Thalassiosira* and *Licmophora* (17, 4 and 3 species, correspondingly) and also *Calyptrosphaera* and *Syracosphaera* (4 and 3 species, correspondingly). Coccolithophorales *Emiliania huxleyi* were registered in the samples year through; other taxonomic groups were found only solitary. The surveys made at the stations have shown two maximums, one in April and the other in November 2009, when the number of recorded species amounted to 47 and 49, respectively.

Field records from the coastal sea water of Sevastopol have disclosed two peaks of the abundance, 325 and 385 million cells/m³, in June 2009 and in February 2010, correspondingly, when Bacillariophyta (*Sceletonema costatum, Cerataulina pelagica*) prevailed. During 2009 spring and autumn maximums estimated 992 and 912 million cells/m³ were registered at the central part of Sevastopol bay in April and in October, respectively. Among the main contributors were both small-cell (*Sceletonema costatum, Chaetoceros socialis*) and large-cell (*Cerataulina pelagica, Proboscia alata, Pseudo-nitzschia delicatissima*) species as well as at Dinophyta – *Prorocentrum cordatum* and *Goniaulax spinifera*.

In June 2009 an outbreak of Coccolithophorales *Emiliania huxleyi* happened, presumably related with upwellings and a sudden increase of inorganic phosphorus concentration in the Sevastopol bay. For the recent years the abundance of as yet diverse Dinophyta has decreased because of the large freshwater inflow from the Chernorechenskoye storage reservoir.

Measurements carried out from July to October 2009 in the coastal sea water of Sevastopol estimated the phytoplankton biomass as 275 – 203 mg/m³. At the lower reaches of the Sevastopol bay maximums developed in July and October – nearly 2 and 3 g/m³, correspondingly, and at the central part of bay in June-July and October – 3 and 2.8-3 g/m³, correspondingly. Large-sized Bacillariophyta (*Cerataulina pelagica, Proboscia alata, Pseudosolenia calcar-avis*) and Dinophyta (*Prorocentrum micans, P. cordatum*) have been the major contributors to the biomass.

Average volume of phytoplankton cells varied depending on the cell size of dominant species and was as large as nearly 16 000 μmi in July and October 2009.

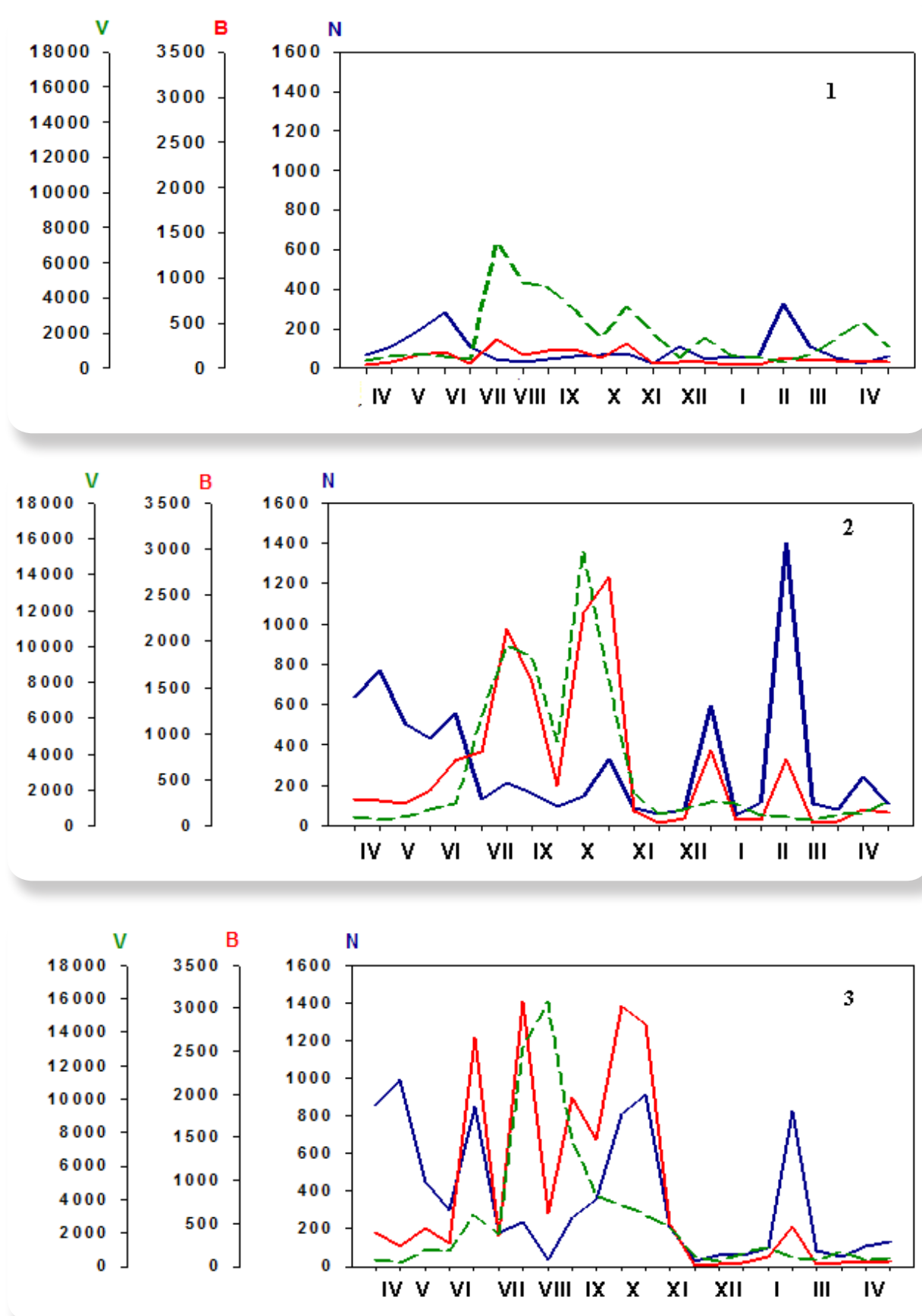Fig. 3.1.1. Season dynamics of average volume (V, mkm^3), biomass (B, mg/m^3) and abundance (N, mln cels/m^3) of phytoplankton cells in the coastal waters of Sevastopol (1), in the lower (2) and central (3) part of the Sevastopol bay off April 2009 up to April 2010

Introduction

Our observations point out that the coastal waters near Sevastopol represent a rich assemblage of nearly all classes of phytoplankton occurring in the Black Sea; the species composition, abundance and biomass are subject to interannual and seasonal variations, while the list of dominating species has not altered for the decades.

Phytoplankton at the Cape Kazantip. The major producer in this seawater area, phytoplankton there is represented by fresh-, brackish- and saltwater complexes. In the samples of phytoplankton taken from the coastal zone of Cape Kazantip, Arabatsky and Kazantip gulfs in June 2007, 29 species and varieties, five divisions and one taxonomic group (tiny flagellated cells were not identified because of too small dimensions) were determined (Table 3.1.1).

Bacillariophyta and Dinophyta (12 and 10 species and intraspecific taxa, respectively, or 41 and 34% of the total species number, respectively) prevailed in the phytocenosis. Cyanophyta, Prymnesiophyta and Chlorophyta were represented by 4, 2 and 1 species, correspondingly, i.e., 14, 7 and 3%, respectively. Among Bacillariophyta, large-sized *Pseudosolenia calcar-avis*, mass growth of which was registered at every station, fundamentally dominated by both abundance and biomass. Moreover, during that period we observed a local event of fish kill and traced the associated abiotic and biotic factors (see chap. 4). In summer 2009, 44 species and varieties of 7 divisions and one taxonomic group (small flagellate) were found in the vicinity of Cape Kazantip. Largest diversity of species and intraspecific taxa was characteristic of Dinophyta and Bacillarioiphyta – 15 and 12, correspondingly. Prymnesiophyta, Cyanophyta and Chlorophyta were represented by 6, 5 and 3 species, respectively, and Cryptophyta and Chrysophyta only solitary found. During 2009 large-celled *Rhizosolenia setigera* (Bacillariophyta), non-native for the seawater area, prevailed in the phytoplankton. Off Cape Kresty blooming *Gymnodinium sp.* (Dinophyta) had colored the sea brown. Cyanophyta *Gloeocapsa sp.*, *Microcystis sp., Merismopedia punctata* were registered at all sampling stations. When the survey was carried out, the sea in the area though to 28.2 – 28.8°C warm was turbulent that, probably, inhibited phytoplankton bloom and fish rill development. In 2010 near the Cape Kazantip 22 species and varieties of 5 divisions were found; Bacillariophyta and Dinophyta dominated, Prymnesiophyta, Cyanophyta and Xantophyta were only solitary.

Phytoplankton of the Eastern Sivash Gulf. The largest diversity in the gulf was registered in 2008 when 40 species and varieties of 5 divisions and one taxonomic group (small flagellate) were identified (Table 3.1.1). The major contributors to the total diversity were Bacillariophyta, Dinophyta and Cyanophyta – 19, 15 and 3 species, correspondingly; findings of Chlorophyta, Chrysophyta and Euglenophyta were only solitary. The abundance and biomass were greatest (460 million cells/m^3 and 186 mg/m^3, respectively) in the upper southwestern part and minimal (49 million cells/m^3 and 33 mg/m^3, respectively) in the lower part of the Eastern Sivash. The number of phytoplankton species has considerably decreased for 2009-2010. Species typical of freshwater bodies grow in plenty because of the huge freshwater inflow into the gulf. The shallow and well-mixed water of the Eastern Sivash harbors many benthic Bacillariophyta such as *Achnanthes brevipes, A. longipes, Pleurosigma elongatum* and some other.

Thus phytoplankton community of the Eastern Sivash fluctuates with the intensity of freshwater species invasion from the Dnieper across the NCC; further prognosis depends upon economical activity in the area.

3.2 Zooplankton

In functioning of marine ecosystems zooplankton is of significance as the major food item for juveniles fish, in the Black Sea and the Sea of Azov as well as for adult pelagic species these are sprat, anchovy, horse mackerel, kilka, sand smelt etc.

Zooplankton in the coastal sea water of the Tarkhankut peninsula and Cape Martyan. The study of coastal zooplankton was made in two Crimean locations: on the shoal stretching along the Tarkhankut peninsula and in the sea water of the nature reserve Cape Martyan (in June 2011 and in September 2011, correspondingly). Species richness near the Tarkhankut peninsula was not as large as at the nature reserve – 11 species and taxa in comparison to 15 zooplankton species and taxa, and larvae of lancelet and fishes, respectively (Table 3.2.1)

In 2011 quantitative characteristics of zooplankton in the nature reserve were an order of magnitude as large as near the Tarkhankut peninsula (Table 3.2.1). It is unlikely that this difference is solely owing to predatory *Mnemiopsis leidyi*; indeed, this ctenophore drastically reduce the abundance of zooplankton in the Black Sea but in the mid – and late summer (Finenko et al., 2006).

Measurements of the abundance which were made in September 2011 in the sea of the nature reserve Cape Martyan indicated several abundant zooplankton groups instead of a dominant species. .

The year before, in September 2010, zooplankton of the nature reserve was represented only by harpacticoids (in particular *Mitis ignea*), which together made up to 90% of the total zooplankton abundance, and larvae of Cirripedia. Quantitative characteristics of the zooplankton were very poor – abundance and biomass estimated 100 ind/m^3 and 1.9 mg/m^3, respectively. Probably, the difference between the records made in 2010 and in 2011 is explained by different sampling techniques used. In 2011 nearly 2 m^3 of the sea water were filtered through Juday net and in 2010 only 100 l through a plankton bowl equipped with the sieve having the same mesh-size as the net; therefore the overall seawater sample having been filtered was insufficient for reliable assessment of zooplankton species composition and abundance. Besides, in 2010 samples were collected in the narrow coastal zone where pelagic forms were few and benthic-pelagic forms of harpacticoids and larvae of bottom-dwelling organisms prevailed.

Zooplankton in the sea at Cape Kazantip. In the bay Russkaya (st. 1) situated in the northern extremity of Cape Kazantip the zooplankton is represented by two copepods, *Acartia clausi* "small form" and *Acartia tonsa,* larvae of Bivalvia and Gastropoda, and Foraminifera. After detailed examination in the laboratory, *Acartia clausi* "small form" from the Sea of Azov has been qualified as *Acartia margalefi* Alcaraz, 1976 (Fig. 3.2.1). Further on we shall use this specific name each time when the small form of Acartia is anyhow mentioned in this section.

In August 2010 total abundance of the zooplankton amounted to 2940 ind/m^3 and the biomass to 18.7 mg/m^3. In the species ratio *A. margalefi* surely won the dominance, producing 96% of the total zooplankton abundance, the next was *A. tonsa* – 1.9 % (Fig. 3.2.2).

3. The species diversity

Table 3.2.1. The average zooplankton abundance (N) and biomass (B) in the coastal waters of the Cape Martyan and Tarkhankut peninsula in 2011

Species and other taxa	Cape Martyan		Tarkhankut peninsula	
	September, 2011		June, 2011	
	N, ind./м³	B, mg/м³	N, ind./м³	B, mg/м³
Acartia clausi	2408,33	43,74	0,00	0,00
Centropages ponticus	0,56	0,03		
Paracalanus parvus	4,72	0,02	40,53	0,19
Pseudocalanus elongatus	8,33	0,07		
Pontellida mediterranea			1,67	0,02
*Oithona davisae**	22,22	0,09		
Harpacticoidae			326,61	0,73
Mitis ignea			28,30	0,51
Ova Copepoda			1,67	0,00
Total Copepoda	2444,17	43,94	398,78	1,45
Penilia avirostris	901,39	31,55		
Pleopis polyphemoides	4,17	0,04	3,33	0,03
Pseudevadne tergestina	33,33	1,33		
Evadne spinifera	4,17	0,17		
Total Cladocera	943,06	33,09	3,33	0,03
Larvae Bivalvia	840,28	2,52	10,00	0,03
Larvae Cirripedia	20,83	0,52	3,33	0,02
Larvae Decapoda	1,39	0,21		
Larvae Gastropoda	311,11	2,19		
Larvae Polychaeta	236,11	14,07	17,20	0,99
Ostracoda			1,67	0,04
Larvae of benthic anumals	1409,72	19,50	32,20	1,08
Sagitta setosa	19,44	1,68		
Branchiostoma lanceolatus	0,83	0,14		
Larvae Pisces	0,28			
Insecta			3,33	0,00
Acari			3,33	0,84
TOTAL	**4817,50**	**98,35**	**440,98**	**3,41**

* Temnykh, Nishida, 2012

In May 2011 eight bays of the Cape Kazantip were surveyed in which 10 species and other taxonomic units of zooplankton were found: *Acartia clausi* and *A. tonsa*, *Pleopis polyphemoides*, Rotatoria not identified to species, various Harpacticoidae, Foraminifera, larvae of Cirripedia and Bivalvia, Ostracoda, *Oikopleura dioica*.

Table 3.2.2 gives the estimates of zooplankton abundance and biomass computed for each of the bays; the values were maximal at st. 6 and minimal at st. 8.

Table 3.2.2. Total zooplankton abundance (N) and biomass (B) in the different bays along the coastalline of Cape Kazantip in May 2011

Stations	N, ind./m^3	B, mg/m^3
St. 1	10 428,6	64,40
St. 2	8 805,0	55,56
St. 3	3 577,1	22,71
St. 4	4 834,3	30,61
St. 5	12 601,7	79,90
St. 6	36 390,0	233,98
St. 7	25 363,3	160,36
St. 8	1 825,0	11,39
Average	**11 838,4**	**75,35**

In August 2010 small copepod *A. margalefi* was the prevailing member of zooplankton; in May 2011 larvae of Cirripedia were the major fraction (97% of the total abundance of zooplankton and 97% of the total biomass) in the coastal water plankton community near the Cape Kazantip (Fig. 3.2.3).

Zooplankton in the Eastern Sivash Gulf. In August 2010 the diversity of zooplankton in the inspected area was confined to harpacticoids and a small jellyfish. This extreme scarcity explains why the abundance and biomass were as low as 20 ind/m^3 and 5.18 mg/m^3, correspondingly; without the jellyfish the biomass would be 0.18 mg/m^3 only. Species composition was not fully identified because of the small number of samples.

In May 2011 zooplankton samples were collected at six stations; compared to August 2010, the diversity has increased to 12 species and higher taxa (Table 3.2.3); at one station fish larvae were found. Along with Black sea zooplankton (*Acartia clausi, A. clausi*, small form =*Acartia margalefy, A. tonsa, Pleopis polyphemoides*), which have become common in the Sea of Azov, and benthos larvae, nauplii of halophilic *Artemia* sp. were found at the salted-water 4th creek (see chap. 2). Our attempts to exactly identify the species from the nauplii failed. Presently, *Artemia salina* alone is known in the Eastern Sivash (Zagorodnyaya, 2006), though other species of this genus occur in Crimean salt lakes.

Fig. 3.2.1. Pictures of female *Acartia margalefi* (left) and its urosome (right) (photo by I. Prusova)
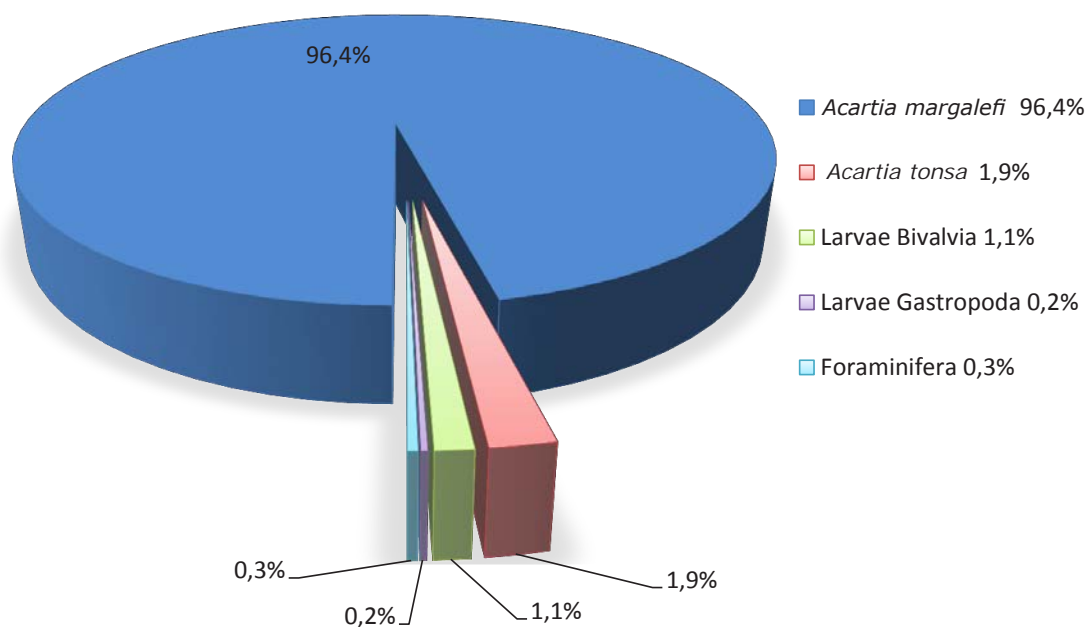
Fig. 3.2.2. Diagram of the percentage of different zooplankton species and taxa in the Sea of Azov in August 2010 (in abundance)
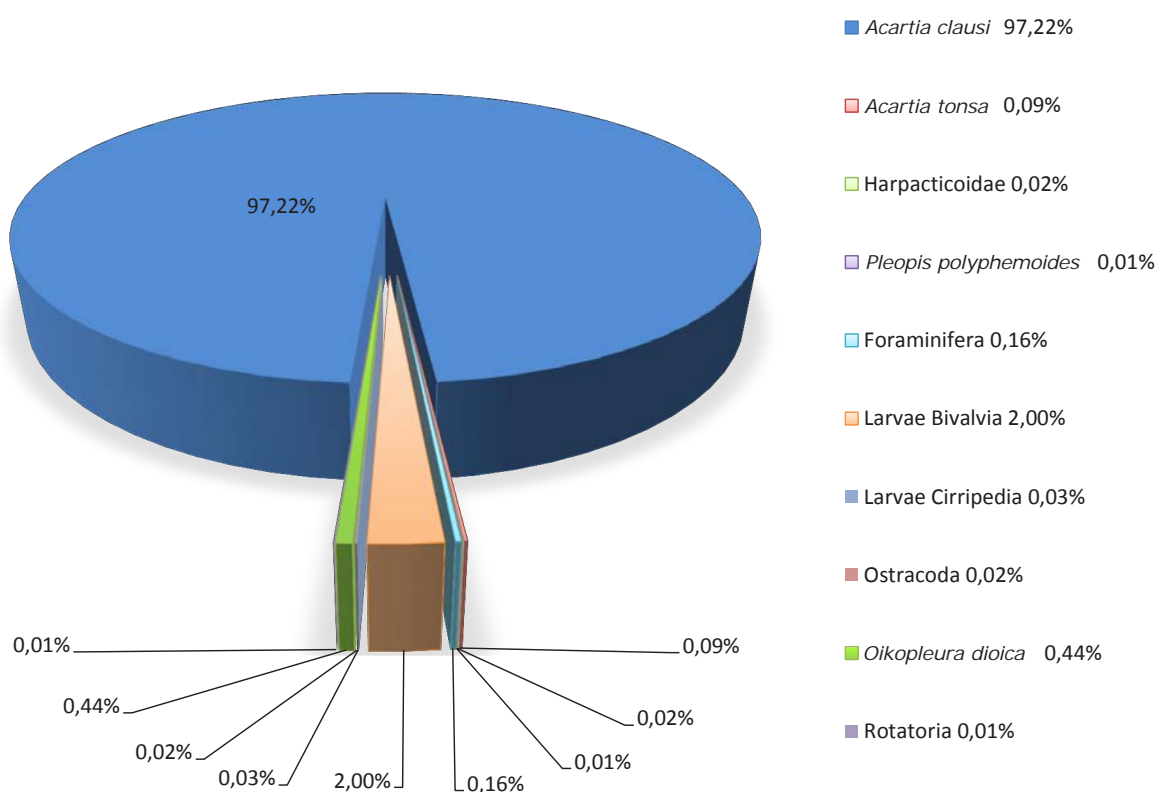
Fig. 3.2.3 Diagram of zooplankton species percentage in bays of the Sea of Azov in May 2011 (in abundance)

Legend:
- *Acartia clausi* 97,22%
- *Acartia tonsa* 0,09%
- Harpacticoidae 0,02%
- *Pleopis polyphemoides* 0,01%
- Foraminifera 0,16%
- Larvae Bivalvia 2,00%
- Larvae Cirripedia 0,03%
- Ostracoda 0,02%
- *Oikopleura dioica* 0,44%
- Rotatoria 0,01%

Fig. 3.2.4 Diagram of percentage of different zooplankton species and taxa in the Eastern Sivash in May 2011 (in abundance)

Legend:
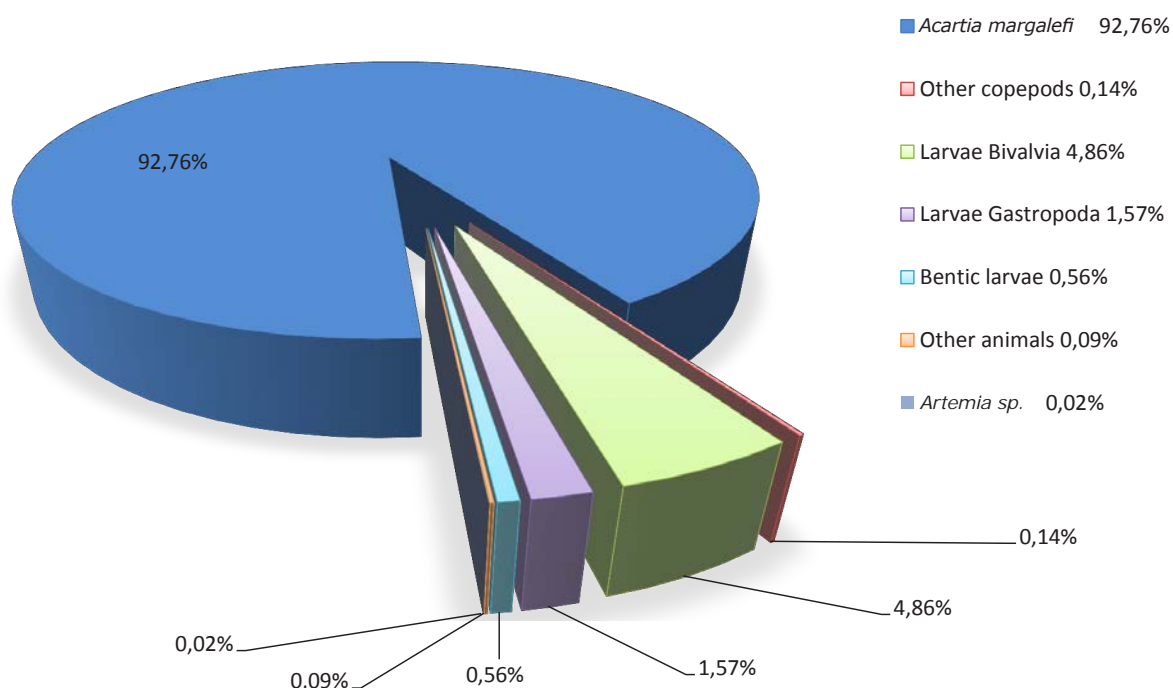- *Acartia margalefi* 92,76%
- Other copepods 0,14%
- Larvae Bivalvia 4,86%
- Larvae Gastropoda 1,57%
- Bentic larvae 0,56%
- Other animals 0,09%
- *Artemia sp.* 0,02%

3. The species diversity

Table 3.2.3. Composition of zooplankton species, the mean values of their abundance (N) and biomass (B) in the Eastern Sivash Gulf in May 2011

Species and other taxa	N, ind./m^3	B, mg/m^3
Acartia clausi	1,39	0,04
Acartia margalefi	15 318,06	143,62
Harpacticoidae	17,01	0,39
Mitis ignea	4,17	0,08
Foraminifera	9,72	0,10
Gammaridae	2,78	0,17
Larvae Bivalvia	802,78	3,58
Larvae Gastropoda	259,03	1,60
Larvae Cirripedia	64,93	1,45
Larvae Polychaeta	27,78	0,28
Artemia sp.	2,78	0,02
Acari	1,39	0,69
Larvae Pisces	1,39	
TOTAL	**16 513,19**	**152,01**

Table 3.2.3 presents the quantitative characteristics of the zooplankton in May 2011. In May the copepod *Acartia margalefi* had the largest numbers (93% of the total zooplankton abundance) and biomass in the Eastern Sivash (Fig, 3.2.4). Up to 5% of abundance was made by bivalves larvae. The surveys made in the gulf in June and August 2004 disclosed considerably greater abundance of zooplankton species and taxa. The resulting inventory included 57 freshwater, typically marine and euryhaline taxa (Zagorodnyaya, 2006). The surveyed water area extended from the desalinated estuaries of the inflowing rivers and nets of the irrigation canals to the 4th euhaline creek locality, due to which taxonomic richness has been shown. Shannon diversity index varied from 1.5 to 2.5 depending upon the creeks. The abundance of zooplankton estimated in May 2011 was similar to that in 2004, while the biomass considerably fluctuated because the large-size *Artemia sp.* substantially contributed to the biomass, especially in the 4th creek of the Eastern Sivash.

