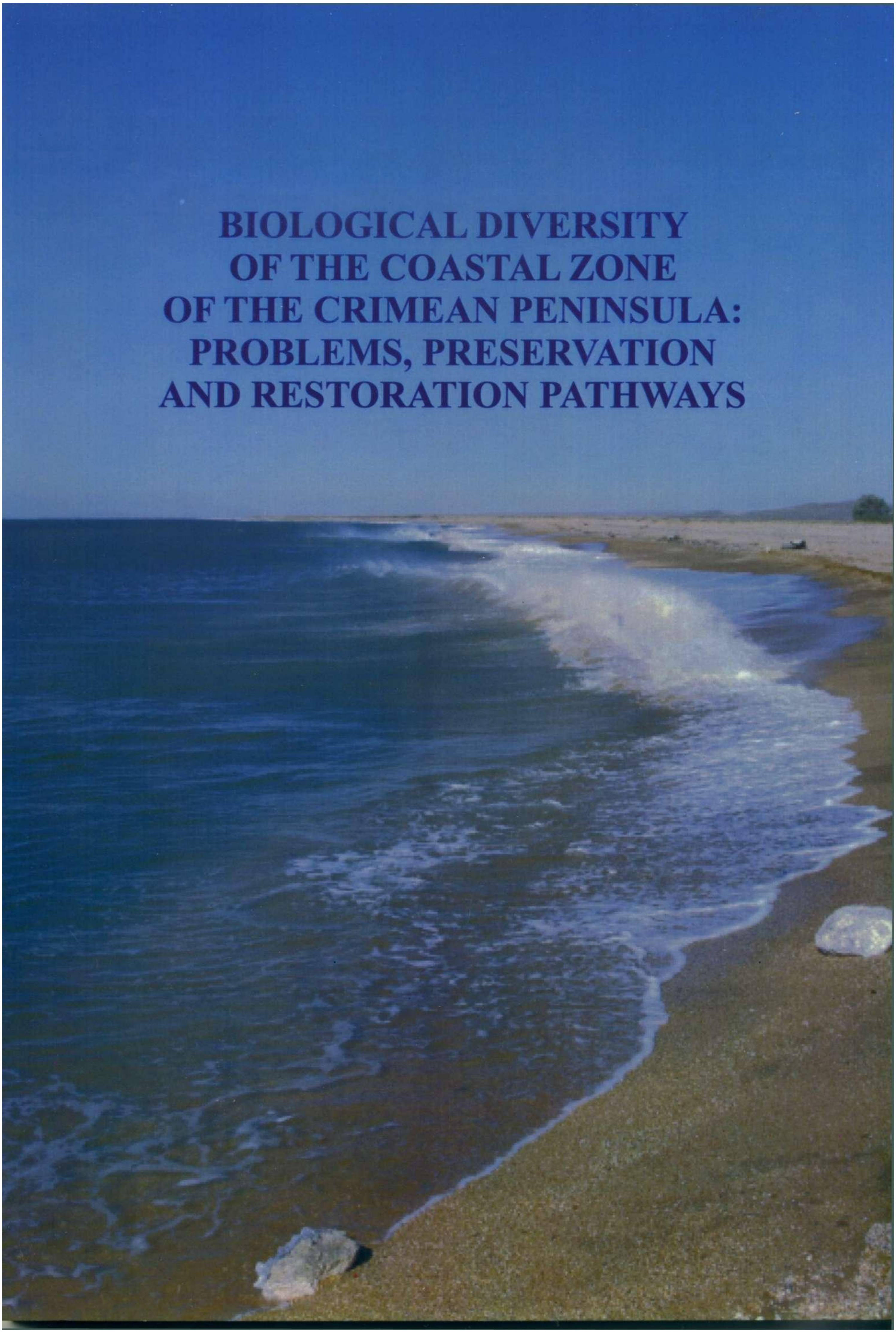
BIOLOGICAL DIVERSITY OF THE COASTAL ZONE OF THE CRIMEAN PENINSULA: PROBLEMS, PRESERVATION AND RESTORATION PATHWAYS



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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.
Figures - 57, tables - 12.

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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 kgxirr² 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 x 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).

