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A SYSTEM OF PROTECTION AND RESTORATION OF THE GULF OF GDAŃSK*

Abstract

Since many years, in the Gulf of Gdańsk various transformations proceeding under the influence of trophic and pollution-induced factors are observed. Changes of especially negative character were found in the biocenosis of the Puck Bay, in which many plant and animal sets became degraded or even devastated. Besides, at present the public feels endangered by bacterial pollution of the coastal zone and increasingly intensive phytoplankton blooming. This limits the possibilities of using these water areas for the needs of tourism and recreation. It was decided that comprehensive activities should be started, both on land and in the Bay itself, in order to limit/remediate the effects of eutrophication of this water area. In 1994 and 1995 monitoring and experimental investigations were carried out. In effect a system for protecting and restoring the biocenosis was developed, and the main assumptions for this system are presented in this paper.

1. Introduction

Even as late as the mid-seventies, the Gulf of Gdańsk, and especially the Puck Bay, due to the natural values and also to the various functions (in that economical) fulfilled by these water areas, were considered unique in the Polish coastal zone [6, 19, 20, 39, 53].

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Investigations carried out in the previous years by various research institutions, in that also by the Institute of Environmental Protection (IEP), have shown that at the break of the sixties and seventies significant, in result of long term influence of economical development occuring mainly on land, very negative changes took place in the environment of this formerly unique water area [4, 5,21, 26, 27, 28, 33, 38, 40, 41, 49]. Decades of excessive discharges of biogenic matter [42, 43] resulted in intense eutrophication, which together with other types of contamination, e.g. by heavy metals, caused increasing degradation of bottom sediments, especially in the deeper parts of the Gulf, and resulted in anthropogenic restructuring of the biocenosis [10, 13, 36]. Full reconstructing of the biocenosis became impossible, and self-purification capacity became weaker, which may be the reason for the slump in biological productivity of this water area [7, 8, 9, 22, 23, 50, 51, 52].

Observed at present signs of increasing degradation of the Gulf of Gdańsk should be a sufficient argument for starting decisive and comprehensive remediatory actions both on land and in the Gulf. The more so, since the expected improvement of the condition of environment does not take place, though for the last several years the supply of biogenes and pollutants has been reduced [47, 48]. On the other hand, during the last years intensification of degradation is observed, as indicated by such phenomena as: long duration and intense blooming of phytoplankton and increasing numbers of potentially toxic algae, bacteriologic contamination of edible fish and of bottom sediments [16, 17,31, 32].

The status of Poland in the protection of the Baltic Sea, the role of the Gulf of Gdańsk in the Baltic Sea ecosystem and in supporting the population living at its coasts, as well as the natural, economical and cultural values of this water area, are an obligation to start as soon as possible intense actions to protect and renew the biocenosis of the Gulf.

The following point to the need for quick starting of actions to protect and renew the biocenosis of the Gulf of Gdańsk:

- the need to stop degradation before the level of devastation is reached,
- the still relatively low cost of presently required actions in comparison with the future costs, which will have to be carried when degradation will develop further (will reach the devastation level),
- this is a good moment to begin comprehensive action, since the Gulf still has a sufficient biological potential to support the regeneration of the biocenosis,
- the unique natural character of the Gulf, in spite of the proceeding degradation,
- the location in the Gulf of three marine protected areas, proposed by Poland to be included in the system of Baltic Sea Protected Areas (BSPA),
- the great importance of this water area as a research and experimental field for many scientific institutions,
- the great importance of the Gulf to the people living off the sea and for the sea,
- the fact that the environment of the Gulf of Gdańsk is a specific form of national heritage, which should be left to the next generations in a possibly unchanged state.

Taking into account the above premises, the IEP started work to develop a system of protection and restoration of the biocenosis of the Gulf of Gdańsk. It was also stated that to achieve these objectives comprehensive and simultaneous action is required:

on land - limiting the supply of biogenes to the Gulf by modernising and developing sewage treatment plants in the direct catchment area of the Gulf, and in the next stages - in the catchment area of the Vistula, which will decrease eutrophication,

in the Gulf of Gdańsk - implementing biotechnical measures, which will facilitate development of a complex, able to self-regenerate biocenosis. The increase of biomass of macro-algae and filtering organisms is also justified by their de-eutrophication abilities, which is important due to the possibility of a strengthening of the process of internal eutrophication of the Gulf.

The main goal of the system of protecting and restoring the biocenosis of the Gulf of Gdańsk is to preserve the biological resources considered as a pool of genes in the presently existing environmental conditions in the Gulf. In the future this pool will be the basis and the guarantee that a full renewal of these resources will be possible, including the important to the functioning of the ecosystem diversity and regeneration capacity.