Summing up, in summer a manifest dominance of usually one species is characteristic of zooplankton inhabiting the Eastern Sivash and the shallow bays of the Sea of Azov, and greater abundance of species and several concurrently dominant and subdominant groups – of the coastal zone of the Black Sea.

3.3. Macrozoobenthos

Macrozoobenthos is one of the key elements in the substance and energy cycle going in coastal ecosystems. Filter-feeding species facilitate self-purification of the seawater area thereby improving quality of the habitat. For many fishes, those of commercial interest in particular, zoobenthos is a basic food. Spatial stability and relatively long life time makes organisms and communities of macrobenthos accessible objects in tracing long-term changes developing in polluted marine environment. Moreover, being easy to interpret, their quantitative characteristics such as biomass, abundance and the number of species underlie a variety of species diversity and "benthos well-being" indices appreciated in ecological monitoring. Field and laboratory records of species structure in bottom biocenoses, quantitative characteristics of the species, spatial and temporal distribution patterns enable better insight into a regional ichthyofauna and more accurate forecast of would-be changes that is of special significance for the seawater areas which have for a long time been subject to human impacts.

Macrozoobenthos in the bays of Sevastopol. Sevastopol bay is one of the most exploited and heavily polluted in the Crimea; in the broad spectrum of pollutants it receives oil hydrocarbons dominate. On most regular stations bottom sediments are black or deep-grey mud, in the centre of the bay it smells hydrogen sulfide and oil products. The upper light surface of the sediment has an oxidated coat, 2-5-mm thick. Usually bottom sediments display negative Eh values (to −174 mV) indicative of reducing environment. Natural moisture content exceeds 50% suggesting aleurite-pelite accumulation (Mironov et al., 2003).

Receiving massive inflow of a large variety of pollutants, concentrations of which are far beyond the allowable limits, Sevastopol bay is gravely polluted.

The most stable indicator of oil pollution of the bottom sediment are chloroform-extracted compounds (A_{chl}), their fraction in organic matter of the polluted sediment sometimes amounts to 50%. As the tests have shown, the A_{chl} content varied from 220 to 2060 mg/100 g of dry sediment. In the central part of Sevastopol bay and in Southern bay bottom sediment is worst (Mironov et al., 2003). In the top and mid-parts of the bay the muddy sediment has accumulated 150 and 2230 mg/100 g oil hydrocarbons, correspondingly, i.e., to 30% C_{org} (organic carbon). In relatively unpolluted bottom sediment oil hydrocarbons make up to one-third of total organic substance (concentration up to 5 mg/100 g of dry sediment).

The investigation of spatial distribution of oil hydrocarbons and macrozoobenthos and Sevastopol bay ranging along pollution gradient has elicited a hot spot directly in the central part of the bay. For ecosystem of the bay Pollution Load Index (PLI) was computed that permitted to ascertain three environmental zones of which zone I and zone II (mouth and top of the bay) are of relative well-being (integral PLI = 0.39-8.33) and zone III (central part of the bay) is hazardous (integral PLI = $8.02\text{-}10^{-16}$) (Osadchaya et al., 2004).

Seawater areas in which largest oil hydrocarbon estimates were measured ("hot spots") adjoin the localities regularly receiving industrial, municipal and storm sewage; the waste effluents distribute depending on locality-special hydrodynamic and hydrological conditions.

3. The species diversity

Progressively accumulating in the bottom sediment, pollutants bring about persistent quantitative and qualitative disturbances in the bottom biocenoses and, eventually, in the marine environment.

In the beginning of the 20th century bottom biocenoses in Sevastopol bay generally conformed to the typical scheme of the Black Sea biocenoses. By the 1970s, the species composition and distribution patterns have radically changed, the species diversity declined. Living macrozoobenthos have vanished from the central area of Sevastopol bay and almost everywhere in Southern bay (Milovidova, Kiryuhina, 1985). In the late 20th century an increase of species diversity and quantitative characteristics, especially in the central part of the bay, was observed both in overall macrozoobenthos and in dominant species. The number of species has been more than twice as large as during 1985 – 1988 (Mironov et al., 2003).

Surveys made at 19 stations evidence that presently in the Sevastopol bay macrozoobenthos of 52 species and higher taxa are found including 13 species of gastropods, 14 species of bivalves, 5 species of crustaceans, 17 species of marine bristle-worms, as well as Nemertea, Oligochaeta and Platyhelminthes (Fig. 3.3.1). The predominance of mollusks and polychaete worms is typical of benthos communities occurring along the coast of the Crimea.

Total number of macrozoobenthos species found in the bay varied from 4 to 19 depending on station, at the top of the bay and in the mouth of a higher species richness was observed (Fig. 3.3.2); the abundance varied from 105 to 1966 ind./m^2. In the innermost and central parts average abundance of macrozoobenthos increased to a maximum owing to *Hydrobia acuta*. *H. acuta* abundance in these localities amounted up to 1535 and 1658 ind./m^2, correspondingly. Estimates not larger than 1000 ind./m^2 were characteristic of the central and mouth parts of the bay; the major contributors in the former were polychaete *Heteromastus filiformis* and mollusk *H. acuta* and in the latter *H. filiformis,* mollusk *Spisula subtruncata* and small hermit crab *Diogenes pugilator*. Macrozoobenthos biomass dropped to the minimum of less than 1.0 g/m^2 in the centre part of the bay and in some mouth localities (Fig. 3.3.2). In the upper reaches it varied from 1 to 45 g/m^2, being produced mainly by mollusks *Abra segmentum, H. acuta, Bittium reticulatum* and *Nassarius reticulatus*. Average estimates, lowest in the central part, were relatively large in the lower reaches of the bay owing to large individual crustaceans such as *Upogebia pusilla* and *Macropipus holsatus*.

Different characteristics of bottom sediment and the uneven anthropogenic loading explains spatial distribution of macrozoobenthos in the inspected locations. Thus, the biomass of crustaceans is greatest at the lower reaches of the Sevastopol bay (Fig. 3.3.3); their abundance distributes more evenly along the bay outline and increases in the polluted central area (Fig. 3.3.4) owing to small pollution-resistant organisms such as *Balanus improvisus* and *Iphinoe elisae*. The abundance and biomass of polychaete worms, many of which well tolerate the pollution, increase towards the centre of the bay; quantitative characteristics of Gastropoda and Bivalvia demonstrate similar tendency being maximal at the upper reaches of the bay. At the same time, in the lower reaches of the bay the biomass of bivalves, including sensitive species, was low, probably as the result of slightly yet steadily rising pollution level.
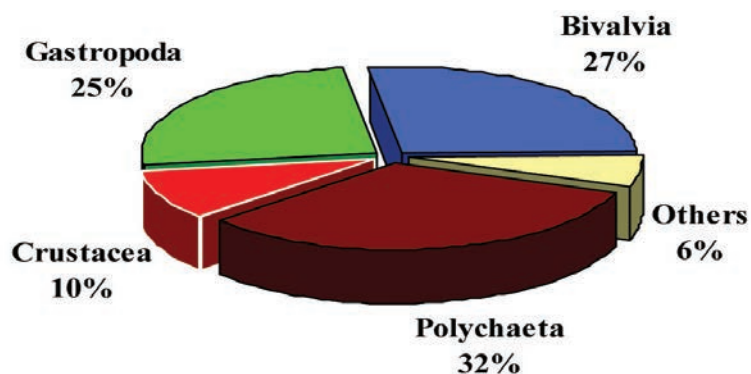
Fig. 3.3.1. Percentage share of the major zoobenthic taxonomic groups in the total number of taxa in the Sevastopol bay

Fig. 3.3.2. Spatial distribution of zoobenthic number of species, abundance and biomass in the Sevastopol and Southern bays
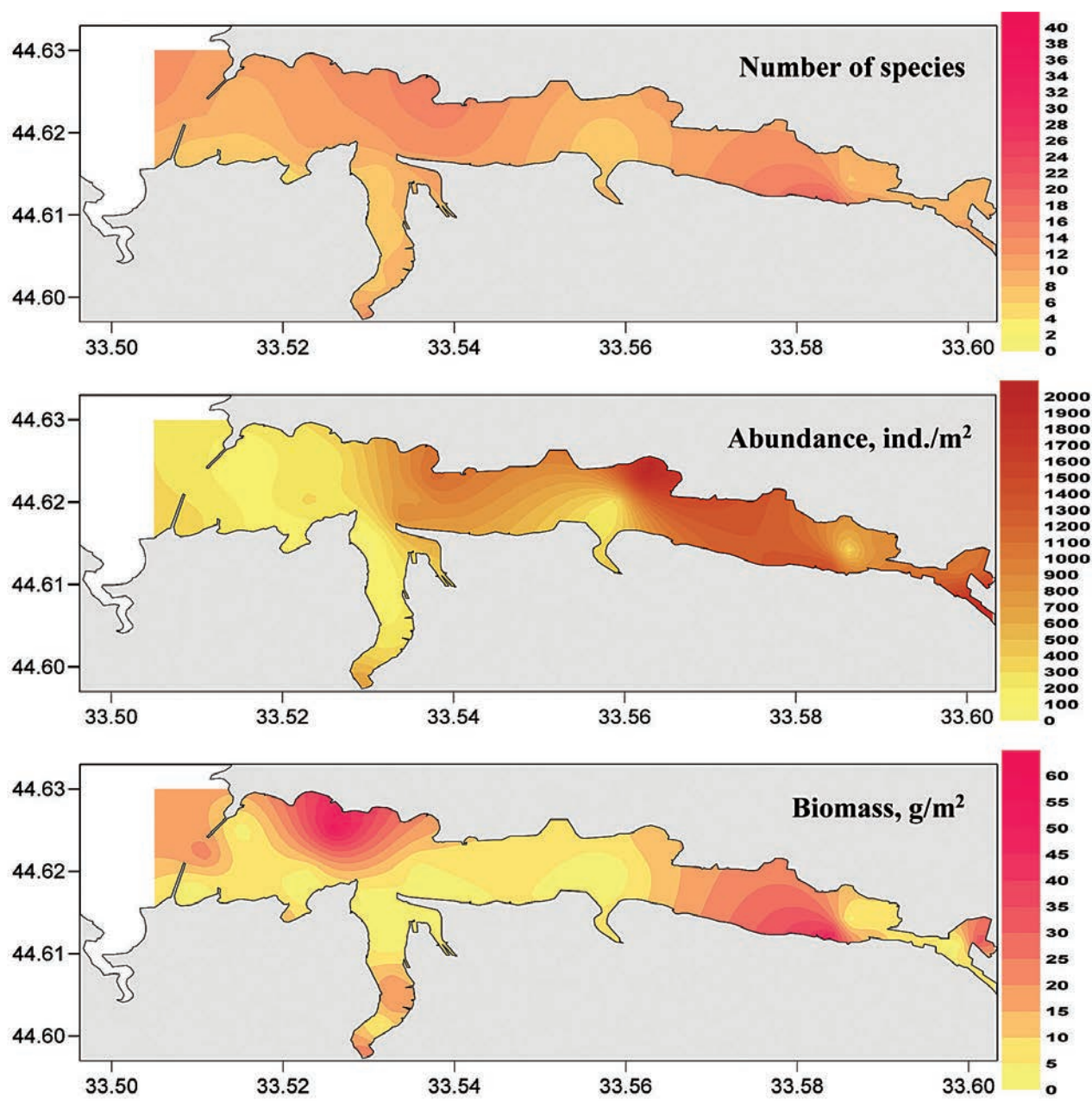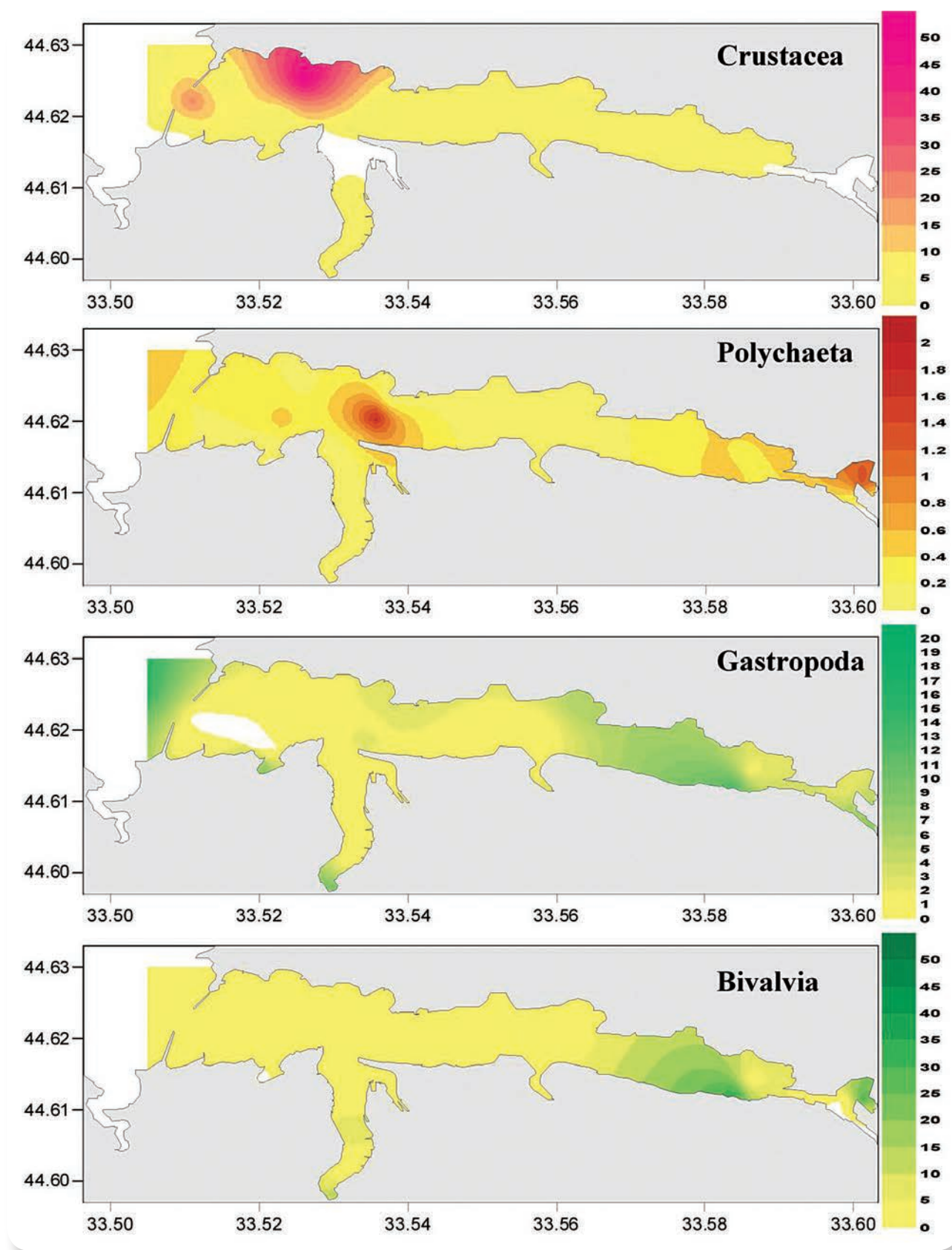
Fig. 3.3.3. Spatial distribution of the major zoobenthic taxonomic groups biomass (g/m^2) in the Sevastopol and Southern bays
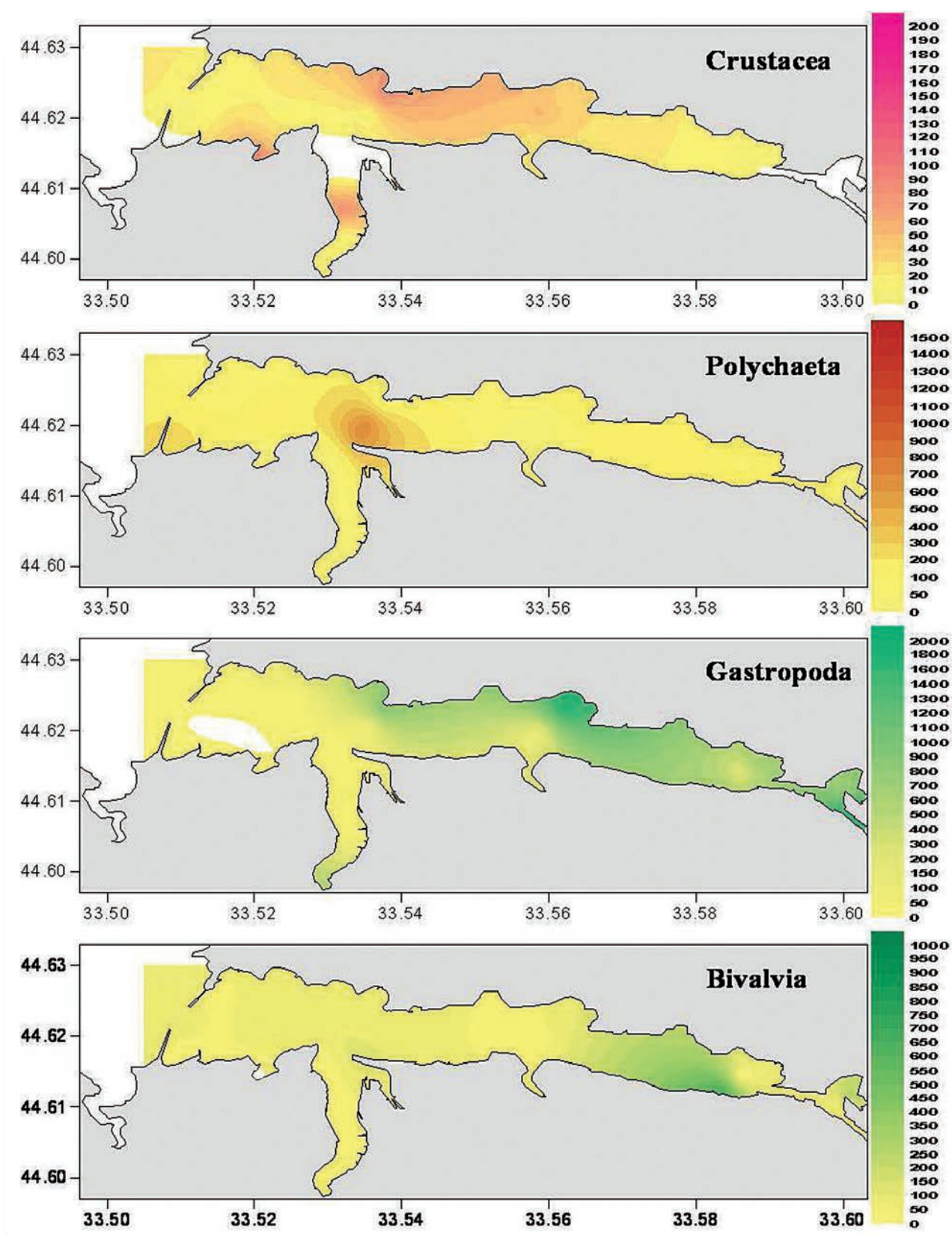
Fig. 3.3.4. Spatial distribution of the major zoobenthic taxonomic groups abundance (ind./m^2) in the Sevastopol and Southern bays

3. The species diversity

M-AMBI index was used in ecological assessment of bottom macrofauna at several stations located in the Sevastopol and Southern bays (Table 3.3.1). The results characterize the environment at stations 4 and 14 in Sevastopol bay as good, at stations 1, 2, 7, 8a and 12 as poor and at most stations as moderate.

Table 3.3.1. Values of AMBI and M-AMBI for sampling station in the Sevastopol and Southern bays

Sta-tions	AMBI	Disturbance Clasification	M-AMBI	Status
1	2.97	Slightly disturbed	0.35	Poor
2	3.13	Slightly disturbed	0.35	Poor
4	1.93	Slightly disturbed	0.65	Good
5	3.00	Slightly disturbed	0.39	Moderate
7	3.00	Slightly disturbed	0.36	Poor
8	2.85	Slightly disturbed	0.43	Moderate
7a	3.70	Moderately disturbed	0.40	Moderate
8a	2.85	Slightly disturbed	0.34	Poor
10	3.15	Slightly disturbed	0.40	Moderate
11	2.52	Slightly disturbed	0.45	Moderate
12	3.96	Moderately disturbed	0.35	Poor
14	1.75	Slightly disturbed	0.56	Good
16	2.73	Slightly disturbed	0.52	Moderate
17	3.05	Slightly disturbed	0.45	Moderate

High oil hydrocarbon content in the bottom sediments and the quantitative characteristics of macrozoobenthos groups point out that Sevastopol bay in the central part and Southern bay are environmentally unsafe zones. Concentrations of oil products in these locations were the largest, therefore the low abundance and biomass of macrozoobenthos and the poor species diversity in bottom communities dominated by species tolerant to organic pollutants, in particular oil, while sensitive species were absent. According to characteristics of bottom sediment and occurrence of macrozoobenthos communities Sevastopol bay was divided into three zones: upper, central and lower, including the adjacent sea water (sts. 1 – 6; sts. 7 – 9, 7a – 9a; and sts. 13 – 19, respectively). *Hydrobia acuta, Abra segmentum* and *Cerastoderma glaucum* are the dominant macrozoobenthos in the internal zone, gastropods *H. acuta, Nassarius reticulatus* and the crustacean *Iphinoe elisae* in the central zone, and the polychaete *Heteromastus filiformis* and bivalves *Spisula subtruncata* and *Tellina fabula* in the bay's mouth.

The zones of environmental risk ask for urgent rehabilitation; the steps to be done are reduction of anthropogenic load, i.e., lessening and proper treatment of wastewater inflow, and purification of the sea (see chap. 5).

Macrozoobenthos at the coastal zone of Cape Kazantip. Macrozoobenthos there is represented by 29 species: 10 Crustacea, 9 Polychaeta, 7 Mollusca (one gastropod and 6 bivalves) and also Oligochaeta, Platyhelminthes and Anthozoa (*Actinia equina*); hence, species richness *of* Polychaeta and Crustacea is the largest (Fig. 3.3.5). Compared to distant localities of the SW Sea of Azov inhabited by only 17 bottom-dwelling species, mainly Bivalvia (46% of the total species richness) (Terent'ev, 2009), the sea near Cape Kazantip harbors larger number of macrobenthic species in total and polychaetes and crustaceans in particular. Percentage of the predominant taxonomic groups depended on station: Crustacea varied from 14 to 67% and Mollusca from 24 to 50%. Depending on station the number of species varied from 9 to 14 (Fig. 3.3.5) At station 2 only three solitary organisms were found, two of them identified as crustaceans *Pontogammarus maeoticus* and *Iphinoe maeotica*, and one as bivalve mollusk *Lentidium mediterraneum*. For seven species of the total inventory the frequency of occurrence was assessed more than 50% (Table 3.3.2); 11 species were registered at only one station.

For most stations Shannon index computed from the abundance estimates fluctuated within 1.7 – 2.5, abruptly dropping to 0.2 – 0.7 at two stations (Table 3.3.3). Shannon diversity index calculated from the biomass was larger than 1.0 at a half of the sampling stations; the low diversity was due to the pressing dominance of individual species (low estimates of Pielou evenness index).

In the Tatarskaya bay (st. 8) and the adjacent eastern coastal sea of the Cape Kazantip (st. 7) macrozoobenthos abundance was the largest amounting to 15 – 19 thousand ind./m^2 (Table 3.3.3). *Lentidium mediterraneum* (st. 8) and *Mytilaster lineatus* (st. 7) produced here more than 90% of the total abundance. At stations 1, 3, 4 and 5 macrobenthos abundance was estimated 1800 – 7750 ind./m^2.