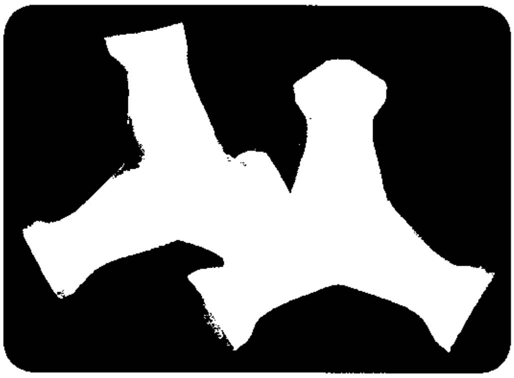
In 1985 installation for hydrobiological treatment of oil polluted water for the Sheskharis oil base in Novorossiysk was set up and this will be discussed later. In 1987-1989 Anapa Municipal Council ordered to install ARs of rubble type of large size limestone at a depth of 3-12 m in the Anapa Bay (Black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



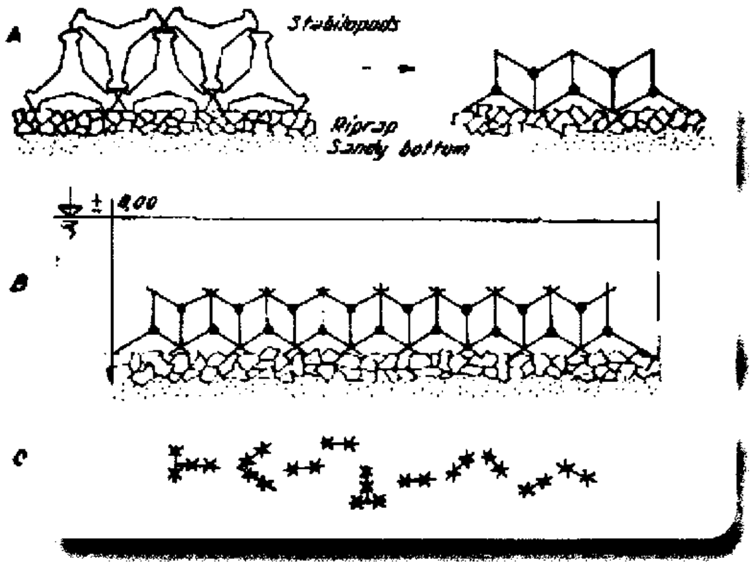


Fig. 5.3. Concrete stabilopods used for protecting the coastal zones of the sea against wave action, ports of Varna (Bulgaria), Constanta and Mamaia resort (Romania), 1980-1982.

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.

5. Modern methods for protection of the marine coastal zones environment

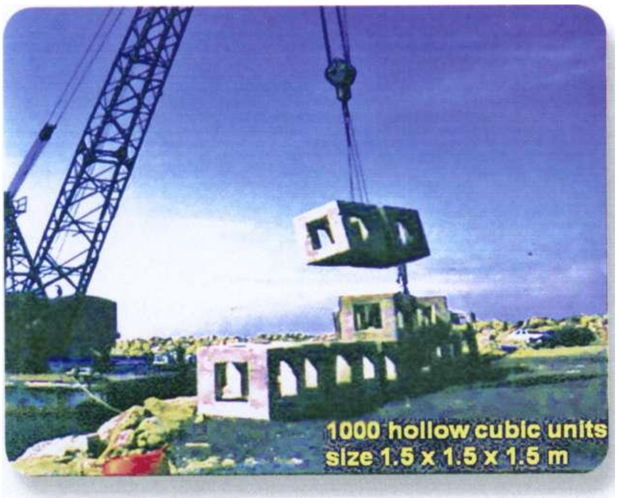


Fig. 5.4 Artificial reefs at the coast of Turkey (Zonguldak, 1999) for protecting from illegal trawling trade

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

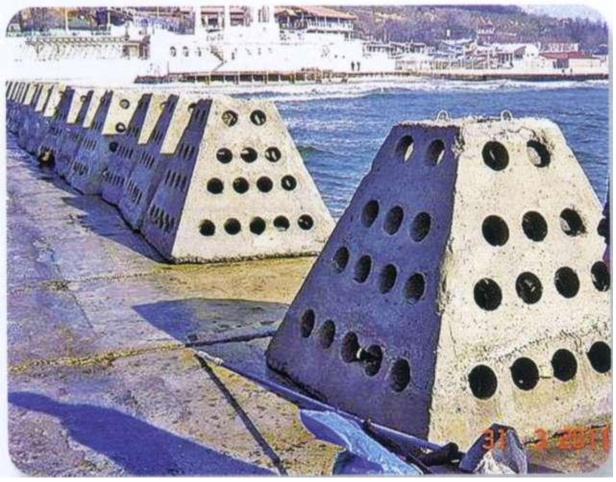


Fig. 5.6 Artificial reefs "Reefball" at the coast of Odessa (beach "Arcadia", 2011)

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 - 111, 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 - 650000 m^2, Ukraine - 256155 m^2, Romania - 155000 m^2, Russian Federation - 200 m^2, Turkey-10 m^2.