2. Region, scope and methods of researches

The basis for the system were the results of monitoring and experimental researches in the environment of the Gulf, carried out by the IEP in the years 1992 [26], 1994 and 1995 [15, 28, 29, 46], as well as results obtained by other institutes, and analyses of the activities which at present limit the supply of pollutants to the area bordering the Gulf.

Comprehensive monitoring was carried out during two seasons, i.e. in autumn (October) of 1994 and summer (June) of 1995.

Control measurements were carried out in the Kuźnica and Górki Wschodnie regions, within the strip between 1 m. and 20 m. water depth. The profiles and stations were located at the same places as in 1992 [26], i.e. profile III - Kuźnica, V - Mechelinki, VI - Oksywie, VII - Sopot, VIII - Nowy Port, IX - Górki Wschodnie (Fig.1). Along each profile, depending on parameter, samples were taken or measurements were made on stations located at water depths of 1, 2, 3, 5, 10 and 20 metres. Material for analyses was taken in the whole water column, in the surface layer or near the bottom, and in the surface layer of deposits. The investigations included phytoplankton, chlorophyll "a", zooplankton (benthos larvae), phytobenthos and zoobenthos, total number of bacteria and NPL of faeces type coli, temperature, transparency, salinity, total nitrogen, total phosphorus, organic matter, pH, redox and grain size distribution. Biological and chemical materials were analysed in accor-dance with the methods of the Baltic Monitoring Programme (BMP) and the methodological guidelines for the IIIrd stage of monitoring (BMEPC 1988); also own methodologies and methodologies conforming with the adopted criteria (Polish Standard) were used.

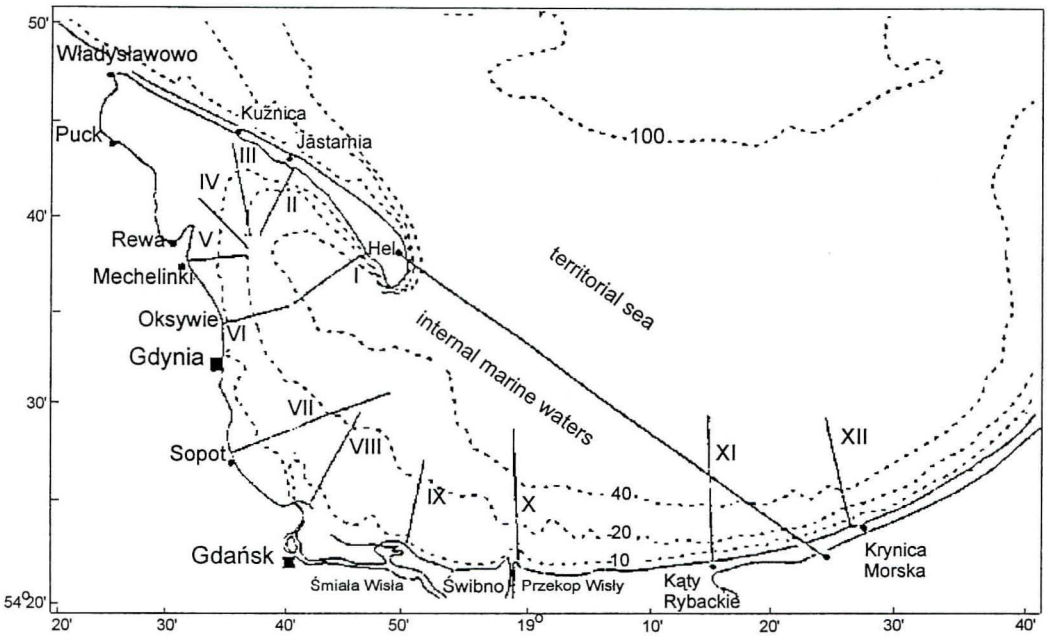

Fig.1. Location of the sampling profiles in the Gulf of Gdańsk, along which measurements were carried out in summer 1992 (profiles I-XII, to the 60 m depth contour) [26], and in autumn 1994 and summer 1995 (profiles III, V-IX, to the 20 m depth contour)

Experimental investigations were carried out in two cycles. In the bi-annual cycle, in the years 1993 and 1994 an experiment concerning the development of biofiltrators and macro-algae on artificial reefs placed near Mechelinki, at stations M_1 and M_2, was performed; and between April and October 1995 additional experimental investigations were carried out at stations: near Mechelinki - station M, near the caisson - station M_3, and by the old torpedo house - station M_4. Depending on the carried out experiment, the stations were placed at a distance of 150 to 800 metres from the coast (Fig.2). Fishing nets were used as the substratum for the growth of biofiltrators and algae of the *Enteromorpha* species. The time of exposure of the nets was one to three months, depending on the scope of tasks. During the experimental investigations also certain physiochemical and microbiological parameters in the water column were controlled.