Total biomass of macrozoobenthos usually varied from 300 to 640 g/m^2 (Table 3.3.3) rising to a maximum near the northern shore of the Cape Kazantip (st. 7). At the same time, the poorest diversity, the numbers and biomass less than 100 ind./m^2 and 0.5 g/m^2, correspondingly, were measured in the Senka bay (st. 2). Periodic inflow of water polluted by oil products from a small earth reservoir lying in the central part of the Cape Kazantip in case of its overflow storm or flood waters can be the possible reason of sharp decrease in a biodiversity and quantitative characteristics of a benthos on this site of the coast. Contamination of reservoir waters and bottom sediments by hydrocarbons is probably caused by oil recovery in the central part of the Cape.

Generally, in most inspected coastal sea areas of the Cape Kazantip quantitative characteristics of macrozoobenthos conform to those in the SW Sea of Azov and near the Kerch Strait region, and species richness is greater (Eremeyev et al., 2008; Terent'ev, 2009).

Bivalves prevail in abundance of macrozoobenthos inhabiting the coastal zone of Cape Kazantip (Fig. 3.3.6). At three stations their portion in the total abundance was evaluated 72 – 78%; it rose to 92 – 99% at stations 8 and 7 in Tatarskaya bay and decreased to 50% at station 6 where increasing share of the polychaetes (mainly *Heteromastus filiformis* and *Alitta succinea*) and crustaceans (*Balanus improvisus*) evaluated 40 and 8%, respectively. To the total zoobenthos biomass Bivalvia contributed 86 – 98%. Results of the survey have acknowledged the significance of mollusks in formation of benthic communities of the Sea of Azov.
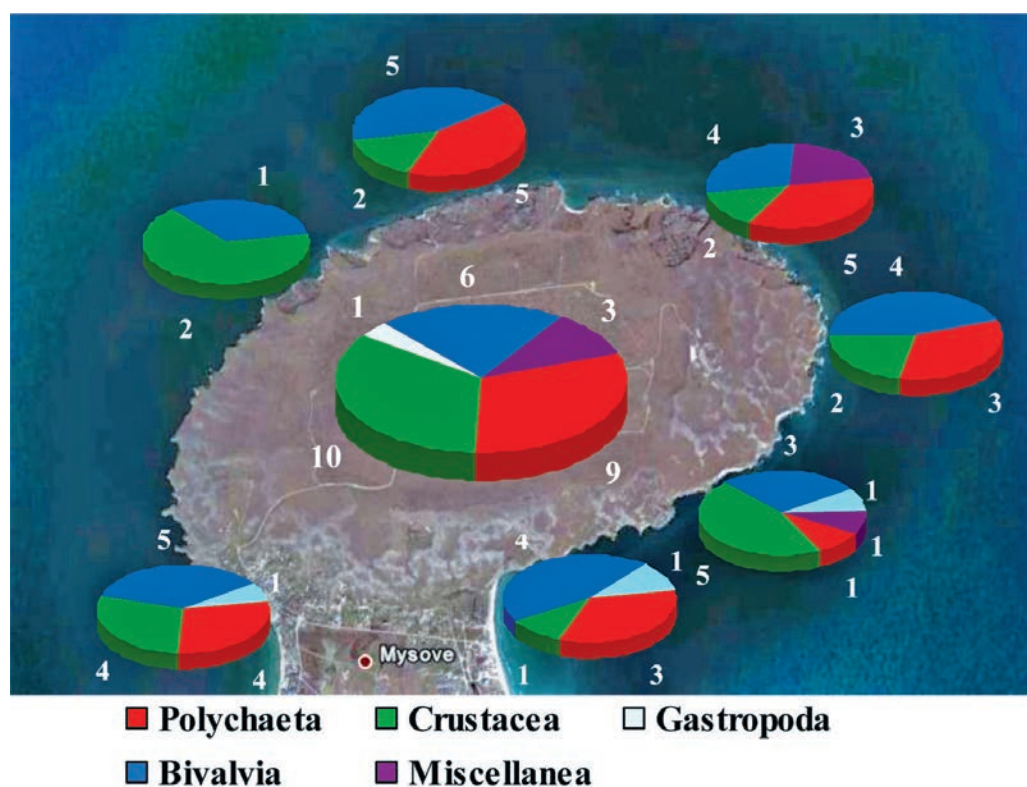
Fig. 3.3.5. Number of species in the major zoobenthic taxonomic groups in the total number of taxa (center) and at the different stations of the Cape Kazantip coastal waters
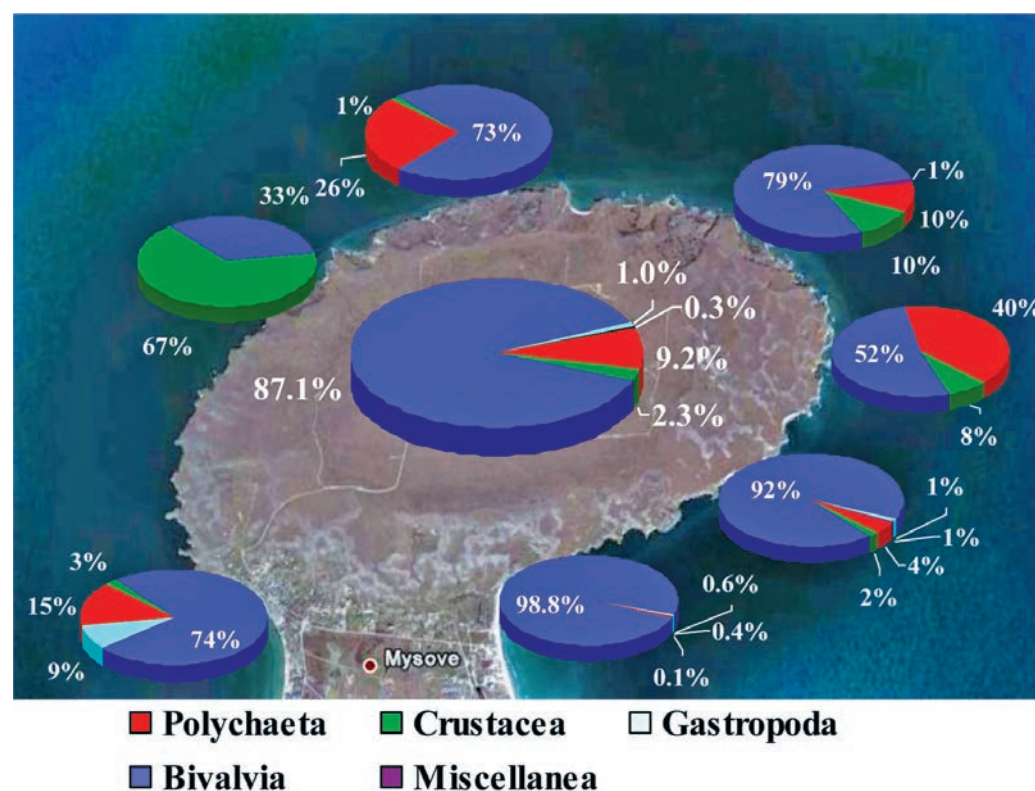

Fig. 3.3.6. Percentage share of the major zoobenthic taxonomic groups in the total average abundance (center) and at the different stations of the Cape Kazantip coastal waters

Table 3.3.2. Occurence (%) and quantitative characteristics of main macrozoobenthos species at the coastal zone of Cape Kazantip

Species	Oc-curence, %	Abundance, ind./m²		Biomass, g/m²	
		min	Max	min	max
Abra segmentum (Récluz, 1843)	85.7	6	316	0.11	4.60
Anadara inaequivalvis (Bruguiére, 1789)	42.9	79	263	4.22	26.57
Cerastoderma glaucum (Bruguiére, 1789)	85.7	13	3276	4.69	614.40
Lentidium mediterraneum (O.G.Costa, 1829)	57.1	13	15213	0.28	287.90
Mytilaster lineatus (Gmelin, 1791)	85.7	19	17461	0.07	179.86
Hydrobia acuta (Draparnaud, 1805)	42.9	100	263	0.21	0.35
Balanus improvisus (Darwin, 1854)	57.1	26	355	0.97	42.72
Rhithropanopeus harrisi (Gould, 1841)	57.1	13	66	1.16	7.28
Capitella capitata (Fabricius, 1780)	57.1	13	211	0.01	0.05
Mysta picta (Quatrefagues, 1865)	42.9	6	105	0.05	0.22
Heteromastus filiformis (Claparéde, 1864)	42.9	132	1437	0.05	0.92
Alitta succinea (Frey & Leuckart, 1847)	42.9	171	750	0.79	3.31
Spio filicornis (Müller, 1776)	42.9	13	263	0.01	0.08

Table 3.3.3. Values of abundance, biomass, Shannon diversity index (H') and Pielou evenness index (J') for sampling station at the coastal zone of Cape Kazantip

Sampling station	Abundance			Biomass		
	ind./m²	H'	J'	g/m²	H'	J'
8	15557	0.20	0.06	301.52	0.23	0.07
7	19410	0.73	0.21	302.82	1.28	0.37
5	3133	2.55	0.80	445.05	1.40	0.44
4	4066	1.76	0.46	351.69	1.84	0.48
3	7752	2.35	0.66	641.15	0.35	0.10
2	39	1.58	1.00	0.31	0.57	0.36
1	1883	1.84	0.48	342.47	0.19	0.05

At the majority of stations absolute values of the abundance of *Mytilaster lineatus* varied from 140 to 2670 ind./m² and the biomass from 0.4 to 71.0 g/m²; at st. 7 as large numbers as 17460 ind./m² was registered. As a rule, *Mytilaster* made up about 25% in the total macrozoobenthos abundance, and amounted to 70 – 90% of the total numbers and 48 – 59% of the total biomass at stations 4 and 7 (Fig. 3.3.7).

Found at nearly all near-shore stations of the Cape Kazantip, *Abra segmentum* had biomass and numbers not larger than 4.1 g/m² and 316 ind./m², correspondingly, i.e., contributed less than 1% to the macrozoobenthos total biomass and about 3% to the total abundance.

3. The species diversity

Bivalve *Lentidium mediterraneum* was observed at larger part of stations located along the coastal sea of Kazantip nature reserve; the numbers and biomass of this mollusk were usually not larger than 13 – 100 ind./m^2 and 0.3 – 1.5 g/m^2, correspondingly. A mass settlement (15 000 ind./m^2, 280 g/m^2) was noted only in the Tatarskaya bay (st. 8, 1-m depth). *L. mediterraneum* dominated over this seawater area, contributing 95% to the total biomass and 98% to the total abundance of macrozoobenthos (Fig. 3.3.7, Fig. 3.3.8).

Anadara inaequivalvis, first found in the Kerch Strait in 1986 (Zolotaryov, 1987), by 1997 has formed biocenosis in the Kazantip and Arabatsky gulfs (Frolenko, Derevyankina, 1998). At three stations in the coastal sea of Kazantip reserve, *A. inaequivalvis* was quantitatively represented as modestly as 79 – 263 ind./m^2 and 26.6 g/m^2. In the total benthos abundance and biomass of *Anadara* was estimated 4 and 8 %, correspondingly (Fig. 3.3.7, Fig. 3.3.8).

Hydrobia acuta is a mass species in the Sea of Azov; prospering on pelite silts in the northwestern and east-central parts of the sea it had maximum abundance and biomass – 35 – 49 thousand ind./m^2 and 75.3 – 87.0 g/m^2, respectively. At three stations along the Kazantip shore *Hydrobia acuta* was the only one gastropod registered. The numbers and biomass of this species were estimated 100 – 263 ind./m^2 and 0.21 – 0.35 g/m^2, correspondingly, making 0.6 – 8.7% and 0.1% of the overall zoobenthos abundance and biomass.

The barnacle *Balanus improvisus* and the white-fingered mud crab *Rhithropanopeus harrisi* were the prevalent crustaceans (57% frequency of occurrence). White-fingered mud crab (alien species for the Sea of Azov), was first abundantly found near the coast of the Cape Kazantip during the survey we made in 2010.

On stations 5 and 4 *B. improvisus* had the largest contribution to the total macrozoobenthos abundance and biomass (7 – 9 and 7 – 12 %, correspondingly; (Fig. 3.3.8); the peaks of near 355 ind./m^2 and 42.7 g/m^2, correspondingly, also concentrated there. On the same stations as *Balanus*, *Rhithropanopeus harrisi*, considerably inferior to the latter, was estimated about 66 ind./m^2 and 7.3 g/m^2, or less than 2% of the total abundance and biomass, correspondingly.

Among polychaetes *Heteromastus filiformis* and *Alitta succinea* with the numbers as high as 1437 and to 750 ind./m^2, respectively, dominated. At station 5 Polychaeta made up to 40% of the total zoobenthos abundance and, due to small body size, less than 1% of the total biomass.

In trophic structure of the macrozoobenthos dwelling near Cape Kazantip filter feeders dominated, which produced 56-99% of the total abundance and 96-98% of the total biomass. *Nephtys hombergii* was the only one carnivorous detected.

Methods of the cluster analysis of similarity/dissimilarity matrix assuming 40%-Bray-Curtis criterion enabled uniting most stations in the coastal sea of Kazantip nature reserve into a group (Fig. 3.3.9); station 2 is notable for strikingly poor species diversity. The united group comprises subgroups of shallow-sea stations 8 and 1 located in Tatarskaya and Russkaya bays and a series of 4 – 11-m deep stations along the Cape Kazantip coastline. Very similar species composition in all the stations suggests that the observed macrozoobenthos complexes, though with varying key species, have originated through a transformation of *Cerastoderma* biocenosis, widespread in this part of the sea.
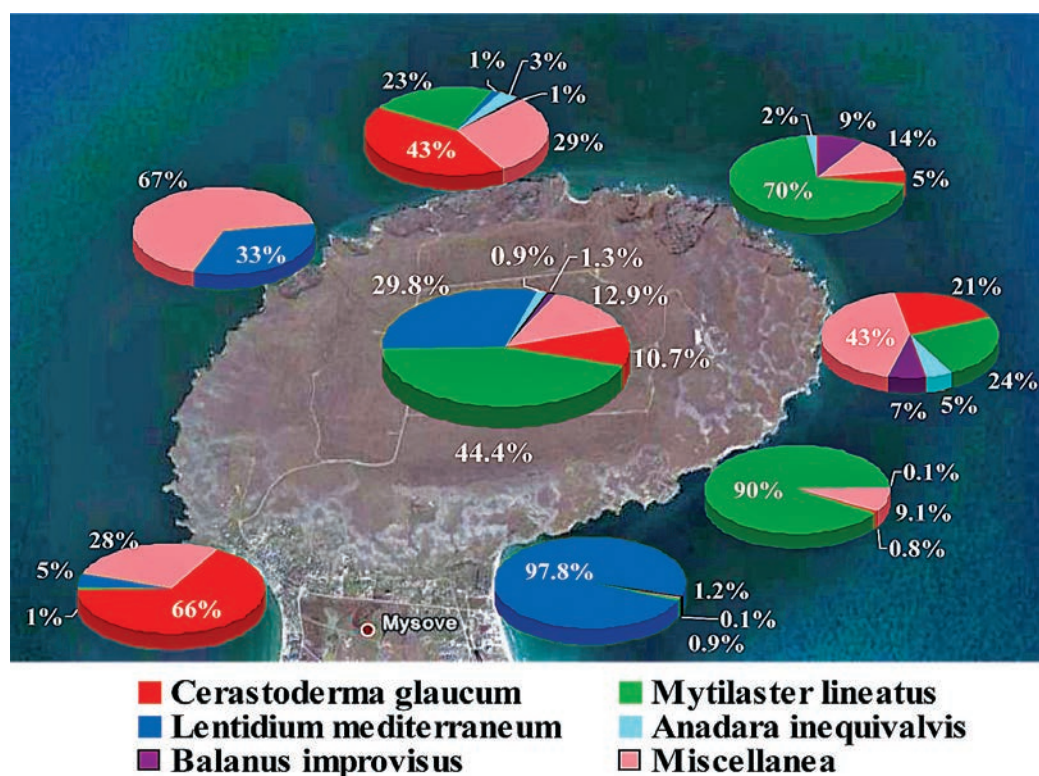
Fig. 3.3.7. Percentage share of the of the main zoobenthic species in the total average abundance (center) and at the different stations of the Cape Kazantip coastal waters
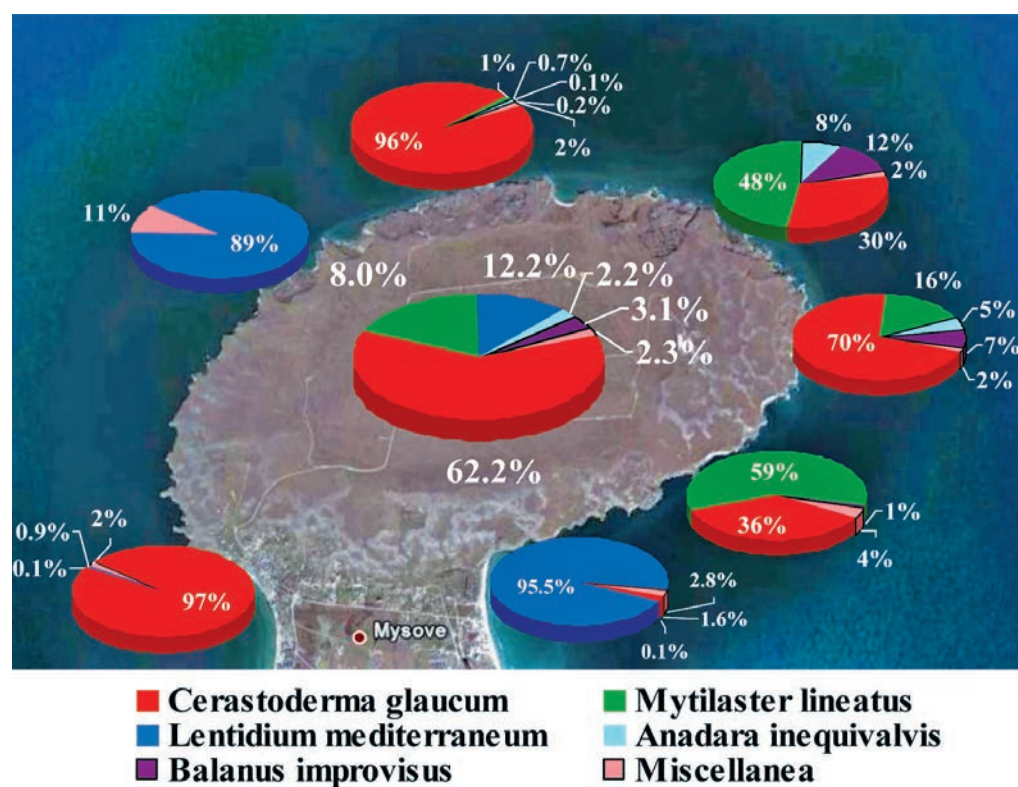

Fig. 3.3.8. Percentage share of the main zoobenthic species in the total average biomass (Kazantip coast) and at the different stations of the Cape Kazantip coastal waters
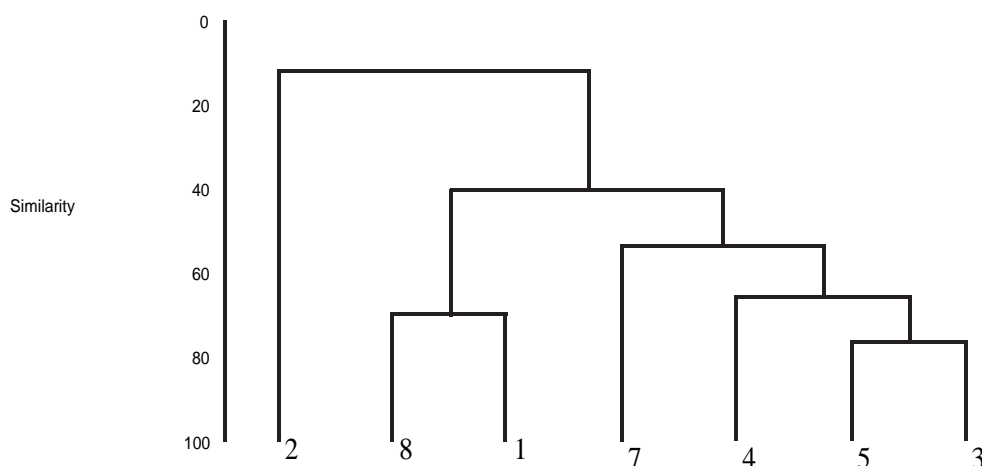
3. The species diversity

Fig. 3.3.9. Result of cluster analysis of macrozoobenthos stations at the Cape Kazantip coastal zone

Based on the records of species composition and quantitative parameters of the bottom communities, indices AMBI and M-AMBI were determined as locality-specific (Table 3.3.4). The values of AMBI index evidence undisturbed communities at stations 7 and 4 and slightly disturbed over the rest stations of the Cape Kazantip coastal zone; station 2 was excluded because of the poorest species diversity. Though M-AMBI index interprets marine environment of most stations as good, the majority of these estimates fluctuate closely between good and moderate. Therefore, any manifest impact upon the bottom communities would be a threat to their shaky status. The difference of quantitative characteristics, species composition and ecological status of the macrozoobenthos observed in different sites of the sea-floor can be owing to seasonal succession, patchy distribution, uneven local seawater salinity and persistent human load. The plain dominance of some species and the inadequate species diversity in the Sea of Azov clearly indicate that unless and until pollution of the sea is uninterrupted, the bottom communities and hence the self-purification capacity of the sea will be fatally impaired.

Table 3.3.4. Values of AMBI, M-AMBI and ecological status for the 6 stations (Cape Kazantip coastal zone)

Sampling stations	AMBI	Disturbance Clasification	M-AMBI	Status
8	1.51	Slightly disturbed	0.43	Moderate
7	0.31	Undisturbed	0.58	Good
5	2.63	Slightly disturbed	0.55	Moderate
4	0.79	Undisturbed	0.69	Good
3	2.69	Slightly disturbed	0.59	Good
1	2.91	Slightly disturbed	0.58	Good

As early, the Sea of Azov provides an important area of the commercial fishing, therefore any outward impact on its vulnerable ecosystem must be minutely investigated. Environmental rehabilitation of the Sea of Azov requires large-scale nature protection actions which cannot be scheduled and implemented without assessment of the health of bottom-dwelling communities exposed to intense anthropogenic loads.

3.4. Ichthyofauna

Fish are very important in the functioning of marine ecosystems in the Black Sea and the Sea of Azov because are mainly 3rd and 4th order consumers and the main target species of marine aquatic resources of these seas. To assess the current state of biodiversity of ichthyofauna in various coastal areas and trends of its transformation a number of sections of the Crimean coastal zone, in which hydrochemical and hydrologic characteristics, biotopes and anthropogenic loading largely differed were investigated.

Ichthyofauna of the Karkinit Gulf. Information about the ichthyofauna of the Karkinit Gulf is very few. Early overviews (Vinogradov, 1960; Svetovidov, 1964) for gulf, mainly the western deep-sea area, indicated about 50 species of fish. In the east, in the shallow area from the Dzharylgach gulf to Bakal sand spit we found 39 species of 19 families (Table 3.4.1); the scientific literature data for the fish fauna about this region increases this number to 44 species from 22 families. Distinguished by the diversity of the families Gobiidae, Cyprinidae, Syngnathidae and Mugilidae (9, 5, 5 and 4 species, correspondingly), three families are represented by three species and the rest by one each. At present, the regional ichthyocenosis includes marine and freshwater fishes, brackish-water Ponto-Caspian relicts and diadromous fishes (26, 7, 6 and 4 species, correspondingly) (Fig. 3.4.1).

Structure of ichthiocenosis varies considerably in different areas of eastern part of the Karkinit Gulf (Fig. 3.4.3). In the open waters near the Khorly peninsula and Bakalskaya sand spit in typical seagrasses biocenoses Cobiidae, Syngnathidae, Labridae, Mugilidae and Atherinidae dominate by the abundance and species richness. In some bays degradation of sea grasses biocenoses through desalination and siltation was observed, freshwater fishes, mostly Cyprinidae many of which have little commercial value (*Rutilus rutilus*, *Alburnus alburnus*, *Scardinius erythrophthalmus*, *Carassius gibelio*), either dominate or make up a large portion in the catches, marine and brackish-water fishes are in the minority.

In isolated areas with abnormally high salinity – Perekop and Dzharylgach gulfs, depletion of the fish fauna was observed and it was mainly represented by certain species of the families Gobiidae and Syngnathidae.

Our observations point out that the structure of the ichthyofauna of the shallow part of the Karkinit Gulf undergoes substantial changes, the final consequences of which are directly connected to the negative influence of anthropogenic factors.

Ichthyofauna of the coastal waters of the Cape Tarkhankut. Fish fauna of this area has formerly been considered an integral part of the Karkinit Gulf fish fauna as a whole. However, species composition and ecological structure in these two regions have been formed under the influence of very different abiotic environmental characteristics; therefore there is the dissimilarity between the two faunas. In this area we noted 59 species of fish, which dominated: the marine (52) species, brackish water and diadromous include 6 and 1 species correspondingly. (Table 3.4.1, Fig. 3.4.1).