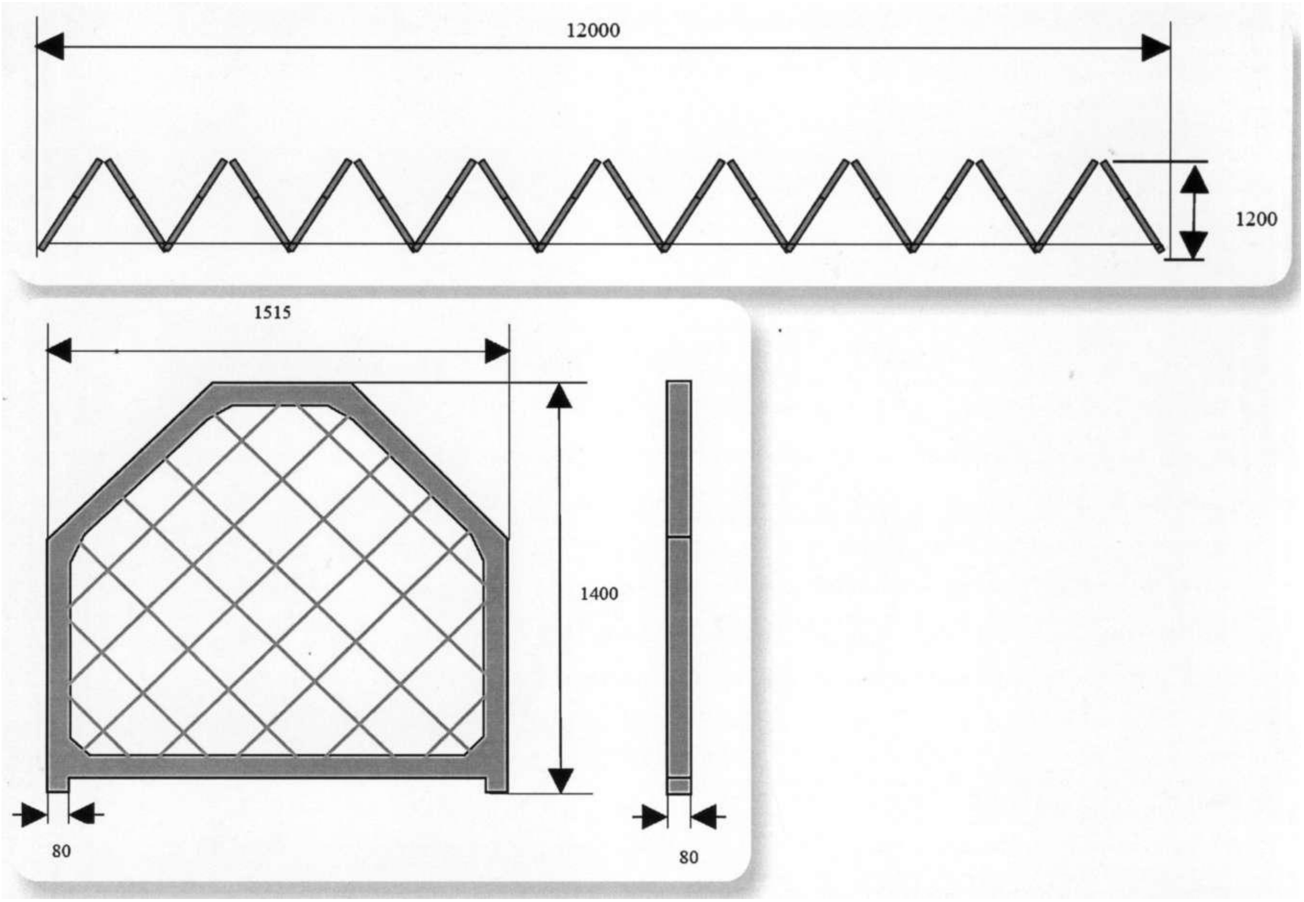


Fig. 5.9. The structure of reef-like "Accordion" (in mm). Series of articulated concrete frames attached to one another by hinges at an angle of 60°. One concrete frame with plastic grid.

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 (Alexandras 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 (Alexandras 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 VCLF- 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/So) 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 VCLF 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 (Alexandras 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; Cs - specific surface of hard substrate (concentration of fouling surface in volume of living space), S/VCLF × nrr[1], S/So - 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 VCLF, mgxcm[3], R - respiration intensity, Jxcnrr[3] x dienrr[1], Vf — daily intensity of water filtration by fouling according to VCLF / S and S_{ph} - photosynthetic surface of algae and macrophytes; 3) ameliorative effect: N_{min} - mineral nitrogen content, N_{tot} - total nitrogen, Ptot - total phosphorus, $O_{\%}$ - saturation of water with oxygen, POM - particular organic matter, P_{ph} - phytoplankton production, Nbac - 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 $POM = 2.553\text{-}DW^{0166}$, (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· day^{-1}	40,0	769,0	19
S_{ph}	m^2	1,9	45,1	24
Water quality				
N_{min}	$\mu g \cdot l^{-1}$	50,000	1952,000	39
N_{tot}	$\mu g \cdot l^{-1}$	397,000	8323,000	21
P_{tot}	$\mu g \cdot l^{-1}$	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· 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