Coastal underwater landscapes in this region are formed predominantly by hard substrate: steep underwater rocks thickly coated with macrophytes, large boulders and fragments of rocks, extended to a depth of 10 – 12 m and at a distance of 30 – 250 m from the shore.
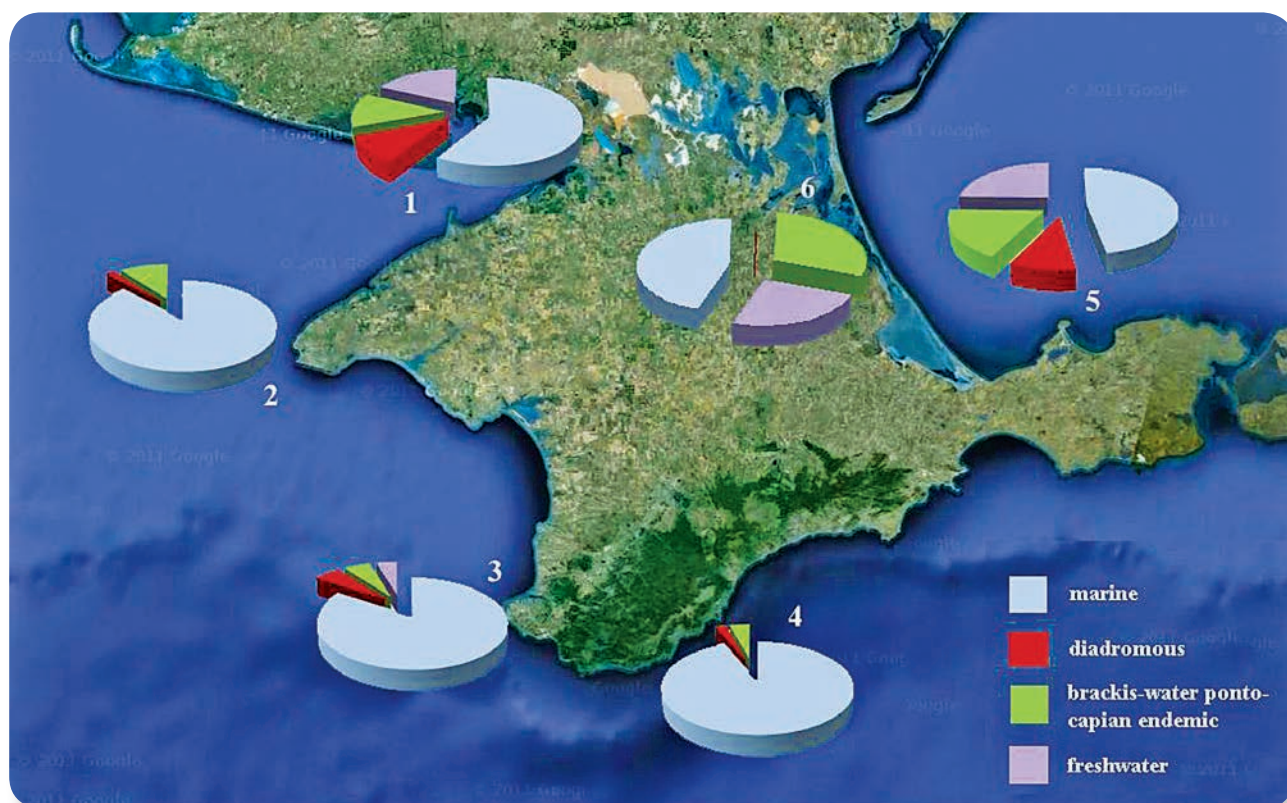
Fig. 3.4.1. Ecological structure of ichthiofauna at different parts of Crimean coast: eastern part of Karkinit Gulf (1), Tarhancut peninsula (2), bays and coastal zone of Sevastopol (3), *Cape Martyan* (4), Cape Kazantip and adjacent waters (5), Eastern Sivash Gulf (6).

Fig. 3.4.2. Underwater landscapes of the eastern part of the Karkinit Gulf

Fig. 3.4.3. Comparative number of specimens of most numerous fish's families in different parts of the Karkinit Gulf

Fig. 3.4.4. *Parablennius tentacularis* – typical inhabitant of the rocky and stony biotopes in the near-shore water of the Tarhankut peninsula

3. The species diversity

Table 3.4.1. Fish check-list of the investigated areas of the Crimean coastal zone (original data)

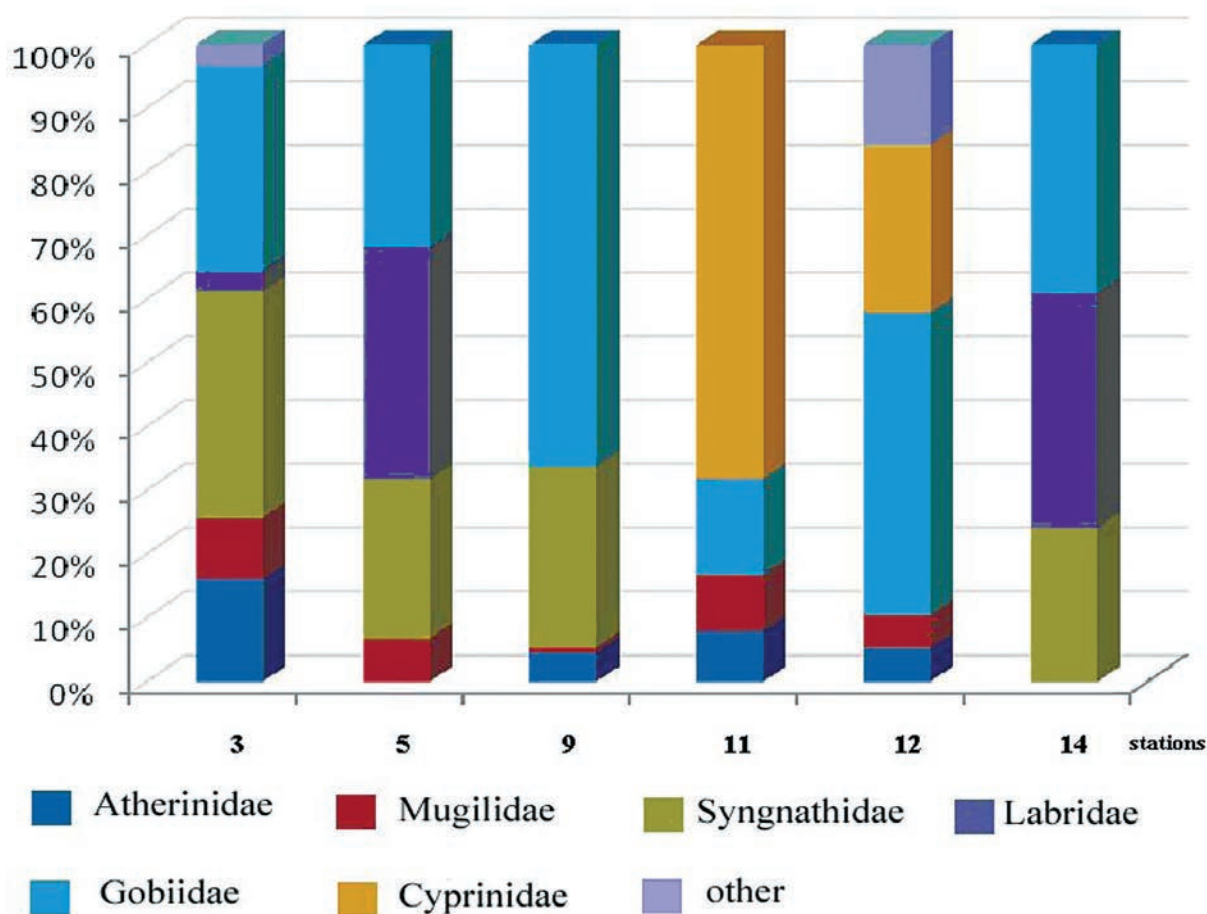| Family	Species	Karkinit Gulf (eastern part)	Tarkhankut peninsula	Coastal zone and bays of Sevastopol	Cape Martyan	Cape Kazantip	Eastern Sivash Gulf
1	2	3	4	5	6	7	8
Squalidae	*Squalus acanthias* (Linnaeus, 1758)	-	+	+	-	-	-
Rajidae	*Raja clavata* (Linnaeus, 1758)	-	+	+	+	-	-
Dasyatidae	*Dasyatis pastinaca* (Linnaeus, 1758)	+	+	+	-	+	-
Acipenseridae	*Acipenser gueldenstaedtii* (Brandt et Ratzeburg, 1833)	+	+	+	+	+	-
	Acipenser stellatus (Pallas, 1771)	-	-	+	-	+	-
	Huso huso (Linnaeus, 1758)	+	-	+	-	+	-
Anguillidae	*Anguilla anguilla* (Linnaeus, 1758)	+	-	+	-	+	-
Engraulidae	*Engraulis encrasicolus ponticus* (Aleksandrov, 1927)	+	+	+	+	+	-
	Engraulis encrasicolus maeoticus (Pusanov, 1926)	-	-	-	-	+	+
Clupeidae	*Alosa caspia* (Eichwald, 1838)	-	-	-	-	+	-
	Alosa immaculata (Bennett, 1835)	+	-	+	-	+	-
	Clupeonella cultriventris (Nordmann, 1840)	-	-	-	-	+	+
	Sardina pilchardus (Walbaum, 1792)	-	-	+	+	-	-
	Sardinella aurita (Valenciennes, 1847)	-	-	+	-	-	-
	Sprattus sprattus (Linnaeus, 1758)	-	-	+	+	+	-
Cyprinidae	*Abramis brama* (Linnaeus, 1758)	-	-	-	-	+	-
	Alburnus alburnus (Linnaeus, 1758)	+	-	-	-	-	+
	Carassius gibelio (Bloch, 1782)	+	-	+	-	+	+
	Alburnus leobergi (Freyhof et Kottelat, 2007)	-	-	-	-	+	-
	Ctenopharyngodon idella (Valenciennes, 1844)	-	-	-	-	+	-
	Cyprinus carpio (Linnaeus, 1758)	+	-	-	-	+	-
	Hypophthalmichthys molitrix (Valenciennes, 1844)	-	-	-	-	+	-
	Pelecus cultratus (Linnaeus, 1758)	-	-	-	-	+	-
	Pseudorasbora parva (Schlegel)	-	-	+	-	-	+
	Rhodeus amarus (Bloch, 1782)	-	-	-	-	-	+
	Rutilus rutilus (Linnaeus, 1758)	+	-	-	-	+	-
	Scardinius erythrophthalmus (Linnaeus, 1758)	+	-	-	-	+	+
	Vimba vimba (Linnaeus, 1758)	-	-	-	-	+	-
Siluridae	*Silurus glanis* (Linnaeus, 1758)	-	-	-	-	+	-
Salmonidae	*Salmo labrax* (Pallas, 1814)	-	-	+	-	-	-
Esocidae	*Esox lucius* (Linnaeus, 1758)	-	-	-	-	+	-
Phycidae	*Gaidropsarus mediterraneus* (Linnaeus, 1758)	-	+	+	+	-	-
Gadidae	*Merlangius merlangus euxinus* (Nordmann, 1840)	-	+	+	+	+	-
	Micromesistius poutassou (Risso, 1827)	-	-	+	-	-	-
Ophidiidae	*Ophidion rochei* (Muller, 1845)	-	+	+	+	-	-
Mugilidae	*Chelon labrosus* (Risso, 1827)	-	-	+	-	-	-
	Liza aurata (Risso, 1810)	+	+	+	+	+	+
	Liza ramada (Risso, 1827)	-	-	+	-	-	-
	Liza saliens (Risso, 1810)	+	+	+	-	+	-
	Mugil cephalus (Linnaeus, 1758)	+	+	+	+	+	-

Table 3.4.1. Cont.

1	2	3	4	5	6	7	8
	Liza haematocheila (Temminck et Schlegel, 1845)	+	+	+	–	+	+
Atherinidae	*Atherina bonapartii* (Boulenger, 1907)	–	–	+	–	–	–
	Atherina pontica (Eichwald, 1831)	+	+	+	+	+	+
	Atherina hepsetus (Linnaeus, 1758)	–	+	+	+	–	–
Belonidae	*Belone belone euxini* (Gunther, 1866)	+	+	+	+	+	–
Poeciliidae	*Gambusia holbrooki* (Girard, 1859)	–	–	+	–	–	–
Gasterosteidae	*Gasterosteus aculeatus* (Linnaeus, 1758)	+	–	+	–	+	+
	Pungitius platygaster (Kessler, 1859)	+	–	–	–	–	+
Syngnathidae	*Syngnathus abaster* (Risso, 1827)	+	+	+	–	+	+
	Syngnathus acus (Linnaeus, 1758)	–	–	+	–	–	–
	Syngnathus schmidti (Popov, 1927)	–	–	+	–	–	–
	Syngnathus tenuirostris (Rathke, 1837)	–	–	–	–	+	–
	Syngnathus typhle (Linnaeus, 1758)	+	+	+	+	+	+
	Syngnathus variegatus (Pallas, 1814)	–	–	+	–	–	–
	Nerophis ophidion (Linnaeus, 1758)	–	–	+	–	+	–
	Hippocampus hippocampus (Linnaeus, 1758)	+	+	+	+	+	–
	Scorpaena porcus (Linnaeus, 1758)	–	+	+	+	–	–
Triglidae	*Chelidonichthys lusernum* (Linnaeus, 1758)	–	+	+	+	+	–
Moronidae	*Dicentrarchus labrax* (Linnaeus, 1758)	–	–	+	–	–	–
Serranidae	*Serranus scriba* (Linnaeus, 1758)	–	+	+	+	–	–
Centrarchidae	*Lepomis gibbosus* (Linnaeus, 1758)	+	–	+	–	–	–
Percidae	*Acerina acerina* (Güldenstädt, 1775)	–	–	–	–	+	–
	Percarina demidoffi (Nordmann, 1840)	–	–	–	–	+	–
	Perca fluviatilis (Linnaeus, 1758)	–	–	–	–	+	–
	Sander lucioperca (Linnaeus, 1758)	+	–	+	–	+	–
Pomatomidae	*Pomatomus saltatrix* (Linnaeus, 1758)	–	–	+	+	+	–
Carangidae	*Trachurus mediterraneus ponticus* (Aleev, 1956)	+	+	+	+	+	–
Sparidae	*Boops boops* (Linnaeus, 1758)	–	–	+	–	–	–
	Diplodus annularis (Linnaeus, 1758)	+	+	+	+	+	–
	Diplodus puntazzo (Cetti, 1784)	–	+	+	+	–	–
	Sarpa salpa (Linnaeus, 1758)	–	–	+	–	–	–
	Sparus aurata (Linnaeus, 1758)	–	–	+	–	–	–
Centracanthidae	*Spicara flexuosa* (Rafinesque, 1810)	+	+	+	+	–	–
	Spicara maena (Linnaeus, 1758)	–	–	+	–	–	–
Sciaenidae	*Sciaena umbra* (Linnaeus, 1758)	–	+	+	+	–	–
	Umbrina cirrosa (Linnaeus, 1758)	–	–	+	–	–	–
Mullidae	*Mullus barbatus ponticus* (Essipov, 1927)	+	+	+	+	+	–
Chaetodontidae	*Heniochus acuminatus* (Linnaeus, 1758)	–	–	+	–	–	–
Pomacentridae	*Chromis chromis* (Linnaeus, 1758)	–	+	+	+	–	–
Labridae	*Ctenolabrus rupestris* (Linnaeus, 1758)	–	+	+	–	–	–
	Labrus viridis (Linnaeus, 1758)	–	–	+	–	–	–
	Symphodus cinereus (Bonnatterre, 1788)	+	+	+	+	+	–
	Symphodus ocellatus (Forsskål, 1775)	+	+	+	+	+	–
	Symphodus roissali (Risso, 1810)	–	+	+	+	–	–
	Symphodus tinca (Linnaeus, 1758)	–	+	+	+	–	–
	Symphodus rostratus (Bloch, 1791)	–	–	+	–	–	–
Ammodytidae	*Gymnammodytes cicerellus* (Rafinesque, 1810)	–	+	+	+	–	–
Trachinidae	*Trachinus draco* (Linnaeus, 1758)	–	+	+	+	–	–
Uranoscopidae	*Uranoscopus scaber* (Linnaeus, 1758)	–	+	+	+	–	–

3. The species diversity

Table 3.4.1. Cont.

| 1	2	3	4	5	6	7	8
Tripterygiidae	*Tripterygion tripteronotus* (Risso, 1810)	-	-	+	-	-	-
Blenniidae	*Aidablennius sphynx* (Valenciennes, 1836)	-	+	+	+	-	-
	Coryphoblennius galerita (Linnaeus, 1758)	-	-	+	+	-	-
	Salaria pavo (Risso, 1810)	-	+	+	+	-	-
	Parablennius incognitus (Bath, 1968)	-	-	+	+	-	-
	Parablennius sanguinolentus (Pallas, 1814)	-	+	+	+	-	-
	Parablennius tentacularis (Brünnich, 1768)	-	+	+	+	-	-
	Parablennius zvonimiri (Kolombatovič, 1892)	-	+	+	+	+	-
Gobiesocidae	*Diplecogaster bimaculatus* (Bonnaterre, 1788)	-	+	+	-	-	-
	Lepadogaster candollii (Risso, 1810)	-	-	+	-	-	-
	Lepadogaster lepadogaster (Bonnaterre, 1788)	-	+	+	+	-	-
Callionymidae	*Callionymus pusillus* (Delaroche, 1809)	-	-	+	-	-	-
	Callionymus risso (Lesueur, 1814)	-	-	+	-	-	-
Gobiidae	*Aphia minuta* (Risso, 1810)	-	+	+	-	-	-
	Benthophiloides brauneri (Beling et Iljin, 1927)	-	-	-	-	+	-
	Benthophilus stellatus (Sauvage, 1874)	-	-	-	-	+	-
	Gobius bucchichi (Steindachner, 1870)	-	+	+	-	-	-
	Gobius cobitis (Pallas, 1814)	-	+	+	+	-	-
	Gobius cruentatus (Gmelin, 1789)	-	-	+	-	-	-
	Gobius niger (Linnaeus, 1758)	+	+	+	+	-	-
	Zosterisessor ophiocephalus (Pallas, 1814)	+	-	+	-	-	+
	Gobius paganellus (Linnaeus, 1758)	-	+	+	-	-	-
	Gobius xanthocephalus (Heymer et Zander, 1992)	-	+	+	-	-	-
	Mesogobius batrachocephalus (Pallas, 1814)	+	+	+	-	+	-
	Millerigobius macrocephalus (Kolombatovič, 1891)	-	-	+	-	-	-
	Neogobius cephalargoides (Pinchuk, 1976)	-	+	-	-	+	-
	Neogobius eurycephalus (Kessler, 1874)	-	+	+	+	+	-
	Neogobius fluviatilis (Pallas, 1814)	+	-	+	-	+	+
	Neogobius melanostomus (Pallas, 1814)	+	+	+	+	+	+
	Neogobius platyrostris (Pallas, 1814)	-	+	+	-	-	-
	Neogobius ratan (Nordmann, 1840)	-	+	-	-	+	-
	Neogobius syrman (Nordmann, 1840)	-	-	-	-	+	-
	Proterorhinus marmoratus (Pallas, 1814)	+	-	+	-	-	+
	Pomatoschistus bathi (Miller, 1982)	-	+	+	-	-	-
	Pomatoschistus marmoratus (Risso, 1810)	+	-	+	-	+	+
	Pomatoschistus minutus (Pallas, 1770)	-	-	+	-	-	-
	Knipowitschia caucasica (Berg, 1916)	-	-	-	-	-	+
	Tridentiger trigonocephalus (Gill, 1859)	-	-	+	-	-	-
Sphyraenidae	*Sphyraena pinguis* (Günther, 1874)	-	-	+	-	-	-
	Sphyraena sphyraena (Linnaeus, 1758)	-	-	+	-	-	-
Scombridae	*Scomber scombrus* (Linnaeus, 1758)	-	-	+	-	-	-
	Sarda sarda (Bloch, 1793)	-	-	+	+	-	-
Scophthalmidae	*Scophthalmus rhombus* (Linnaeus, 1758)	-	-	+	-	-	-
	Psetta maeotica (Pallas, 1814)	+	+	+	+	+	-
	Psetta torosa (Rathke, 1837)	-	-	-	-	+	-
Pleuronectidae	*Platichthys flesus luscus* (Pallas, 1814)	+	+	+	-	+	-
Bothidae	*Arnoglossus kessleri* (Schmidt, 1915)	-	-	+	-	-	-
Soleidae	*Pegusa lascaris* (Risso, 1810)	-	+	+	+	-	-
TOTAL	**137**	**39**	**59**	**109**	**48**	**61**	**20**

a)

b)
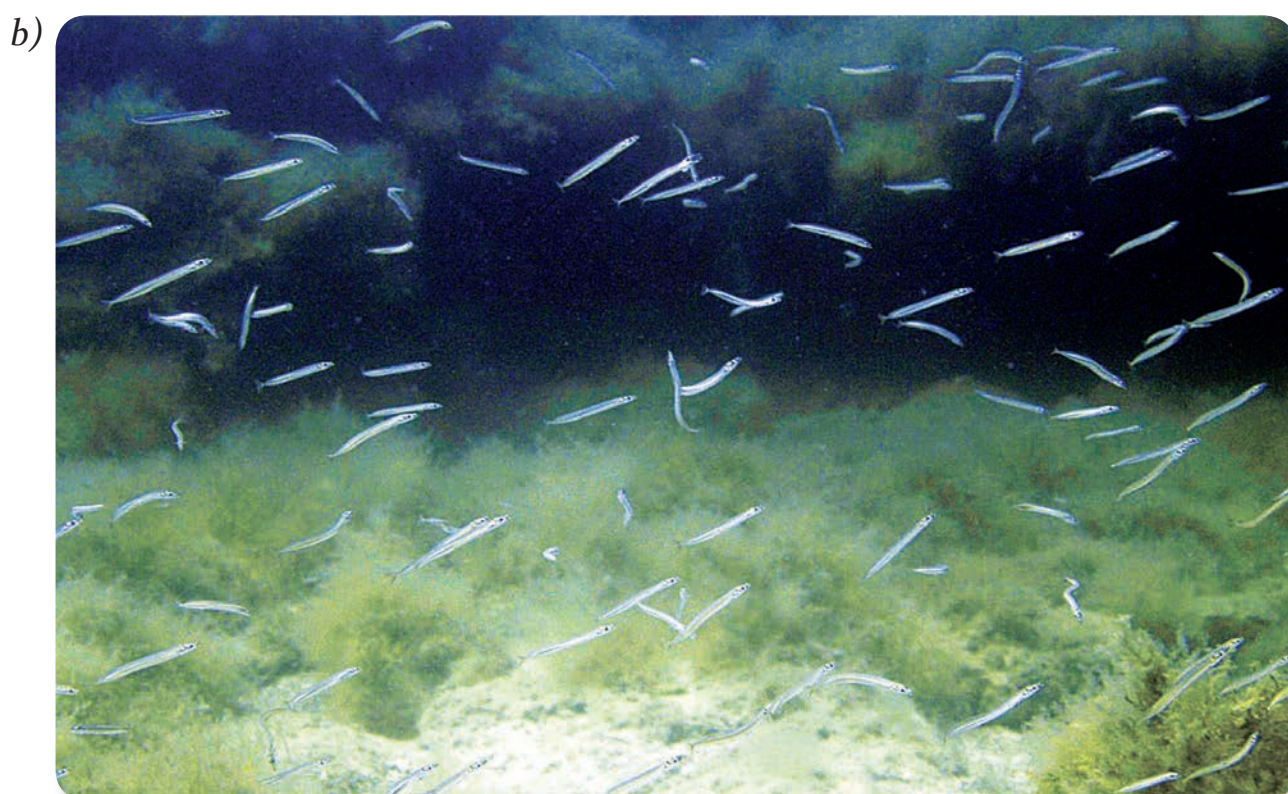
Fig. 3.4.5. Typical underwater landscapes of hard bottom with *Symphodus ocellatus* (a) and soft bottom with *Gymnammodytes cicerellus* (b) near the Tarhankut peninsula

3. The species diversity

There Blenniidae and Labridae prevail (Fig. 3.4.4, 3.4.5a), *Scorpaena porcus* are also numerous, more rarely *Diplodus annularis* and *Gaidropsarus mediterraneus* and are encountered. *Sciaena umbra*, *Serranus scriba*, *Diplodus puntazzo*, *Chromis chromis*, the species of small numbers and also put into the Red Book of Ukraine, were solitary found. In the relatively shallow water, benthic landscapes are represented by medium-sized rocks and boulders, interspersed with sand – gravel sections; gobies from genius *Gobius* and *Neogobius* are observed, including large populations of *Gobius bucchichi* and *G. paganellus*, which are listed in the Red Book of Ukraine.

At depths greater than 8 – 10 m the submarine landscape is replaced by sands and shells with a predominance of such bottom fish as *Mullus barbatus ponticus*, *Gobius niger*, *Ophidion rochei*, *Uranoscopus scaber*, *Trachinus draco* and *Scorpaena porcus*, which are observed to a depth of 40 m (Fig. 3.4.5b). In April, May and October *Psetta maxima maeotica*, *Raja clavata*, *Dasyatis pastinaca* and *Trigla lucerna* come nearer to the shore. At depths greater than 40 m *Merlangius merlangus euxinus* can be seen.

The presence of two alien species of fish was firstly noted in the area. On the rocky walls of Cape Atlesh the *Gobius xanthocephalus*, firstly detected in 2007 near Sevastopol, was found. Another species – *Pomatoschistus bathi* – was observed in large numbers in sandy bottom to a depth of 15 m (Fig. 3.4.6a, b). Since the early 2000s, the latter has been noted near Sevastopol and in 2008 we found it in coastal zone of lagoon Donuzlav.

In general, the ichthyofauna near Cape Tarkhankut is in satisfactory condition.

Ichthyofauna of the bays and coastal zone of Sevastopol. According to the results of our long-term studies, a list of species of fish in the bays and coastal waters of Sevastopol now includes 109 species from 49 families, and by the literature data – 120 species from 49 families (Table 3.4.1), representing 51.1% of the total number of species (235) registered to the Black Sea. The greatest taxonomic diversity is characteristic for family Gobiidae, represented by 23 species, of which 10 species are Ponto-Caspian endemic belonging to genera *Mesogobius*, *Neogobius* and *Proterorhinus*, and the rest – by Mediterranean immigrants. The family Syngnathidae and Blenniidae are represented by 8 species each, Labridae by 7, Mugilidae by 6, Clupeidae and Sparidae – by 5 each, Acipenseridae, Atherinidae, Gobiesocidae and Scombridae – by three species each. Thus, 8 families are represented by 2 species each and 30 by one species only.

Based on 15 years of observations, we can conclude about the possibility of inclusion in the fish fauna of the region, as a permanent element the 9 Mediterranean (Atlantic-Mediterranean) and 2 West-Pacific marine fish species. Settling of the Mediterranean species is directly related to the natural process of permanent mediterranization and the Pasific fishes – coming due to the human activity. By now, off the coast and in bays completely naturalized such bottom species as *Parablennius incognitus*, *Gobius xanthocephalus*, *G. cruentatus*, *Millerigobius macrocephalus*, *Tridentiger trigonocephalus* (Fig. 3.4.7) and *Pomatoschistus bathi* (Boltachev et al., 2009 (a); Boltachev, Karpova, 2010, Boltachev et al., 2010 (b)) have completely naturalized. Conclusion of the naturalization of these species is based on the presence of different age groups, the nests guarded by males, the gradual expansion of habitats.

Since 1999, in the coastal zone near Sevastopol three Atlantic-Mediterranean fishes, *Sarpa salpa*, *Sparus aurata* and *Chelon labrosus*, have been regularly found; and now they are objects of amateur fishing (Boltachev, Yurakhno, 2002; Boltachev et. al, 2009 (a)). Most
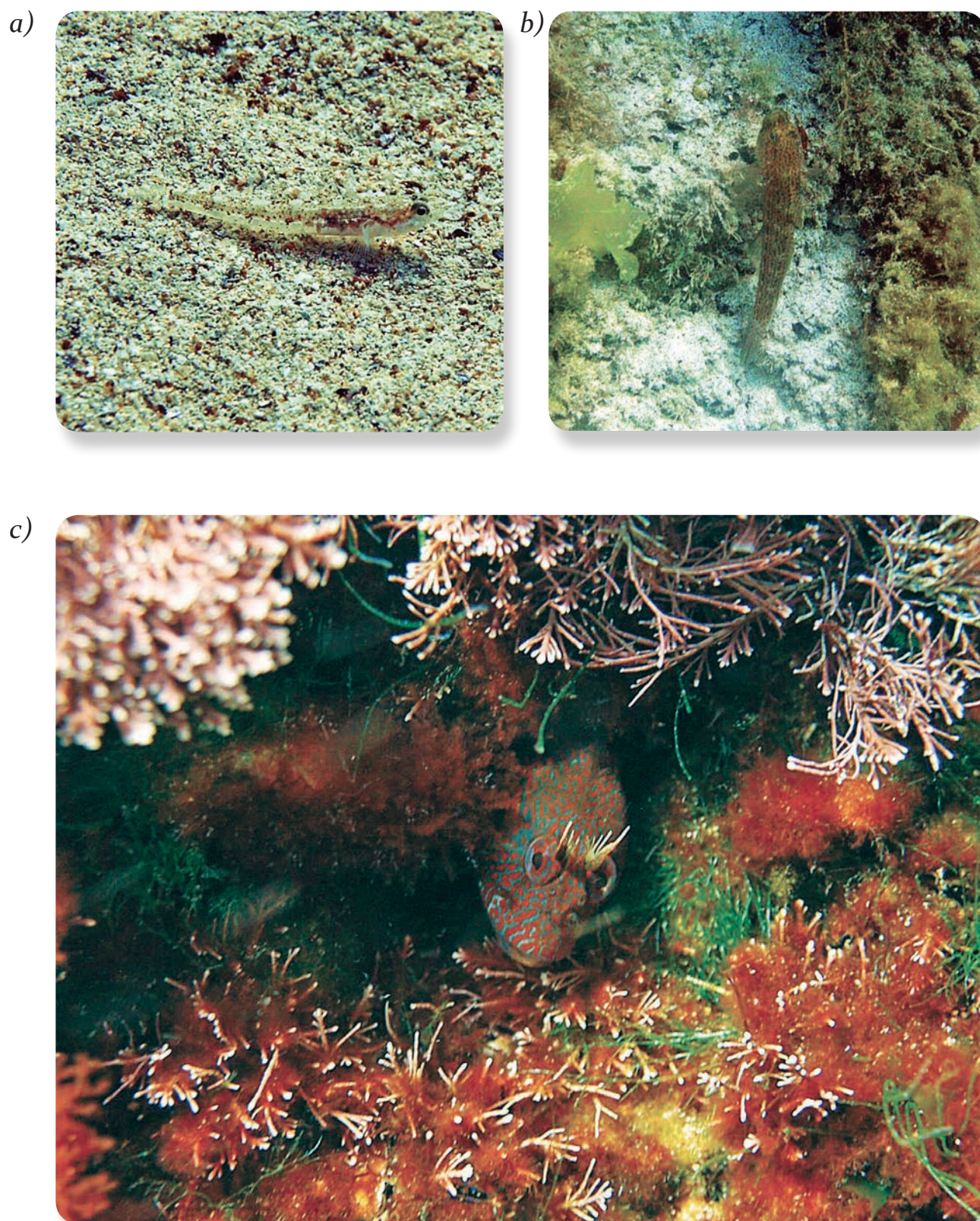
a)

b)

c)

Fig. 3.4.6. Alien species, for which we registered new places of inhabitation – *Pomatoschistus bathi* (a) and *Gobius xanthocephalus* (b) near the Tarhankutsky peninsula, *Parablenniuc incognitus* in the region of Cape Martyan

Fig. 3.4.7. Alien species of gobies, population of which inhabit the Crimean coast only near the Sevastopol – *Tridentiger trigonocephalus* (a), *Millerigobius macrocephalus* (b), *Gobius cruentatus* (c)

probably that *T. trigonocephalus,* the Far Eastern endemic, appeared due to the unauthorized release into Sevastopol bay of more than 20 adult fishes which in 1981 were specially transported from the Gulf of Possiet as the exhibits to enrich Sevastopol Aquarium. Other Far Eastern Endemic *Liza haematocheila*, artificially introduced and fully naturalized in the Azov-Black seas basin, for the first time two specimens were caught near Sevastopol in June 1993. In the following years, from late May to early July, *L. haematocheila* formed a spawning aggregation in the coastal zone from Balaclava to Cape Khersones, and the greatest concentration was in his mid-1990s, and then their numbers dropped substantially.

Semi-anadromous freshwater *Sander lucioperca* is very rare in the Balaklava bay, the recent finding dates back to summer 2006. Three freshwater species inhabit the estuary of the river Chornaya, two of these fishes were purposely introduced into the Crimean inland water during 1930s: *Carassius gibelio* for aquaculture and *Gambusia holbrooki* for combating malaria mosquito. The third, *Pseudorasbora parva*, could have been either brought by chance with the Dnieper water and carried through the branched network of the North-Crimean canal or accidentally installed in artificial reservoirs together with commercial fish species and in a relatively short period spread in the basins of major rivers of the Crimea up to their mouths (Boltachev et al., 2010 (a)). All three species are seriously rival to the aboriginal fish fauna.

Thus, of the 120 species listed for the coast and bays of Sevastopol 84 are common and mass, few in number, but occasionally occurring – 17; 7 are very rare yet of potential occurrence afterwards – 6 – negeigible (*Lophius piscatorius*, *Zeus faber*, *Trachurus trachurus*, *Scomber japonicus*, *Balistes capriscus*, *Clupeonella cultriventris*) and virtually impossible – one (*Heniochus acuminatus*). The findings of six species (*Lipophrys adriaticus*, *Neogobius ratan*, *N. syrman*, *N. gymnotrachelus*, *N. cephalargoides*, *Syngnathus tenuirostris*) need confirmation.

All the four ecological groups prevailing in the Black Sea are more or less widely represented in the coastal sea water of Sevastopol. There are 99 marine, 11 brackish-water Ponto-Caspian relicts, 6 diadromous and 4 freshwater and semi-diadromous species, their percentage is estimated 82.5, 9.2, 5.0 and 3.3%, respectively (Fig. 3.4.1).

The degree of anthropogenic load is another factor influencing species diversity. In the Sevastopol, Streletskaya and Quarantine bays heavily oil-polluted bottom substrate (Mironov et al., 2003) has badly changed the habitats of bottom fishes such as Gobiesocidae, Callionymidae, some Blenniidae and Gobiidae; in the bays Sevastopol, Streletskaya and Balaklava the piers, concrete embankments and other waterworks in recent decades have extensively destroyed natural biocenoses. In the Kruglaya bay, one of a few public city beaches, the warm-season recreational overload has been suppressing the coastal biocenoses for years.

The highest species richness, the intricate ecological structure of ichthyofauna into which almost each ecological group of Black Sea fishes with their specific species ratios is incorporated and the naturalization of unique alien species of fishes are the arguments for the selection of this site as separate Sevastopol natural – history area of the coastal zone of the Crimea.

Ichthyofauna of the coastal waters of the Cape Martyan. Information about some marine organisms, fishes in particular, which occur in the coastal waters of the reserve, is very few, if any. According to our preliminary results in the vicinity of Cape Martian 48 species of fish were discovered (Table 3.4.1); with reference to the available literature this number increases to 67 species from 37 families. Gobiidae and Blenniidae are represented by 7 species each, Labridae and

Fig. 3.4.8. Mass species of the Cape Martyan – *Symphodus tinca, S. ocellatus, Chromis chromis*
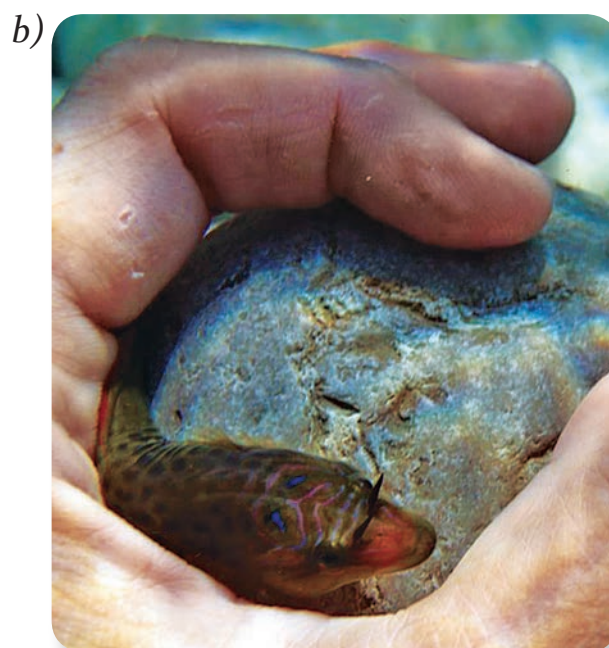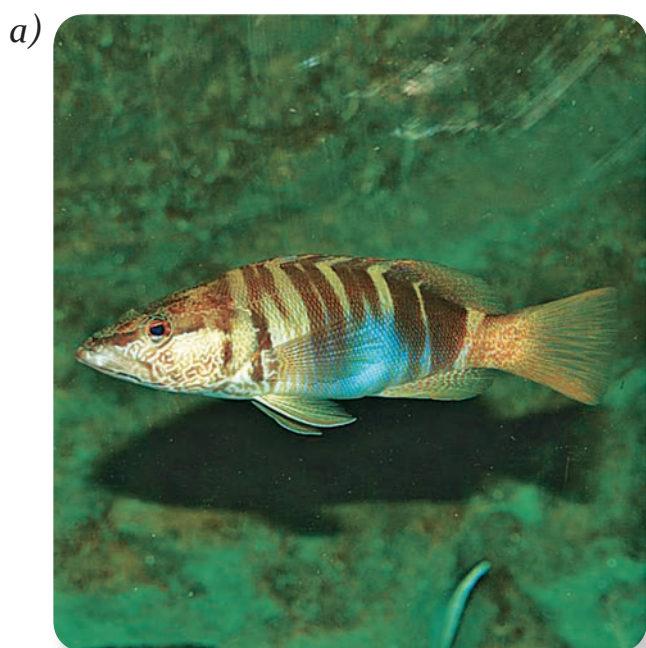
a)

b)

Fig. 3.4.9. Protected species *Serranus scriba* (a) and *Lepadogaster lepadogaster* (b) is numerous at the Tarhankut peninsula and Cape Martyan

Syngnathidae by 6 and 4 species, correspondingly; Clupeidae, Gobiesocidae and Acipenseridae by 3 species each, Mugilidae, Atherinidae and Sparidae by 2 each; other families are confined to one species each. *Parablennius incognitus*, non-native species, in this locality of the sea were abundantly found for the first time on the underwater cliffs to 2-m depth (Fig. 3.4.6c).

Biotopes of the rocks bearing mussel and macrophyte epibioses are densely populated; large shoals, mainly of Blennidae and Labridae and guarded by Red Book of Ukraine *Chromis chromis* (Fig. 3.4.8), are seen. *Diplodus annularis*, *D. puntazzo*, *Serranus scriba* (Fig. 3.4.9a), *Gaidropsarus mediterraneus* preferred keeping closer to the base of the rocks. These fishes, though fewer, also occurr in biotopes of the rocks and boulders. At the pebble-boulder bottom, were species diversity and abundance of fish decreased to minimum, only *Neogobius eurycephalus* and *Lepadogaster lepadogaster* (Fig. 3.4.9b) are numerous. On the sandy bottom accumulations of *Mullus barbatus ponticus* were observed.

According to our observations, species diversity of fishes in the sea of the reserve Cape Martyan is relatively large and predominantly is marine in nature, due to hydrochemical features of the region. 19 species, i.e. nearly 30% of the fish fauna, are in the Red Book of Ukraine, and some of them, such as *Chromis chromis, Lepadogaster lepadogaster* are quite numerous. A noteworthy feature is very high abundanceof bottom dwelling and pelagic fish.

Ichthyofauna of the coastal and adjacent waters of the Cape Kazantip. Among seas of the Mediterranean basin the Sea of Azov has the least diversity of ichthiofauna, but its genesis, taxonomic and ecological structure is very heterogeneous, due to the rather extreme living conditions and the complex geological history of this reservoir (Fig. 3.4.10a, b). Numerous endemic and relict species, some vanishing as yet, make fish fauna of the Sea of Azov unique. The counts we made in the coastal waters of Kazantip nature reserve show that 61 species of fish of the main ecological groups occur there (Table 3.4.1, Fig. 3.4.1). Families Cyprinidae and Gobiidae are represented by 10 species each, Syngnathidae by 5 and Clupeidae, Mugilidae and Percidae by 4 species each. Large species diversity is characteristic of the families which include fishes of freshwater origin, brackish- or euryhaline marine species. The leading fraction of 31 species are marine fishes (Fig.3.4.10 c, d, e).

Brackish-water Ponto-Caspian relicts having been constant in the Sea of Azov are a special group; 11 species, many of which provide the base of the regional commercial fishing, were found in the examined hauls. The most widespread of these is a typical pelagic schooling species – *Clupeonella cultriventris*. The diversity of this group is mainly owing to 9 members of family Gobiidae; *Neogobius melanostomus* dominate by weight in the catches as well as by occurrence. Sometimes small shoals of *Percarina demidoffi* were noticed coming near the shore.

Six anadromous species dwell in the Sea of Azov. A number of laws have been adopted to prohibit sturgeon fishing and protect Acipenseridae which all are in the Red Book of Ukraine, yet the situation remains very grave because of massive poaching.

Semi-diadromous species represented by 7 species primarily from the family Cyprinidae: *Abramis brama*, *Cyprinus carpio*, *Pelecus cultratus*, *Rutilus rutilus*, *Carassius gibelio*, as well as the *Silurus glanis* and *Sander lucioperca*. In catches from the surveyed seawater area these fishes were not numerous. Usually these fishes in the region studied in the catches occur in small numbers. Populations of most of them is poor as a result of overfishing and the deterioration of spawning and feeding areas.

a)

b)

c)

d)

e)

Fig. 3.4.10. Typical underwater landscapes of the Sea of Azov – sandy bottom (a), mass of algae on the stones (b) and its inhabitants – *Neogobius eurycephalus* (c), sand goby *Pomatoschistus marmoratus* (d) and juveniles of Mugilidae (e)

The group of freshwater fish was found in the catches usually during a significant freshening of the sea in a small amount, and the presence of its representatives in the area of Cape Kazantip is, as a rule, casual. Six species included in this group are *Esox lucius*, three Cyprinidae: *Scardinius erythrophthalmus*, *Ctenopharyngodon idella* and *Hypophthalmichthys molitrix*, and two Percidae: *Perca fluviatilis* and *Acerina acerina*.

Factors that endanger ichthyofaunas of the Kazantip nature reserve and the Sea of Azov are overfishing, poaching, trawling which is fully impermissible in this shallow sea, recurrent phytoplankton blooms and ongoing pollution (see chap. 4).

Ichthyofauna of the Eastern Sivash Gulf. A special hydrochemical condition in the Eastern Sivash makes its fish fauna different from that in the Sea of Azov. Until the mid-1960s 29 species have been ascertained for the gulf, 25 of them as constant or largely constant. Fishes of marine origin were the vast majority – 19 species or 76% of the total diversity; four brackish-water Ponto-Caspian relicts and two anadromous fishes contributed 16 and 8%, correspondingly, being far behind the leading group (Pavlov, 1960; Svetovidov, 1964). Investigations conducted during the early 2000s evidenced that the ichthyofauna has significantly changed. The intensive discharge of fresh water from rice fields has stimulated arrival of freshwater fish and ousted marine species thereby decreasing their fraction (Demchenko, 2005). For the overall observation period 36 constant and migratory species from 15 families have been registered; taking into the account incidental species, this list increases to more than 50 species. Families Cyprinidae, Gobiidae, Syngnathidae, Mugilidae, Clupeidae and Gasterosteidae were represented by 8, 6, 5, 4, 3 and 2 species, correspondingly, other 9 families by one species each. The share of marine species decreased to 55%, followed by freshwater (19%) and brackish-water (17%) fish, the smallest proportion of diadromous and semi-diadromous fish (6 ‰ and 3 ‰, respectively) (Fig. 3.4.11).
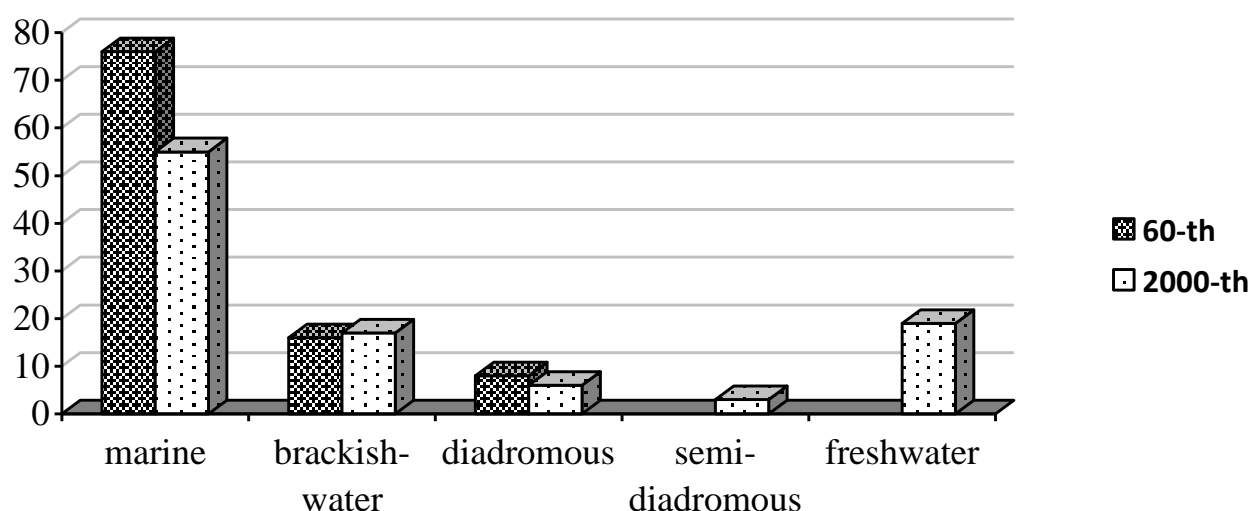

Fig. 3.4.11. Ecological structure of ichthyofauna of the Eastern Sivash Gulf to beginning of the process of desalination and now (Pavlov, 1960; Demchenko, 2005; our data)

a)

b)

c)

Fig. 3.4.12. Numerous at present time inhabitants of the Eastern Sivash Gulf freshwater *Alburnus alburnus* (a) and brackish-water *Proterorhinus marmoratus* (b) and *Knipowitshia caucasica* (c)

Our investigation has specified that only 20, which are 8 mass and the rest less abundant, are common and constant during warm season of the year. As to ecological identity, the marine, brackish-water and freshwater groups are estimated 9 (45%), 6 (30%) and 5 (25%), correspondingly. Distribution pattern has become radically different. The early publications stated that only the northern area of Sivash, not farther than the 1st and 2nd creeks, had been fish-inhabited and only a few species (e.g., Mugilidae) happened to enter the 3rd creek southwards.

Presently fish occur all through the gulf. For example at the water area of 3-d creek we found for the first time 20 fish species. Fresh water species, of which *Carassius gibelio* and *Albburnus alburnus* were the most massive (Fig. 3.4.12a) were localized in the regions of the discharging canals and did not leave brackish water zones, exept silver carp. Gobies: *Neogobius fluviatilis, Proterorhinus marmoratus* (Fig.3.4.12b) and *Neogobius melanostomus* by their abundance stand aside the brackish-water pontic-caspian species. *Atherina pontica, Liza aurata*, *Zosterisessor ophiocephalus*, *Syngnathus abaster* were the most mass species, as they were before. *A. pontica* spawning was observed at all the water area of the Eastern Sivash. In the estuaries of the discharging canals from rice checks and in the coastal zone in June dense shoals of these species fry, with abundance of hundreds of thousands of exemplaries, were registred.

In the 4th euhaline creek only 6 species were met. *Atherina pontica*, *Syngnathus abaster*, *Pomatoschistus marmoratus* were numerous in the coastal zonea and *Neogobius fluviatilis* – in the northern part of this creek. Near the boundary of the macrophytes coastal band *Knipowitschia caucasica* formed accumulations up to tens of specimens each at 50 cm depth (Fig. 3.4.12c). Finding of brackish water species *Clupionella cultriventris* at such high salinity is of interest (34.6-38.2%).

Thus, at present there is an grow in the number of freshwater fish species as a result of their penetration through the channels of discharge from the ponds and irrigation networks and their resettlement to the freshened areas of the bay.

Aggressive species *Lepomis gibbosus*, that is new for this region, is violently competing with many fishes in inland water bodies of the Crimea and deserves special concern. High content of heavy metals in bottom sediment at the upper part of the gulf also gives cause for alarm.

By now desalination processes in the hydrochemically changeable Eastern Sivash have slowed down and, possibly, paused that can again transform the fish fauna through an increase of marine species.

4. THE MAIN ANTHROPOGENIC FACTORS GENERATING "HOT ECOLOGICAL POINTS" IN THE COASTAL ZONE OF THE CRIMEA

In recent years special attention was given to the ecology of the Black Sea and the Sea of Azov in relation to the growing cascade of human impacts. In this section the array of threats to marine biocenoses along the Crimean coastline is discussed.

Artificial discharge of the used Dnieper water into the sea. In 1963, when the first stage of the North-Crimean canal (NCC) has been constructed and activated, it was receiving 1800 million m^3 of the annual inflow from the Dnieper; by 1990, further construction has increased the flow-through capacity to 3202 million m^3 (Ustoycheviy Krim, 2003). Since the late 1960s sizeable stretches of the coast has been given to flooded rice fields. In the northern Crimea and in the south of Kherson and Odessa regions the extensive rice-growing farms occupied 13.1, 5.3 and 2.7 thousand hectares (38% of the total area under the crop of rice in Ukraine), correspondingly. As the rice-growing technology dictates, the fields stay flooded from spring to autumn, about 600 – 700 million m^3 of the used fresh water are regularly discharged into the coastal shallow pate of the Karkinit and Eastern Sivash gulfs (Ustoycheviy Krim, 2003). In 1990 Ministry of Nature Protection and Ministry of Health resolved to veto aerial insecticide-spraying and top-dressing of the crops farmed close to the seaside. Later, the freshwater release from the rice-fields into the gulfs was banned, too. The environmentally safe cultivation technologies were rather costly and some farms had abandoned rice for cereals traditional for the region; the rice acreage had decreased four-fold, the used freshwater outflow put under rigid control and pesticides fully prohibited. However, after disintegration of the Soviet Union the rice farms were privatized and the outdated ecologically dangerous technologies have come back (Fig. 4.1).

The Eastern Sivash and some nearshore districts at eastern part of the Karkinit Gulf have undergone nearly all the harms inherent to rice farming. Its hydrological regime has radically changed, the seawater salinity widely dropped an order of magnitude, and the now unsteady species and ecological structure of phyto- and zooplankton communities depends on economic activity in the region.

The largest Crimean piscicultural farm was organized in Krasnoperekopsk district; the total area and volume of these 59 freshwater ponds make up 1028 hectares and 8899 thousand m^3, respectively. Both the waste water from this fish-pond system and the non-registered Dnieper outflow directly from the NCC main conduit are discharged in the east of the Karkinit Gulf. As a result of overloading considerably decreased water salinity in the gulf, changed hydrochemical parameters and forced up silting – the probing evidenced 50-60-cm thick mud on the sea floor. In response, native pelagic and benthal biocenoses in the Chatyrlyk, Samarchik and Shiroky bays (eastern part of the Karkinit Gulf) have conspicuously transformed. The newly appeared freshwater species bring about structural changes in the phytoplankton communities and ichthyocenoses (see chap. 3).

Heavy metals, oil hydrocarbons and some other pollutants. Until recently, information about heavy metals in bottom sediments of the internal part of the Karkinit Gulf has been absent. Our chemical tests of the bottom substrate evidence a variety of heavy metals present, their concentrations (mg/kg) varying as widely as: cadmium – 0.1-5.24 (1.19 on the

a)

b)

c)

Fig. 4.1. Problems of rise-growing – discharge the freshwater (a), sedimentation of silt (b), dispersion of fertilizers (c).
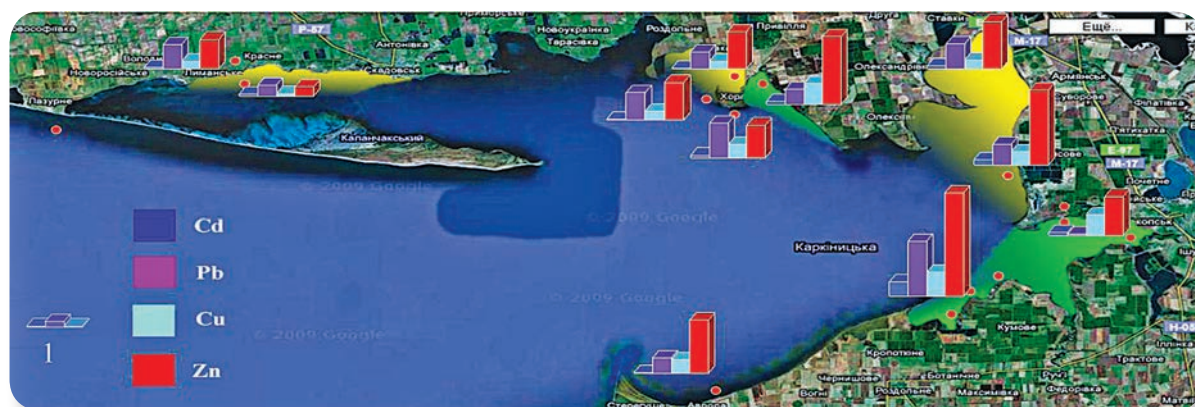

Fig. 4.2. Pollution of the bottom sediments of the Karkinit Gulf by heavy metals (1 – background values of pollutions)

average), lead – 0.4-20.62 (8.29), copper – 0.86-8.85 (5.0), zinc – 3.42-38.73 (18.86). High concentrations are characteristic mainly of the innermost part of the gulf and lesser of the northern shore area. Maximum estimates of all metals were reported from station 14 and above-the-average, arranged as receding from station to station, are as follows: cadmium (sts. 9, 10), lead (sts. 6, 5, 2, 8), copper (sts. 10, 7, 11, 9) and zinc (sts. 9, 10, 7, 16) (Fig. 4.2) (Boltachev et al., 2009). For comparison, in bottom sediments of the western part of the gulf average estimates of cadmium, lead and copper were significantly lower: 0.2, 1.5, 0.2 mg/kg, correspondingly (Aleksandrov et al., 2009), yet greater than the background estimates in the NW Black Sea, probably as the result of oil and gas exploration and extraction in the Karkinit Gulf.

Presumably, heavy metals which have been accumulated in the internal eastern area of the Karkinit Gulf are brought with the Dnieper water and rice-field outflow, with the wind emissions from the chemical industry plants located in Krasnoperekopsk district and during aerial spraying processing of the rice fields (Fig. 4.1).

Bottom sediments of the Sevastopol bay are heavily polluted with oil hydrocarbons. The sites where highest estimates were measured ('hot spots') adjoin the seawater areas regularly receiving industrial and municipal sewage and rain drainage discharges. Spatial distribution of the pollutants is strongly influenced by hydrodynamic and hydrochemical conditions specific for each locality. In the bottom substrate from the central part of Sevastopol bay and from Southern bay, oil hydrocarbons amounted to 1200-2000 mg/100 g dry residue, that is hundreds times as large as the estimates in unpolluted locations of the Crimean coastal zone (Mironov et al., 2003). The related disturbances of the local bottom biocenoses have been discussed above (see chap. 3)

Anthropogenic press, mostly from recreation, upon the sea around Cape Martyan is considerably milder. Coastal zone of the Southern Crimea is referred to conditionally pure or slightly polluted; the regional zooplankton assemblage includes a large diversity of abundant species producing large biomass, ichthyocenoses have the structure closely resembling that typical for the Black Sea, and the fish stock, as the visual submarine observations evidenced, is plentiful. The same picture is observed in the sea near the Tarkhankut peninsula, where quantitative characteristics of the communities are significantly lesser that may be due to oil extraction activity in the NW Black Sea. Oil and gas production companies have been intensively developing continental shelf in the recent decades. Drilling test holes and/or production wells on the shelf emit into the sea mud-flush and combustive lubricating agents, fine sludge fractions, oil products, methane and gaseous condensate, i.e., xenobiotics strange for the area. Development of the oil-and-gas fields would aggravate the environmental background on by toxic components of barite (lead, cadmium and copper of barium sulfate make up to 0.22, 0.124 and 0.019 %, correspondingly) dominating in the drilling fluid. Simultaneously, clay and other reactants such as graphite, vital, soda ash, chromates and bichromates, synthetic materials and some others worsen seawater and bottom substrate properties. General pollution of the marine environment severely affects coastal seawater areas adjoining the Crimean peninsula (Rudneva et al., 2008).

More than 1500 enterprises regularly discharge into the Sea of Azov 28 million m^3 drainage waters a day, one-third of the sewage untreated. In the early 1980s, each year the sea received over 15 thousand t oil products, 2 thousand t detergents and 250 t phenols brought

by the inflowing Don and the Cuban rivers and the urban sewage from the maritime cities. (Akimova, Khaskin, 1994).

Fish kill incidents. Only episodically afflicting the NW Black Sea, hypoxic summer fish kills have always been a characteristic feature of the Sea of Azov. Each time this was a tragic disaster for the integral ecosystem of the sea. Mass mortality of marine life involves biodiversity decline, negative structural changes in biocenoses and sizeable economic losses through the devastated stock of commercial fish and mollusks. The rise of economical activity in the recent decades has substantially increased organic substance inflow into the Sea of Azov and made fish kills in the heavily eutrophicated sea more frequent. The seawater stratification specific to windless days of warm season when the seawater column stands motionless and the less saline surface gets very warm also provokes fish kills.

In 2007 members of the summer expedition (27 July – 1 August) launched by IBSS were the eyewitnesses of a summer fish kill in the coastal zone from Cape Kazantip to the Arabatsky and Kazantip gulfs and the related abiotic and biotic factors (Figs. 4.2, 4.3 and 4.4). As the hydrochemical tests showed, the content of nitrites there had been three times as large and of phosphates and nitrates 1.5 orders of magnitude as large as in the unpolluted seawater areas. By 27 July 2007 calm weather had set in. Temperature measurements evidenced that the sea surface at 100-300-m distances from the shore warmed to 28.4 – 28.9°C, the 7-9-m deep near-bottom sea water to 26.5 – 26.9°C and close to the shore to 30°C and warmer. The seawater salinity varied from 10.66‰ in the surface to 10.95‰ near the bottom. Intensive microalgal oxygen evolution during light time of the day increased dissolved oxygen content in the surface layer to 129 – 171% while in some hypoxic near-bottom localities it was 6%.

The abundance of phytoplankton in the sea surface had risen to 1.5 – 35.8 billion cell/m^3 and the biomass to 4.5 – 104 g/m^3. A bloom of cyanobacteria *Anabaena flos-aquae* and *Aphanizomenon flos-aquae* was simultaneously developing. Toxic *Prorocentrum cordatum* and *Prorocentrum micans*, known as red-tide inducers, were also in plenty (Fig.4.3). During the observation period total bacterioplankton abundance was very large, 6.46 ± 2.21 million cell/ml on the average. The bacterioplankton had been mainly 0.113–0268-µm^3 large cocci; only about one-third of the total bacterial abundance had been owing to larger cocci that can be related to vigorous phytoplankton community growth.

On 28 June 2007 about 5 t of *Clupeonella cultriventris* were cast ashore in the Tatarskaya bay (Fig. 4.4a). As pelagic inhabitants, these fishes have been killed not by oxygen deficiency but rather by two mass Cyanophyta, *Anabaena flos-aquae* and *Aphanizomenon flos-aquae*, known for bringing about blooms and also excreting dangerous toxins, e.g., anatoxin and saxitoxin, poisonous for fish, all higher animals and humans. In the sea along the Kazantip coastline *Prorocentrum micans* and *P. cordatum*, dominating by biomass and causing the red-tides, produced a variety of toxins.

As the expedition records evidence, the first victims of the near-bottom oxygen deficiency were ground fishes, gobies in particular. Until afternoon 29 July, masses of sleepy gobies were moving shoreward as an easy prey for the landing-nets and bare hands; the first dead fishes were found by the evening (Fig. 4.4b). In the following four days the fish kill had expanded to the entire coastal zone of Cape Kazantip, some localities in the Arabatsky and Kazantipsky gulfs. The majority of dead fish were four species of gobies: *Neogobius melanostomus*, *Mesogobius batrachocephalus*, *Neogobius fluviatilis*
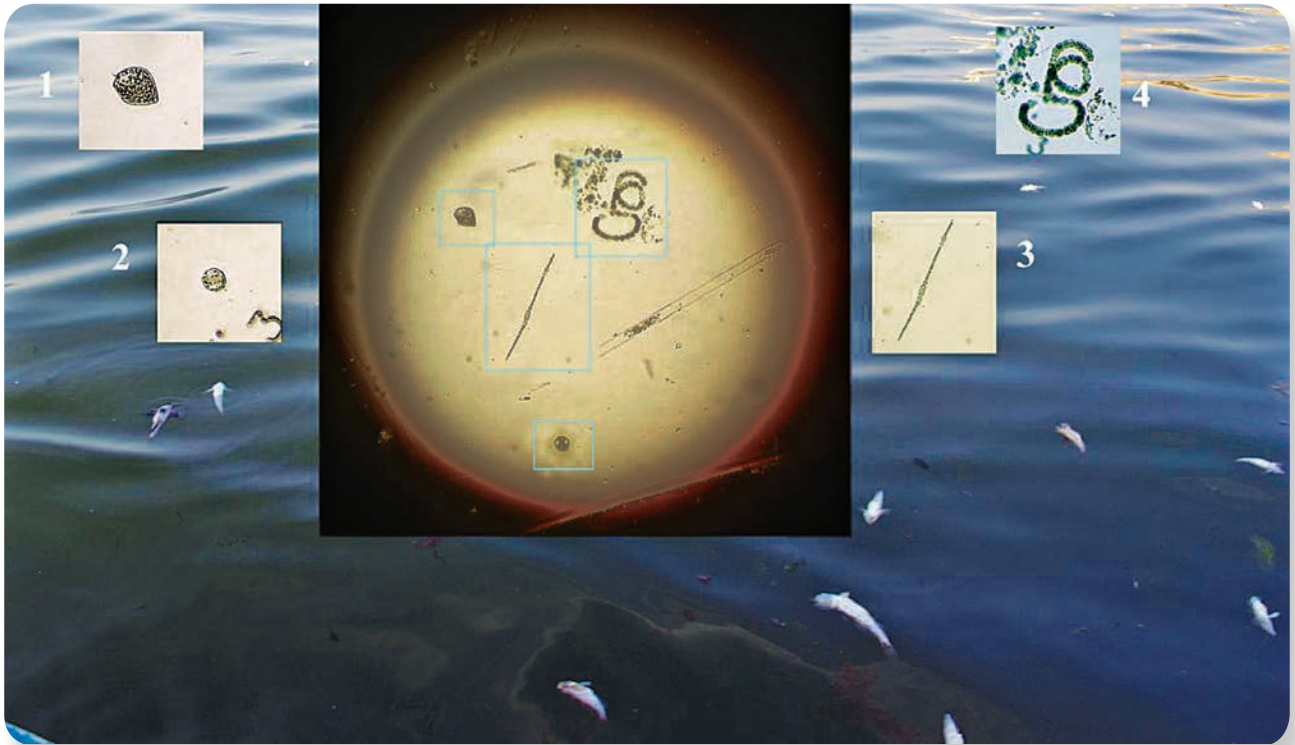
Fig. 4.3. Toxic microalgae *Prorocentrum micans* (1), *Prorocentrum cordatum* (2), *Aphanizomenon flos-aquae* (3), and *Anabaena flos-aquae* (4)
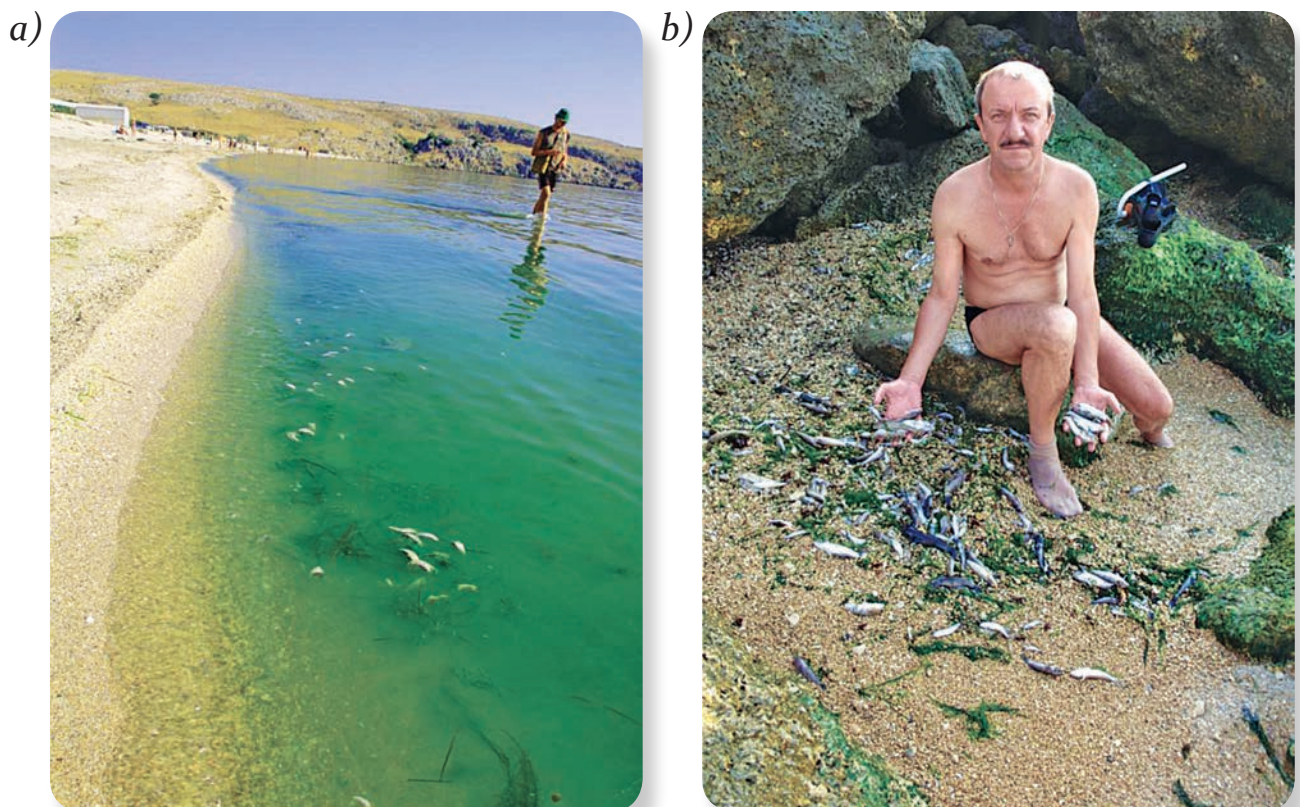

Fig. 4.4. The water bloom in the Tatarskaya bay (a); consequence of the fish kill near Cape Kazantip

and *Neogobius eurycephalu*, estimated 40.2, 29.6, 19.0 and 11.2% of the total loss, correspondingly (Fig. 4.5). Among the dead fish black gobies were found – the males usually change the color for black while guarding the eggs having been laid by the females; most likely, the eggs had died, too. Findings of *Atherina pontica* and shrimps were not as frequent. Dead fishes were washed ashore, scattered on the sea floor (to 190 gobies per 100 m^2 on the average) and floated on the sea surface in a belt from 50 to 150 m in width. According to our observations, the mass mortality zone stretched for 10 km, if not longer. Total damage from the loss of commercial gobies is difficult to calculate because of the patchiness of dead fish fields, locality-specific concentrations and the limited potentialities inherent in representative quantitative count. Approximately, the total stock of dead gobies in the examined seawater area might have weighed to 100 t. A fact to be remembered is that every year in the Sea of Azov several fish-kill happens that strikes different areas of water.

Bottom trawling. The detriment that bottom trawl fishing brings to bottom-dwelling communities and to the whole coastal marine ecosystem has been discussed elsewhere (Zaitsev et al., 1992). In the early 1970s the majority of Black Sea countries initiated bottom trawling as fit for fishing the formerly neglected Black sea sprat, *Sprattus sprattus*, the most abundant fish in the sea. By the 1980s, however, visual observations from manned submersibles have offered a large body of proofs about the fatal extermination of benthic biocenoses on the shelf of the Black Sea (Fig. 4.6), and bottom trawling was banned. Pelagic zone alone was permitted for such sprat fishing that avoided direct contact with the sea bed. However, results of our investigations as well as examination of trawl catches evidence that the law is broken rather than obeyed because in day time the sprat is used to shoal mainly in near-bottom seawater. As the trawl approaches, the school presses to the sea floor, therefore the trawl has to immediately contact the bottom, plowing it with its boards, connecting lower cable ropes and the groundrope.

The gravest threats from the bottom trawl fishing are as follows: a) trade bottom and bottom dwelling fishes, invertebrates and macrophytes simultaneously harvested en masse; b) benthic life exterminated by heavy structural pieces of the trawl; and c) the sea bed muddying by fine sediment (pelitic silt fraction) first stirred up and then settled extensively. The latter is the most ruinous to marine habitats inasmuch as sea currents transport huge masses of the particulate substance 150 – 200 km far off where it settles coating the sea bed for thousands square kilometers (Zaitsev et al., 1992). For instance, westwards of Tarkhankut peninsula and in the western part of the Karkinit Gulf, the underwater zones onto which the suspension permanently settles are covered with the warp 2-5 to 50 cm deep.

The silting entails secondary pollution of the sea with the array of pollutants accumulated in the stirred bottom sediment, higher seawater turbidity and therefore lesser solar irradiance on the sea floor. These factors have led to degradation of Zernov's Phyllophora field, mussel and alga (Chara) biocenoses that earlier occurred on the sandy and shell-debris bottom spaces of the Karkinit Gulf and provided fattening grounds to sturgeons, flatfish, gobies and other fishes.
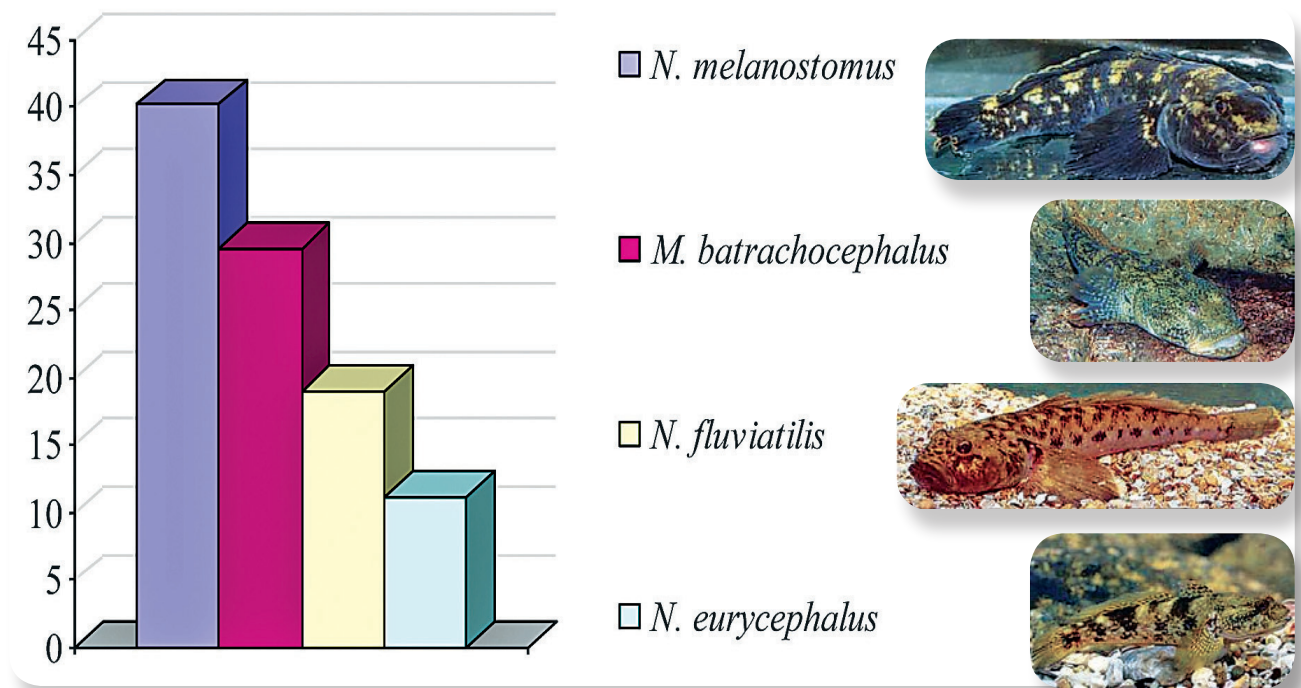
Fig. 4.5. The diagram of the percentage of species of gobies which died due to fish kill
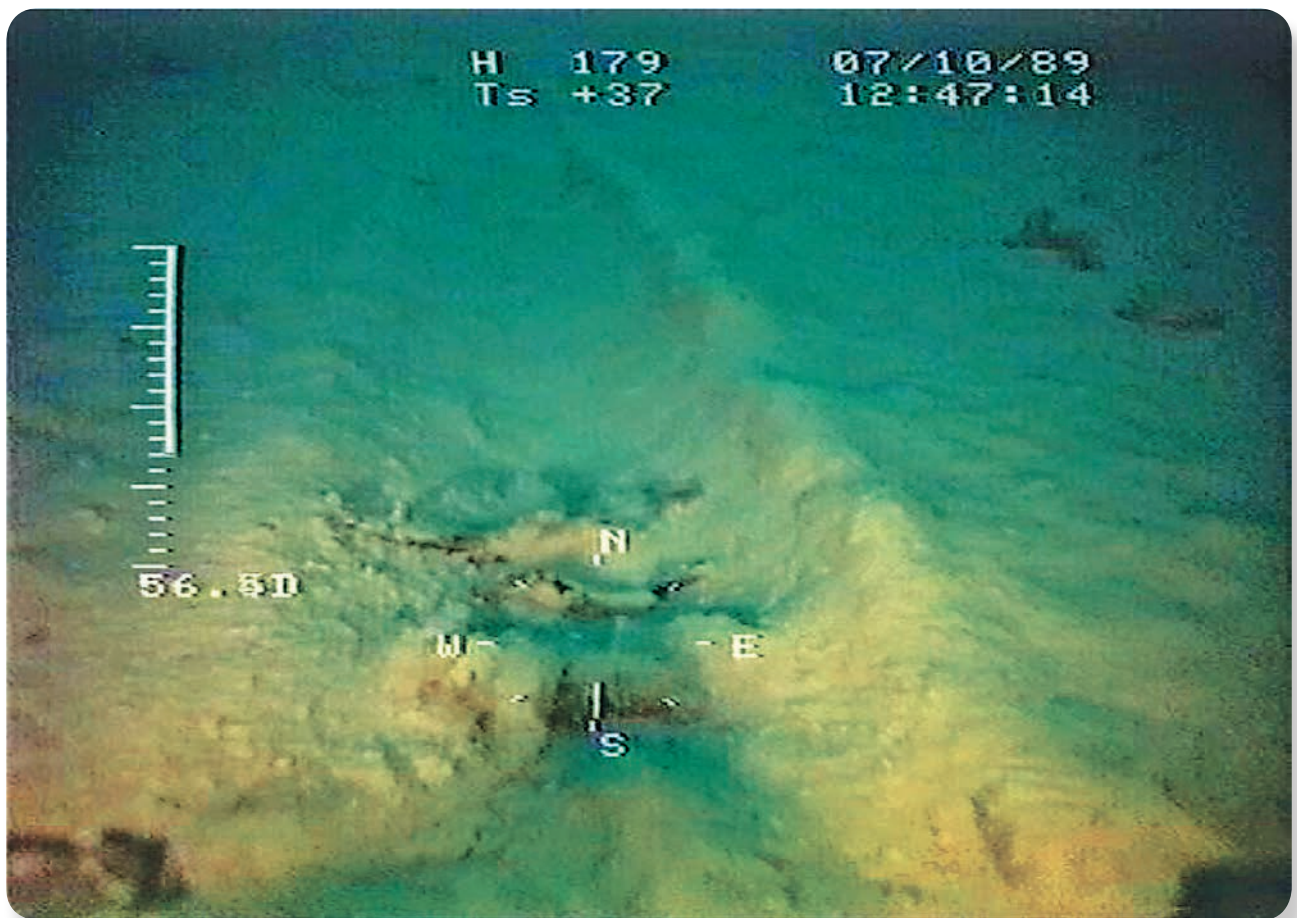

Fig. 4.6. Example of extermination of benthic biocenoses on the shelf of the Black Sea

On the Black Sea shelf soft sediments take over 90% bottom surface (Kiseleva, 1981) yet the area is considered as fit for bottom trawling. In this coastal zone to about 150 m depth 16 bottom biocenoses were spotted and narrowly studied. Three most biocenoses: Venus, Mytilus and Phaseolinus, were spread, contouring the Black Sea shelf (Kiseleva, 1981). Macrozoobenthos of these biocenoses had been the chief element that sustained functioning of coastal ecosystem. Each square kilometer of the Mytilus biocenosis that occupied depths from 20-53 to 60 m filtered 15 – 20 million m^3 of seawater a day (Kiseleva, 1978). Detritus and bottom substrate uptake by highly abundant deposit-feeders, predominantly some polychaetes, was estimated 34 g/m^2 on the average. The Phaseolinus biocenosis inhabited depths from 60 to 125 m and ensured the average rates of seawater filtration of 460 l/m^2 and biosedimentation of 0.7 g/m^2. The deposit-feeding macrozoobenthos consumed to 18 g/m^2 detritus a day.

In those days the entire Black Sea shelf, in biocenoses of which seston-eating mollusks dominated by biomass, had been a giant biofilter. According to calculation data, the daily volume of sea water filtered by seston-feeders spread from the water edge to 100 m depth approximated 260 km^3 and the biosediment to 390 thousand tones (Kiseleva, 1981).

Invertebrates (Mollusca, Polychaeta, Decapoda) were the prey for benthophageous fishes; the forage zoobenthos reserve was assessed 5.5 – 15 million t. Large mollusks, an indirect food item for fish, produced the major portion of pelagic eggs and larvae on which baby fishes such as horse mackerel, Black Sea anchovy, grey mullet and many other fed (Duka, 1973). Mytilus biocenosis supplied most of the eggs and larvae into the seawater column; near the Crimean shore the harvest was estimated 200-300 million eggs or 60-95 g per 1 m^2 of the sea bed (Kiseleva, 1981). The average yield from Phaseolinus biocenosis was as minor as half a million eggs or 1.7 g/m^2.

Bottom trawl fishing of the sprat was performed in the depth range from 30 to 130 m or, more frequently, from 45 to 100 m, on the soft bottom grounds just where the belt of Mytilus and Phaseolinus biocenoses concentrated. The number of daytime bottom trawlings in the recent 15 years has been to 10 thousands a year on the average, the trawls plowing the area no less than 3-6 thousand km^2 that is comparable with the total soft sediment surface on the Crimean shelf (Boltachev, 2006).

More than once we reported that trawl fishing is fatally detrimental to the Crimean coastal marine biocenoses. The TV images of the sea floor that the submarine device MiniRover MC II transmitted directly from the SW Crimean shelf have offered the most convincing proof. The imagery has clearly shown that bottom epifauna has vanished from 47 – 60 m depths. As the MiniRover was moving on, the troubled fine silt rose up from the bottom in clouds throughout the seawater column, making it turbid for long. Numerous tracks left by trawl boards were usually separated by 0.5 – 3 to 10 – 15 m distances (Fig. 4.5). Depending on the remoteness of trawling, the furrows were 0.15 to 0.35 m deep and 0.3 to 0.5 m broad. The scraps of polyethylene film on which sea acorns have settled and empty mussel shells were episodically noticed.

A fact to be recognized is that the belt biocenoses of Mytilus and Phaseolinus on the muddy shelf of the SW Crimea and probably of the entire peninsula have been extensively wiped out. This entailed structure-and-function derangements in the whole shelf ecosystem; their consequences have become apparent yet their actual scope is to be learnt and assessed on.

The general decrease of quantitative characteristics observed in the key filter-feeding macrobenthos has seriously slowed down the rate of natural purification of the sea thereby undermining the recreation capacity of the Crimean coastal zone. The ever-increasing flow of untreated industrial and domestic sewage into the sea makes the situation worse. Hypothetically, the degraded macrobenthos assemblages have ceased being the major unit in the ecosystem's food web. Under the environmental deterioration and ongoing trawl fishing the biocenoses of Mytilus and Phaseolinus have become of little worth as feeding and wintering grounds for demersal fishes, therefore the drop of whiting, surmullet, flatfish and spiny dogfish catches. According to the official statistics, now to 96% of the total catch are pelagic short-life fishes such as sprat, Black Sea anchovy and horse mackerel. The catch, if any, of formerly mass fishes now weighs from a few tens to several hundreds metric tons per year.

The bottom biocenoses would not restore to normal even under fully abandoned bottom trawl fishing; having those macrozoobenthos communities afresh would require many years if not decades. A set of urgent steps necessarily controlled and managed must be made to at least partially rehabilitate the major members of bottom biocenoses. Implementation of the action plan should begin with integrated assessment of the present bottom biocenoses on the Crimean shelf. The results, obtained with consideration of priority and purposefulness will enable working out recommendations of the sea areas forbidden for trawl fishing in which artificial reefs and anchored buoy mussel modules would be constructed, promoting the near-shore biocenoses rehabilitation.

5. MODERN METHODS FOR PROTECTION OF THE MARINE COASTAL ZONES ENVIRONMENT: THE PROPOSALS AND USES

5.1. Artificial reefs as a means of improving the state of aquatic ecosystems: tendencies for organization, experience of the Black Sea countries

Artificial reefs (ARs) take their beginning from coral reefs, rows formed by ridges of calcareous skeletons of coral colonies in the shallow waters of tropical seas having a high productivity and biological diversity. This effect is connected with the high specific surface of hard substrate suitable for the development of fouling communities, giving shelters to numerous invertebrates and fish, which raise their productivity and chances for survival.

The additional marginal effect takes place when intensity of physical-chemical and biological interactions greatly grows on the boundary of water-hard surface of ARs. The most significant value of ARs for human economic activity is in attraction of food fish and making them widely used. ARs have a wide spectrum of beneficial aspects and can be used: 1) for attraction and concentration of invertebrates, as well as commercial fish; 2) as an artificial substrate for egg deposits, attaching of larvae and other fry; 3) for creation of shelters for fish fry and other organisms (especially in places of cultivation); 4) for creation of optimal conditions for the formation of a stable highly productive biocoenose, a type of "refugium" for conservation of species, the existence of which is threatened by changing environmental conditions of habitats as seabed, siltation, hypoxia etc.; 5) as biofilters for clearing waters for pollutants.

As ARs can be sited on the seabed and in the water column and can have any form and dimensions, as well as be made of different materials, ARs may be defined as anthropogenic substrates making positive forms of the relief in the water column with the aim of creating a combination of abiotic and biotic characteristics differing from the background environmental conditions. Taking in consideration that hydrotechnical structures, including ARs can have a biologically negative, neutral or positive influence on the aquatic ecosystem (Zaitsev, Yatsenko, 1983), only biopositive constructions will be considered in this overview.

Interrelation of artificial reefs and the aquatic ecosystem. The intensity and scale of interrelation with any physical body including a hard artificial substrate with the ecosystem of the water body is determined by its dimensions. The question of optimal dimensions and shape of the ARs was considered only from the point of fish attraction. Comparing reefs of different sizes, it was shown that the AR is an attractive shelter for fish when its area is of 2,000-5,700 m^3 (Rounsefell, 1972; Ogawa et al., 1977). A greater effect can be achieved, if hierarchical structural components of different sizes will be used in the ARs, creating not separate structures, but reef complexes. The minimal size of an element of the AR constructions is 100-250 m^3, a separate reef – 800-1,000 m^3, groups of reef – 8,000–10,000 m^3, reef complex – 80,000 – 100,000 m^3 (Ogawa, 1982; Grove, Sonu, 1983).

Experimentally, it was shown that for successful fouling it is necessary to have cavities, holes and interstitial spaces in the AR providing good shelter for the organisms. Their size correlates with the animal size. A mathematical model has been drawn up for the qualitative assessment of the inner and outer AR structure for the purpose of receiving maximum fish

productivity (Williams, Barker, 1997). As a result of natural observation, it has been established that the height of reefs depends on the water depth. Usually this ratio of height to depth is 0.1. More recent studies (Khaylov et al., 1994) have shown a possibility of managing plant fouling communities through the structure of the physical substrate. Quantitative ratios between the phytomass and indices of the AR geometric shape have been obtained with the decrease in dimensions of the elements of reef constructions by a range of magnitude of 0.2 to 12 cm^3. The intensity of their interaction with water flow raises 3 fold. A proper installation of the AR in relation to dominating current flow is more important than the structure and design of the reef itself (Ogawa, 1982).

Describing the symphysiological ties of the ARs fouling communities, not only fish, but also planktonic organisms are involved. The reef functions not only as a natural biofilter helping to reduce the concentration of pelagic organisms due to the activity of invertebrate biofilters, but it helps in ameliorating zooplankton during the breeding period of the fouling organisms with larval development stages. The biotope heterogeneity of the hard substrate due to "projections" causes plankton aggregations. Visual underwater observations show that dense aggregations of copepods (>2000 ind./dm^3) occur near the projections exceeding average abundance (Shadrin, 1990) which explains the attractiveness of the reefs for fish. For establishing the biotechnological basis for ARs it is necessary to study: 1) the relation of the indices of the structure and functioning of plankton and the area of hard surfaces in the water; 2) how the geometry of the reef structure determines the character of plankton distribution, feeding conditions and security of fish fry; 3) how transformations take place in the periphyton-benthos-plankton system (Shadrin, 1990).

Experience in construction of artificial reefs in the Black Sea. The first AR in the Black Sea was established along the northern Caucasus coast, Bolshoi Utrish Cape in 1972, if we do not take into consideration hydrotechnical constructions for protecting the coast from degradation. This reef of nets with rocks of average 8 m^3 size was built for evaluating the prospects of applying similar constructions for ecological and fisheries amelioration (Pupyshev, 1986). In 1976 – 1977 the first experimental car tires reef was built here (Darkov, Machek, 1978). Experimentally, it was proved that the reef is a habitat and breeding ground for many Black Sea species of fish. Car tires were used in many types of constructions. In 1980 1,000 tires were placed on an area of 4,500 m^2 in the Dniester Liman (Goncharov, 1981).The reef made up of 160 car tires with a complicated multilayer rectangular construction (5 x 5 x 2 m) was constructed in 1985 (Fig. 5.1) at a 3.5 – 4.0 m depth at Cape Severniy, Odessa Gulf (author of AR is Yu.D. Verba – project director, senior engineer of Odessa Antilandslide Management).

Wide scale use of car tires was reached in the Sea of Azov. In the 1984 – 1987 period more than 13,000 car tires were installed in Obitochniy Bay and the Biryuchiy Island bar at an area of 469,500 m^2 (Fig. 5.2). A semi industrial AR of a linear plane type for rearing gobies was used. The increase in food zoobenthos in the reef fouling and successful breeding of gobies allowed raising the commercial stock of gobies up to 67 tons (Izergin, 1990).

Besides car tires, special concrete structures were used like tetrapods ("stabilopods") of 4.5 t weights and 2 – 25 m height for constructing reefs of any dimensions. These types were used for building modern piers with biopositive properties in the port of Constanta and Varna in 1980 (Fig.5.3). Within 5 years after the building of breakwater piers in Constanta,

the average biomass of the fouling on the surface reached 26.6 kg×m^{-2} with animal-filtrators dominating (Gomoiu, 1989). Special reefs made of tetrapods were built on the Romanian coast for protecting coastal parts designated for aquaculture protection against pollution and for reaching the trophic base and the successful production of mussels. Similar constructions were established in 1982 for protecting the beach area of Mamaia against wave action and for improving the ecological state of the impoverished biocoenosis of the sandy bottom for this part of the Romanian coast (Gomoiu, 1986) When comparing the fouling on the reef with the sandy sediment community located in the same area at the same depth, it was registered that the biomass of mollusks on ARs was 28 fold, of crustaceans – 7.4 fold higher than that of bottom settlements (Gomoiu, 1989).

In 1982 shore line AR was built on the area 50,000 m^2 to the west from entrance into Grygor'evsky liman, north western part of the Black Sea. This hydrotechnical construction was created for protection of collapsing abrasive shore subject to the landslides, by surpluses of the heterogeneous soils received when building Odessa Priportovy plant. Sea shore part for 1 km was formed there by the blocks of Pontic limestone. Creation of reef promoted increase of biomass of green seaweed 10 times and increase of species of marine invertebrates 3 times. It increased the number of filter feeding animals (mussels and barnacles) for 1-2 orders according to the increase of area of hard substrata. This area of shore became the place of active amateur fishing of gobies (Zaitsev, Yatsenko 1983).General ecological effect in connection with the AR building from the improvement of water quality was evaluated for 568,300 rubles (≈ 56,800 US dollars), or more than 10 rubles on 1 м^2 of AR (Lapchinskaya et al., 1987).

At the same time an AR of a sprawling type was built in the Odessa Bay. It was made up of granite rubble covered with lattice concrete sections and submerged to 1.5 – 2 m depth from the surface breakwater. In contrast to an ordinary breakwater submerged to a depth of 0.5 m, it had a larger specific surface. Comparative studies of the seaweed on the reef and breakwater have shown that in spite of low diversity, algae of the AR had greater functional activity. This is evident in the high water transparency and increase in phosphorus compounds near the reef due to the mussel fouling activity. Intense development of algae led to decline in nitrogen concentration of nitrates, which in turn illustrates the anti-eutrophicating effect of ARs.

Seasonal changes in glycogen content in two groups of mussels (2-3, 3-4 cm in the Odessa Bay fouling show that it is higher in the areas with intense water exchange 2.88 and 3.80% wet weight correspondingly. Similarly, the biomass of mussels was higher than in bottom settlements. A direct correlation (r =0.82) has been noted between glycogen content in mussels and temperature (Lisovskaya et al., 2002)

In 1983 an experimental "Reef" construction for growing mussels was installed at Bolshoy Fontan Cape at an 11 m depth. It was made up of 9 six-meter metallic tubes of 20 cm diameter vertically attached to a 2 × 2 m concrete frame (Vityuk et al., 1987). By 1990 up to 20 reefs were installed in Odessa Gulf. Special studies performed showed high bioameliorative qualities of "Reef" fouling, which helped to reduce the general number of heterotrophic bacteria in the water leaching them by 44% (Govorin et al., 1994).

In 1985 installation for hydrobiological treatment of oil polluted water for the Sheskharis oil base in Novorossiysk was set up and this will be discussed later. In 1987-1989 Anapa Municipal Council ordered to install ARs of rubble type of large size limestone at a depth of 3-12 m in the Anapa Bay (Black Sea coast of Russian Federation). Three- year studies from an under-

Fig. 5.1. Reef made of car tires constructed at Cape Severniy, Odessa Gulf (Ukraine), 1985.

Fig. 5.2. Car tires reef installed in Obitochniy Bay, Sea of Azov (Ukraine), 1984-1987.

water apparatus showed intense development of fouling on the reef and lack of bacterial films near it showing almost complete utilization of organic matter transformed by ARs.

In Turkey AR project for the Black Sea was started in 2000. Aims of the project were to prevent illegal trawling, to enhance small-scale fishery and to provide attachment substrate for mussels. AR consisted of 1000 hollow cubic units with the size 1.5 x 1.5 x 1.5 m each (deployment depth 25-30 m) in western part of the Black Sea coast of Turkey, Zonguldak city (Fig. 5.4). Realization of the project is not finished yet because of financial problems. If not taking into consideration the exploitation of a "star" type construction for cultivating mussels (Konsulov, 1980) and the tetrapods, the first ARs of a special designation were installed in November 1999 in Varna Bay for protection of benthic biocoenoses from siltation due to illegal trawling of sea
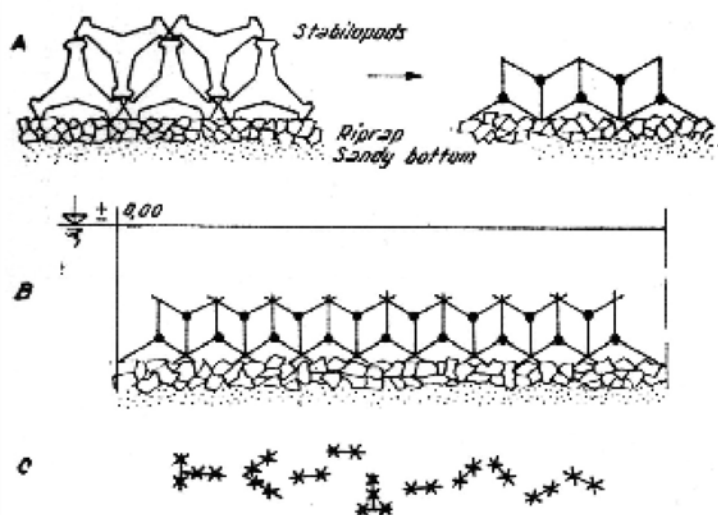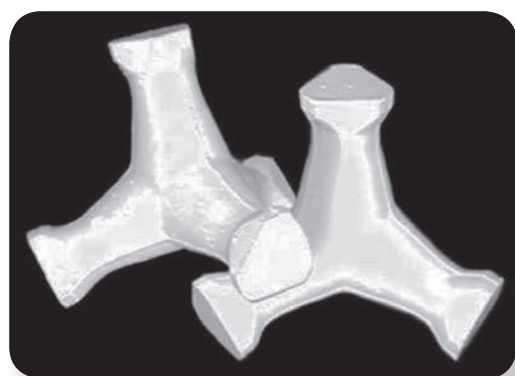
Fig. 5.3. Concrete stabilopods used for protecting the coastal zones of the sea against wave action, ports of Varna (Bulgaria), Constanta and Mamaia resort (Romania), 1980-1982.

snail, *Rapana*. These reefs were 45 truncated concrete pyramids each of 300-700 kg weight (Fig. 5.5) which were sited 4 miles from the shore on an area of 0.65 km^2.

In the Black Sea Environmental Program (GEF, UN), the building of ARs is considered to be a necessary measure for increasing mussel and benthic algae populations (including use of mariculture methods) for increasing water transparency, saturation with oxygen, binding of biogenic substances by the hydrobionts biomass (Black Sea transboundary ..., 1997). Beside ARs are regarded as a real means of restoring the population of 20 goby species – endemic Black Sea species, half of which have commercial significance.

Summarizing the achievements of ARs in the Black Sea and the Sea of Azov it can be noted that ARs are effective in ecological amelioration of coastal waters, increasing production and biomass in the aquatic ecosystem and increasing self-purifying intensity. ARs allow management of distribution and behavior of hydrobionts. The use of ARs as an effective tool for management of aquatic ecosystems has received special attention It has been observed that cultivated mussels have higher values of biochemical composition, especially those cultivated at upper levels of mussel culture structures or collectors than those growing wild.

As biologically positive structures, ARs affect not only the narrow coastal strip along the beaches. Animal larvae and plant spores developing on reefs are dispersed by currents at large distances inhabiting other parts of the seabed and restoring benthic communities after mortalities caused by hypoxia. ARs are not only a means of increasing the biological productivity of the shelf, but also serve as a means of hydrobiological amelioration.

After a slight lag tied with economic difficulties in former FSU countries, work on AR development has been reviewed. Since 1994 in Ukraine a project for theoretical substantiation of ARs of the National Agency of Marine Investigations and Technology on elaboration of profitable technology for optimization of the quality of sea coastal waters in highly trophic and urbanized areas of the Ukrainian Black Sea coast has been implemented (Alexandrov, 1998). Main results on elaborating the theoretical bases of hydrobiological amelioration using artificial hard substrates were received on financial support of the project.

Fig. 5.4 Artificial reefs at the coast of Turkey (Zonguldak, 1999) for protecting from illegal trawling trade

Fig. 5.5 Artificial reefs at the coast of Bulgaria for protecting from illegal trawling trade of *Rapana* (Varna Bay, 1999)

Fig. 5.6 Artificial reefs "Reefball" at the coast of Odessa (beach "Arcadia", 2011)

Fig. 5.7 Artificial reef "ATLANT-M" in Koktebel Bay (2007)

Fig. 5.8 The hydrobiological purification system mounted on the pier piles in the Sevastopol Bay 15 years ago (2008)

Starting from 2007 there were new levels of activities in preparation of artificial reefs. Constructions of "reefballs" type are used practically for a long time, for example by USA and serve as basic. Nowadays 10 – 20 pilot installations of "reefballs" have been set in Ukraine, in the coastal zone of Yalta and Odessa (Fig. 5.6) AR by the project "ATLANT-M" (www.reef.atlant-m.ua) has been installed in October 2007 in the Koktebel Bay (Ukraine) at the depth of 9 m. General weight of the reef – 11 t, height – 90 cm, bottom square – about 20 m^2 (Fig. 5.7).

Unfortunately total area of the Black Sea with artificial reefs is too small – about 1 km^2: Bulgaria – 650 000 m^2, Ukraine – 256 155 m^2, Romania – 155 000 m^2, Russian Federation – 200 m^2, Turkey – 10 m^2.
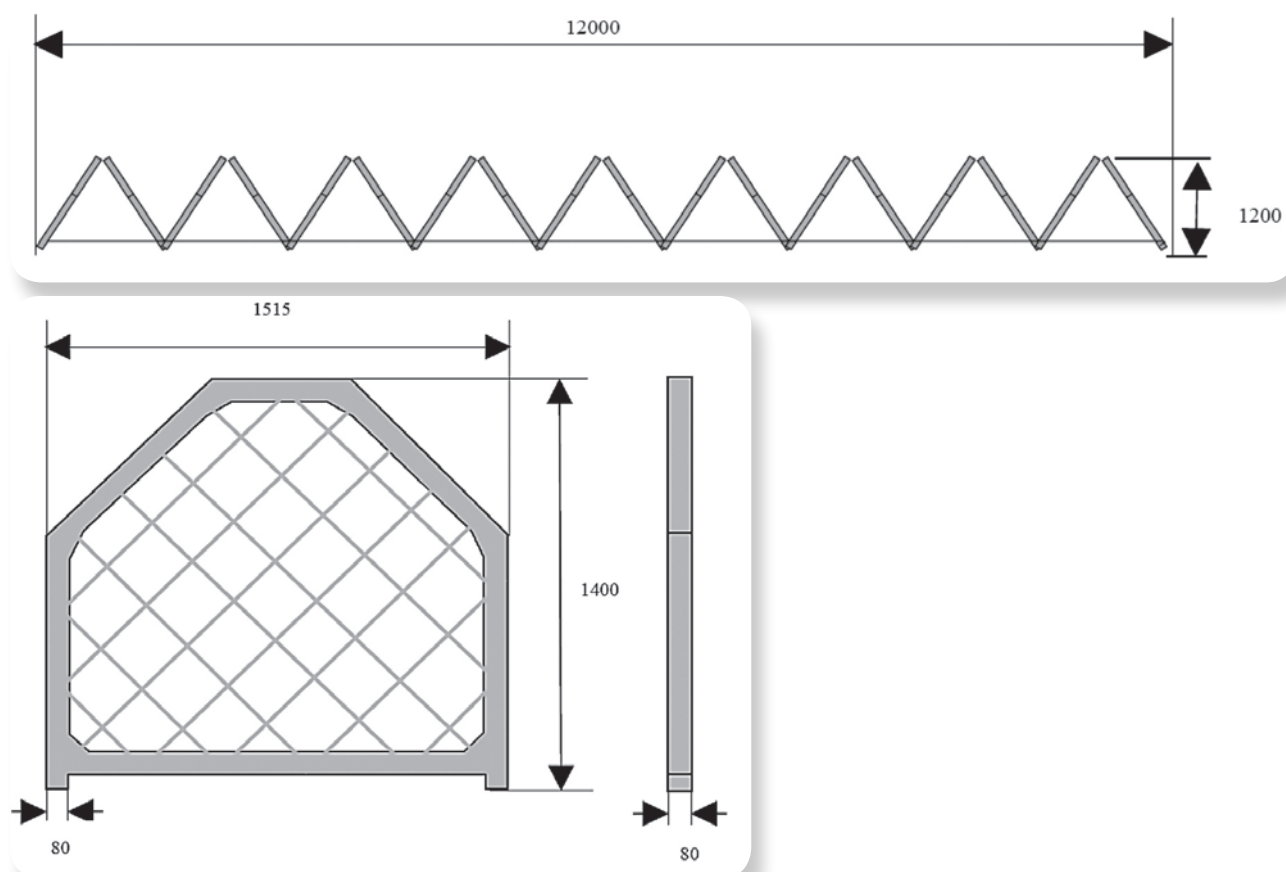

Fig. 5.9. The structure of reef-like "Accordion" (in mm). Series of articulated concrete frames attached to one another by hinges at an angle of 60°. One concrete frame with plastic grid.

In frame of EU Joint Operational Program "BLACK SEA 2007-2013" project was adopted "Research and Restoration of the Essential Filters of the Sea (REEFS)" in 2011. During two years they plan to install artificial reefs in all Black Sea countries. There are six participants of this project: 1) Bulgarian Biodiversity Foundation, Visitors Center "Kaliakra"; 2) Energy Efficiency Centre Georgia and Black sea resources hydrogen development fund; 3) ONG Mare Nostrum, Romania; 4) Southern Branch of Shirshov Institute of Oceanology, Russia; 5) Karadeniz Technical University, Trabzon, Turkey; 6) Odessa Branch, Institute of Biology of the Southern Seas National Academy of Ukraine. "Accordion" worked out by Arman Sarkisyan from Bulgaria is a proposed design. One "Accordion" bulk will consist of 18 concrete panels and it will be movable. The all 8 bulks are to be placed in working position in different configurations according to the specific characteristics of the respective coastal area. Their interpositioning will vary (Fig. 5.9).

5.2. Artificial reefs as a means of hydrobiological amelioration

The fouling community formed on hard substrates plays an important role in the process of transformation of matter and energy of aquatic ecosystems. Up to 74% of primary production and 90% of the destruction of organic matter in the coastal marine zones is produced by fouling (Alexandrov, 1998).

The most complete theoretical elaboration on the interrelations of the community parameters with the geometry of hard substrates was carried out on algae (Khaylov et al., 1994). Using the volume of the closest living fouling space – V_{CLF}, it made possible prediction of the structural-functional characteristics of invertebrates according to dimensions of recruited surface (Alexandrov, Yurchenko, 2000). Transitional stage for assessment of the ameliorative effect of fouling – determination of quantitative relations of water quality and the characteristics of the living fouling space and its biological structure including plant and animal components. However, these absolute values did not take into account their actual amount in the water. For overcoming this disadvantage and for more convenient estimations, it was proposed to assess the relations of absolute values of water quality beyond and within the limits of V_{CLF}. These were the results of observations obtained by experts from Odessa Branch Institute of Biology of Southern Seas, National Academy of Sciences of Ukraine in 1991 – 1998 in freshwater and marine areas of the NWBS. About 1664 water samples were analyzed for 11 water quality indices and 1682 samples of phyto- and zoobenthos fouling were studied.

It has been established that an increase in the specific surface of hard substrate aids in increasing the total biomass of invertebrate fouling and in intensifying the self-purifying quality of the water due to respiratory functioning. The ratios received with high degree magnitude (up to 95%) allow predicting the structural-functional characteristics of the community at different levels of saturation of the aquatic environment of the hard substrate (Table 5.1). For example, if the value of the relation of the hard substrate surface to the bottom area on which it is located (S/S_0) is equal to one, then it is quite possible that the fouling biomass will reach 277 g of dry ash-free matter per one cubic meter of the volume of living space. The daily intensity of self-purification due to catabolism of organic matter during respiration is 2.9 g C_{org}.

For V_{CLF} a decrease in content of mineral phosphorus, particulate organic matter and increase in oxygen saturation of the water has been noted. In contrast to all studied indices, changes in the oxygen regime were insignificant and did not exceed 80% saturation. At the same time due to predominating functional impact of invertebrate fouling there was an increase in the total nitrogen content due to metabolic excretions in animals. The depositing of phosphates on the bed with faeces and pseudofaeces of filtering mollusks mitigates the threat of eutrophication (Alexandrov, 2001).

Evidence for this is the balance between nitrogen and phosphorus. Close to the fouling surfaces their relation was quite stable in spite of the 10 fold variations in absolute values. The high range in variability of environmental indices – up to a magnitude of 3 for which equations were established allowed considering the relation of the rate of transformation of fouling and the pollutant concentration (Table 5.2).

Table 5.1. Parameters of relations of the species lgY = lg a + b lg X between the characteristics of structural-functional organization of the fouling community, its living space and ameliorative impact on aquatic environment (Aleksandrov, 2008)

Relations	n	r	lg a	b
$DW_z = f(C_S)$	43	0,64*	-0,104 ± 0,477	0,846 ± 0,157
$R = f(C_S)$	42	0,55*	-0,563 ± 0,563	0,830 ± 0,201
$P_{tot} = f(V_{CLF})$	46	0,34*	-0,459 ± 0,124	0,040 ± 0,016
$DW_z = f(S/S_0)$	43	0,89*	-0,557 ± 0,288	1,112 ± 0,091
$R = f(S/S_0)$	42	0,91*	-0,883 ± 0,275	1,223 ± 0,087
$V_{CLF}/V_f = f(S/S_0)$	42	-0,76*	-1,342 ± 0,463	-1,087 ± 0,146
$S/V_f = f(S/S_0)$	42	-0,35*	-1,940 ± 0,469	-0,328 ± 0,148
$S_{ph}/V_f = f(S/S_0)$	42	-0,17	-0,553 ± 0,433	-0,153 ± 0,137
$N_{min} = f(S/S_0)$	46	-0,30*	-0,166 ± 0,159	-0,091 ± 0,043
$N_{tot} = f(S/S_0)$	42	-0,44*	-0,258 ± 0,163	-0,158 ± 0,051
$P_{tot} = f(S/S_0)$	42	0,27	0,022 ± 0,127	0,065 ± 0,035
$O_\% = f(S/S_0)$	42	-0,35*	-0,039 ± 0,053	-0,040 ± 0,017
$POM = f(S/S_0)$	41	0,31	0,313 ± 0,281	0,186 ± 0,090
$P_{ph} = f(S/S_0)$	46	-0,18	-0,003 ± 0,569	-0,187 ± 0,156
$N_{min} = f(DW_z)$	42	-0,50*	-0,322 ± 0,147	-0,139 ± 0,038
$N_{tot} = f(DW_z)$	42	-0,53*	-0,369 ± 0,153	-0,158 ± 0,039
$O_\% = f(DW_z)$	42	-0,36*	-0,056 ± 0,053	-0,033 ± 0,014
$POM = f(DW_z)$	41	0,35*	0,407 ± 0,278	0,166 ± 0,072
$N_{bac} = f(DW_z)$	41	-0,11	-0,115 ± 0,238	-0,044 ± 0,063
$BOD_5 = f(S_{ph}/V_f)$	42	-0,11	-0,088 ± 0,208	-0,052 ± 0,075

Note: * – critical value for r for 5 % significance level (significant for 95% confidence). Indices: 1) living space of fouling: V_{CLF} – volume of closest living space, cm^2; C_S – specific surface of hard substrate (concentration of fouling surface in volume of living space), $S/V_{CLF} \times m^{-1}$, S/S_0 – coefficient of packing of hard substrate (total area of hard substrate to area of bottom on which it is based); 2) structural-functional organization of fouling: DW_z-total biomass of dry free ash matter of invertebrate fouling according to V_{CLF}, $mg \times cm^{-3}$, R – respiration intensity, $J \times cm^{-3} \times diem^{-1}$, V_f – daily intensity of water filtration by fouling according to V_{CLF}, S and S_{ph} – photosynthetic surface of algae and macrophytes; 3) ameliorative effect: N_{min} – mineral nitrogen content, N_{tot} – total nitrogen, P_{tot} – total phosphorus, $O_\%$ – saturation of water with oxygen, POM – particular organic matter, P_{ph} – phytoplankton production, N_{bac} – total microbe number, BOD_5 – biochemical oxygen demand (ameliorative effect is evaluated according to the relation of the absolute values of water quality beyond and within the limits of CLF).

When forecasting the ameliorative fouling effect the features of the biological structure should be taken into consideration. The presence of animal filtrators is characteristic to climax communities, which leads to a large increase in V_{CLF} defined as "the geometric water volume within the limits of the fouling contour" (Khaylov et al., 1994).

When comparing literature data with estimations of the ameliorative effect calculated according to the formula POM = $2.553 \cdot DW^{0.166}$, (see Table 5.1) the prognostic capacity of phyto- and bacterioplankton was evident. The difference between prognostic and a definite value of self-purifying capacity of an artificial reef by heterotrophic bacteria reached 12% for mussel fouling at a depth of 5 m and 38% at a depth of 10 m (Govorin et al., 1994).

The values received (see Table 5.1) can be used for determining the optimal parameters of artificial substrates with ameliorative effect when creating hydrotechnical structures of different designation (Alexandrov, 2001)

Table 5.2. Range of indices of studied characteristics

Characteristics *	Dimension	Range of values		
		min	max	max/min
Living space				
V_{CLF}	cm^3	$7,42 \cdot 10^9$	$1,38 \cdot 10^{12}$	186
S	cm^2	$8,32 \cdot 10^6$	$2,11 \cdot 10^9$	254
S_0	cm^2	$5,12 \cdot 10^7$	$1,79 \cdot 10^{10}$	350
Fouling community (values of characteristics reduce to square meter of hard substrate)				
DW_{ph}	г	1,6	169,9	106
DW_z	г	107,8	1282,3	12
R	кJ$\cdot$ day^{-1}	40,0	769,0	19
S_{ph}	m^2	1,9	45,1	24
Water quality				
N_{min}	µg $\cdot$ l^{-1}	50,000	1952,000	39
N_{tot}	µg $\cdot$ l^{-1}	397,000	8323,000	21
P_{tot}	µg $\cdot$ l^{-1}	19,000	300,000	16
$O_\%$	%	82,000	182,000	2
POM	g C $\cdot$ m^{-3}	0,280	7,350	26
P_{ph}	g C $\cdot$ m$^{-3} \cdot$ day^{-1}	0,001	2,199	2199
N_{bac}	mln. cell$\cdot$ ml^{-1}	0,900	506,600	563
BOD_5	mg O $\cdot$ l^{-1}	0,110	3,940	36

Note: * – definitions in previous table, DW_{ph} – biomass of dry ash free matter of macrophytobenthos

5.3. The biological purification systems worked out by IBSS and designed for and used in the polluted seawater areas

The practical experience having been gained at IBSS in using artificial reefs ("hydro-biological purification system" (HPS)) as a tool for improving marine environment quality is proposed to be extended over the Crimean coastal zone. Working as a hydrobiological purification system, i.e., a biofilter, AR constructed in the environmental risk locations would localize oil spillage and cut off further pollution. The marine biota 'condensed' on the biofilter naturally improves biodiversity and self-purification in the seawater area thereby producing salutary effect on the regional marine environment. Long-term investigations carried out in the Black Sea point out that as soon as bottom sediment has accumulated chloroform-extractable substances to 0.1 g/100 g dry residue, the bottom communities began decaying, and under 0.5 g/100 g dry residue the degradation has been catastrophic (Mironov, 1985; Mironov et al., 1986). In most presently inspected seawater areas of the Black Sea and the Sea of Azov pollution of the sea bed is close to critical. Unless stopped, it will inevitably worsen (in some locations has already worsened) quantitative characteristics of the macrozoobenthos and therefore self-purification of the sea. An alarming phenomenon that was registered on the shelf of the Black Sea and the Sea of Azov exploited by oil and gas production companies is the decline of zoobenthos species richness, seston-feeders abundance and biomass at the intensively developed oil and gas fields (Terent'ev, 2009).

In the far year 1969 Professor O.G. Mironov devised a formula for using marine organisms in pollution prevention and in sanitation of the coastal sea. The decades-long investigations in this field provided the essential theoretical basis for designing natural hydrobiological purification systems (HPS) which basis is made by natural processes of self-cleaning. The method of hydrobiological purification and sanitation of polluted seawater areas having been worked out at the Department of marine sanitary biology, IBSS, employs filter-feeding mussels *Mytilus galloprovincialis* as the primary unit that removes pollutants from the sea water.

Mussels as the essential biofilter element. The filter-feeding mussel *Mytilus galloprovincialis* is a chief component sustaining normal self-purification of the sea. These bivalves keep on functioning as if nothing has happened when oil pollution in the seawater area is tens times as high as permissible limits dictate. As an active transformer of oil flow, the mussel acquires special significance in the regions of intensive maritime traffic. Penetrating into the mollusk's body with the sea water passed through its filtering apparatus, some of the oil will be bound in pseudo-feces and some excreted through the gastrointestinal tract with feces. Much has been learn about the filtration activity of mussels under oil pollution, about oil accumulation in their tissues, excretion and clearance (Mironov, 1985; Schekaturina, 1988). Naturally, the heavier oil pollution, the larger oil hydrocarbon content accumulated in mussel tissues: the average estimates measured in a relatively pure and in a polluted bay were 48 and 180 mg/100 g wet weight, correspondingly. Little by little the mussel unloads the accumulated and converted oil into the environment. It was experimentally proved that chemical properties of the oil passed through the gastrointestinal tract changed, in particular, petroleum resin fraction increased (Mironov, 1985). A fact to be remembered is that enzymes capable of converting oil hydrocarbons have not been detected in massels as yet, though oil-oxidizing microflora was detected in the intestine of *Mytilus galloprovincialis* (Mironov, 1987).

The structural design and uses of the hydrobiological purification systems (HPS). This name ("hydrobiological purification system") presumes that the device is purposed specially for natural purification, not mariculture (Mironov, 1969). A variety of HPS have been tested in gravely polluted locations of the Black Sea (Mironov et al., 2000). In 1985 the first pilot HPS was placed near the ballast water of the tankers effluent of the petroleum storage and reloading depot Sheskharis, Novorossiysk. The device was assembled of nine 10 m frames, each bearing 8 m long collectors of foam plates (120 x 40 x 10 mm) intertwined with a kapron cord (Fig. 5.10). By 1986 the mussels settled on the HPS had increased its filtering capacity to 2.9 thousand $m^3 \cdot day^{-1}$ (Alyomov, 1987).

Bearing frames of different design were placed in the sea water of the oil port terminal and by the storm water outlet in Sevastopol bay (Fig. 5.8). Mounted on the pier piles, the HPS had the frames of kapron net panels.
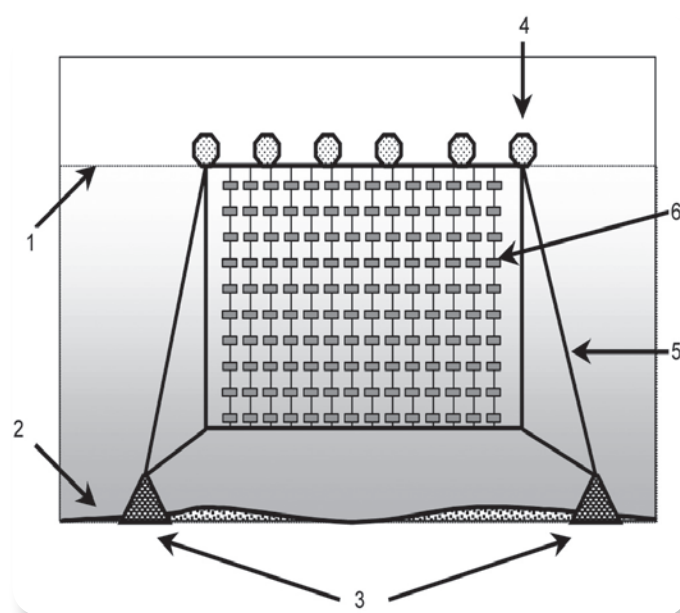

Fig. 5.10. The scheme of hydrobiological purification systems carrier (Novorossiysk, 1985).

1 – surface of sea, 2 – surface of bottom, 3 – anchors, 4 – buoy, 5 – fasteners frames, 6 – collectors.

Operating for as long as ten years and longer all the earlier tested HPS have proved their high resistance to the environmental exposure. However, in deciding between the two varieties, either with its design-specific pluses and minuses, the choice strongly depended on the seawater locality, therefore a universal model of HPS was invented (Fig. 5.11). This is a kapron net attached to the kapron halyard frame; concrete anchors fix the framed net firm on the sea floor and buoys, the number of which increases with growing weight of the biofouling, hold it upright. This universal device is easy to make without applying to special mounting tools. Being portable, it can be installed immediately near the source of pollution, e.g., in an oil port terminal, by the discharge outlets of storm run-off and waste effluents, and serve as the filtering barrier to oil products thereby restricting pollution in the seawater area. Concentrated within the narrow bottom space, the biologically transformed oil pollutants can be easily removed from the marine environment. In 2006 the pilot HPS of this type was placed in Sevastopol bay.

Regular observations of the epibioses developing on the experimental HPS in Sevastopol bay supplied a body of interesting information. During the first two months the pilot HPS was colonized predominantly by sea squirts (Ascidiacea), both solitary and colony-forming; the other numerous yet inferior group were sea acorns (*Balanus imptovisus*). Smaller than 10 mm mussels were only solitary noticed. Four month later the sea squirts had receded giving place to mussels, maximally to 15 mm size, the number of which increased to 3500 ind./m^2 and more (Fig. 5.12). About 10 mm large *Mytilaster lineatus*, estimated 9600 ind./m^2, were the co-inhabitants on the kapron net. The total biomass of Mytilidae made up 92 g/m^2. In eleven months the abundance of mussels had been larger than 40000 ind./m^2; young mollusks to 30 mm in size predominated, also numerous were 40-50 mm large individuals, the maximum mussel's length measured had been 71 mm. The filtering capacity of the HPS was assessed more than 250 m^3/m^2 net surface per day.
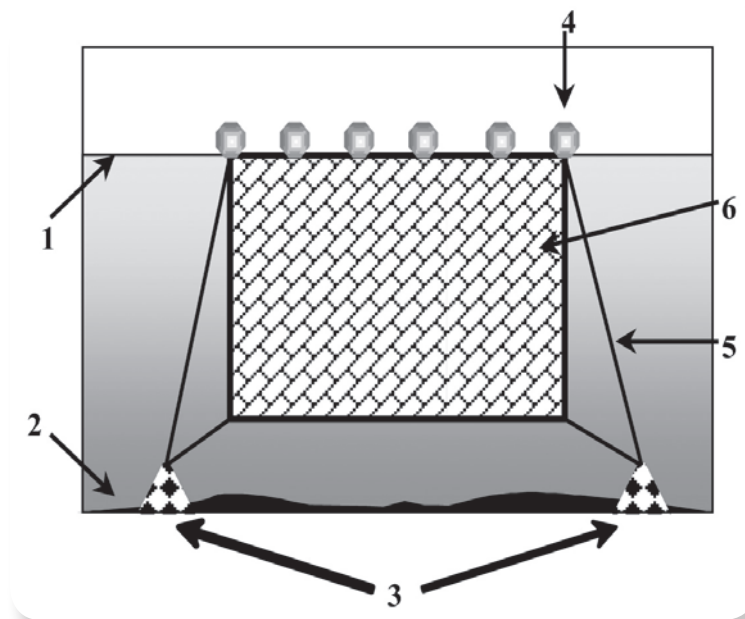

Fig. 5.11. The scheme of the HPS: 1 – sea surface, 2 – sea floor, 3 – concrete anchors, 4 – buoys, 5 – fastening devices, 6 – capron net; the general view and mounting of the pilot HPS in

In later months the abundance of the 50 – 80 mm large mollusk fraction considerably increased, some shells were more than 80 mm long. The amount of large mussels increasing, the biomass of the HPS biofouling community synchronously rose; for the second year mussel biomass estimate had raised to 30 kg/m^2. Three years since the HPS was put into use the mid-size groups, largely mollusks 30 – 60 mm in size, had won the majority. Mollusks larger than 70 mm had vanished – as very weighty they might drop down from the net (see Fig. 5.12).

Various mollusks, crustaceans and polychaeta fauna was registered in the fouling composition, parallel to ascidia and acorn barnacles. Among polychaeta warms *Platynereis dumerelii* was the most abundant (6000 ind./m^2). The crustaceans fauna was represented by Amphipoda, Anisopoda, Decapoda families, among the last – crabs *Pilumnus hirtellus* (Fig. 5.13). Ascidiacea were very abundant on HPS with predomination of singular forms, creating aggregations. In three years 30 – 60 mm mollusks made the main contribution to general HPS. The volume of water filtered by the pilot HPS exceeded 450 m^3 per day at 1 m^2 of the HPS surface, and general filtering activity made about 1800 m^3 per day.

Fig. 5.12. Experimental hydrobiological system on the aquatorium of the Sevastopol bay: A – general view, B – the sample from an experimental system 4 months after installation, C – the sample 11 months after installation, D – the sample 2 years after installation, E – is a general view 3 years after exploitation period.

Fig. 5.13. *Pilumnus hirtellus* and Ascidiacea in periphyton of the pilot HPS

As the main active component of HPS, mussels create an extra surface on which other organisms of periphyton would settle and grow. Bacterial fraction of the biofouling community converts pollutants from mussel feces and pseudofeces and directly from the suspension in the sea water. The conducted researches have shown that in the HPS periphyton oil-oxidizing bacteria were 100 to 10 000 times as abundant as in the surrounding sea water.

Indeed, the supply of mollusk metabolic products enhances bacterial transformation of pollutants in the bottom substrate around the HPS; yet most of the polluted sediment is purified by the secondary unit that combines other marine inhabitants, polychaetes in particular. For instance, when polychaeta *Hediste diversicolor* were present in the experimental tanks with mussels, the rate of chloroform-extractable substances accumulation in the uppermost bottom substrate decreased (Alyomov, 2000).

The total macrozoobenthos biomass produced in the seawater site around the HPS and in more remote localities of the bay differed as greatly as 16.2 and 0.2 kg/m^2, correspondingly, owing to the plenty of large mussels dropped down from the HPS and carnivorous mollusks *Nassarius reticulatus*. Besides, a considerable increase of the abundance and biomass of polychaete worms such as *Alitta succinea* and some Aphroditidae was also observed.

The proposals about the use of hydrobiological purification systems in the Sea of Azov. The intensive development of the shelf zone by oil and gas companies has enhanced environmental risks potentially fatal to coastal biocenoses in the Sea of Azov. In particular in Kazantip nature reserve, for instance, a bottom zone was spotted from which an unidentified impact has largely wiped benthic macrofauna out. Most likely, as profound local decline as that is somehow related to the already mentioned oil extraction on the Cape Kazantip. In other seawater sites of the reserve macrozoobenthos keep on sustaining relatively high diversity and abundance, though a manifest dominance of one-two species is typical of the community. A sharp quantitative decline or extinction of these now leading species under some human impact can radically transform the biocenoses up to overall degradation.

To preclude as catastrophic scenario as that the self-purification capacity of the sea around Kazantip nature reserve need be restored to normal or larger; artificial reefs or/and HPS would adequately respond to this challenge. A set of HPS which are not as time and money consuming as AR are to be installed first near Cape Kazantip, at the station 10 in Senka bay, that crying hot spot, and by the piers for fishing boats. In our opinion further positioning of HPS along the sea borderlines of all Crimean nature reserves is rational.

To summarize the above said we can conclude that there are scientific grounds for creation of optimal in their biopositive characteristics AR; there are experimental exemplaries, national and international programs on construction of artificial reefs in the Black sea, but we lack the most essential – actual realization of these measures at a necessary scale for rehabilitation of the water environment and hydrobionts.

CONCLUSION

The geography of our multidisciplinary investigations in the field of marine ecology reported in this monograph covers the entire coastal zone of the Crimean peninsula from the innermost part of the Karkinit Gulf in the Black Sea to the northern point of the Eastern Sivash Gulf in the Sea of Azov. The research has furnished a fresh body of evidence about unique features and diversity of marine biocenoses there. Some of the habitats, for instance near Cape Martyan, are relatively untouched, some, such as the eastern Karkinit Gulf, Sevastopol bay and the Eastern Sivash Gulf, have been impaired by human activity. In contrast to the generally grave background there are positive, though as yet minor, changes that have been developing for the recent 15 years in the coastal sea of the Crimea. The largely exhausted natural rehabilitation power of ecosystems in the Black Sea and especially in the Sea of Azov is a reason for serious anxiety. Without urgent and vigorous human help the afflicted seawater areas will never recover. It is proved scientifically that creation of the artificial reefs and biological purification systems which guarantee marine environment rehabilitation and betterment of marine flora and fauna will be an effective remedy. If this book will serve as a stimulus for making concrete decisions by the authorities and people, worrying about the destiny of our Ukrainian seas the authors will consider that their many-year work was carried out not in vain.

Pablo Neruda, the prominent Chilean poet and a Nobel Prize winner in literature, who had once been on visit to the Crimean peninsula, told that the Crimea is an Order on the bosom of the planet Earth. Today we must not let this precious award slip through the fingers because of ignorance and neglect. We, the team of experts, would be deeply pleased and consider our research efforts fully rewarded if the top officials and private sector appreciated this book as a competent guide to be consulted before decision making.

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Наводяться результати комплексних гідрохімічних, гідробіологічних та іхтіологічних досліджень ІнБПМ НАН України, виконаних в 6 районах прибережної акваторії Кримського півострова у Чорному та Азовському морях. Аналізуються основні негативні чинники, що викликають зміни структурних та функціональних характеристик гідробіоценозів в досліджених районах і виділяються «гарячі екологічні точки». Розглядаються варіанти різних методів управління прибережними екосистемами, що включають будівництво штучних рифів і застосування біологічних фільтрів з метою очищення води, захисту та відновлення біологічного різноманіття.

Приводятся результаты комплексных гидрохимических, гидробиологических и ихтиологических исследований ИнБЮМ НАН Украины, выполненных в 6 районах прибрежной акватории Крымского полуострова в Черном и Азовском морях. Анализируются основные негативные факторы, вызывающие изменения структурных и функциональных характеристик гидробиоценозов в исследованных районах и выделяются «горячие экологические точки». Рассматриваются варианты различных методов управления прибрежными экосистемами, включающие постройку искусственных рифов и применение биологических фильтров с целью очистки воды, защиты и восстановления биологического разнообразия.