The objective of the experimental investigations was to develop a method to support the process of self-purification (de-eutrophication) of waters in strongly degraded regions, which would result in an increase of the quantitative structure of authochthonic organisms, such as *Enteromorpha* macro-algae and bio-filtrators *Mytilus trossulus* and *Banalus improvisus*.

Experimental investigations in the years 1993-1994 were realised in the framework of Project No. 450101805 of the Committee of Scientific Research, realised by the Institute of Fishery in cooperation with the Gdańsk Branch of IEP. Monitoring in the years 1994 and 1995 and experimental investigations in 1995 were carried out in the framework of the statutory activities of the IEP.

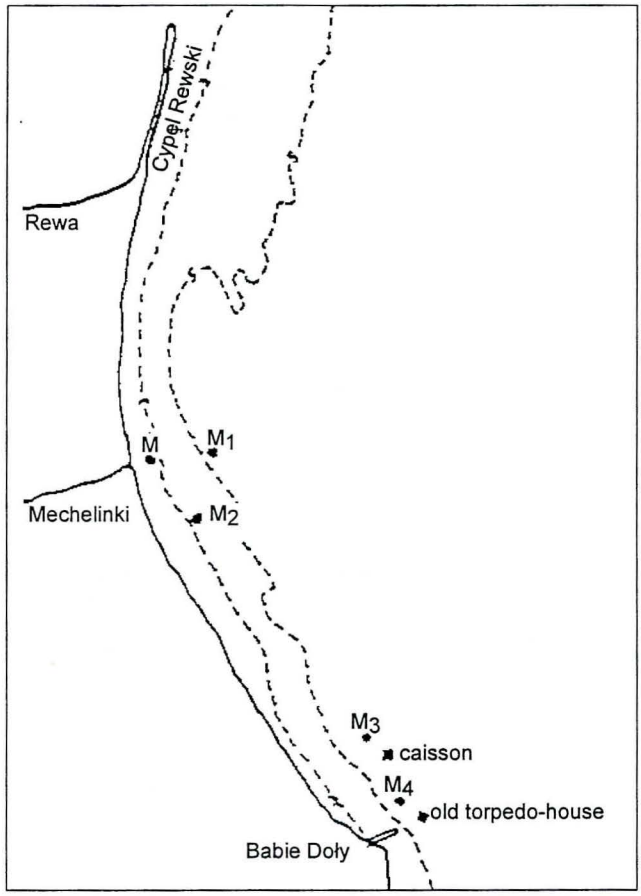

Fig.2. Region of experimental researches (stations M, M_1, M_2, M_3, M_4) carried out in the Gulf of Gdańsk in the years 1993-1995

3. Distribution of areas with varying degradation of water and bottom sediments

The Gulf of Gdańsk includes three subareas: the nearly autonomous inner Puck Bay (called also the Puck Lagoon), the outer Puck Bay (which is the central-west part of the Gulf), and the central-east part. In the region of investigations, i.e. between Kuźnica and Górki Wschodnie, the presence of degradation processes, proceeding in the bottom sediments, was observed. Over an area of 324 km^2 of the bottom, i.e. about 30% of the water basin within the internal marine waters, total or strong degradation was noted. The belt of waters in the Gulf of Gdańsk, reaching to 10 m. water depth and including the Puck Lagoon, covers 280 km^2 and is under a permanent, strong influence of pollution and biogenes supplied by sewage discharges, rivers and from atmosphere. Degradation of the water environment in this zone varies significantly, depending on hydro-meteorological conditions. When winds from the

western sector prevail then the polluted surface waters are propagated towards the Gdańsk Deep, which is the basic factor of purification of the coastal waters [45]. In the coastal waters, which are permanently under the influence of sewage discharges, degradation is becoming permanent and contamination with bacteria exceeds permissible levels.

The following regions of the Gulf of Gdańsk coastal zone, lying in the up to 10 m water depth coastal strip, with permanently transformed environmental conditions by discharges of sewage water and polluted streams have been distinguished (Fig.3):

- the stretch from Władysławowo Bay to Rewa Bay (Swarzewo and rivers of the region),
- stretches along the Hel Peninsula (settlements of Chałupy, Kuźnica, Jastarnia with sewage collectors, Hel),
- the stretch between the Rewa Spit and Babie Doły, especially the area under direct influence of the sewage collector at Mechelinki,
- the stretch adjoining the port in Gdynia (port entrance),
- the stretch between the port in Gdynia and Redłowo Headland (Kolibianka and Kacza streams),
- the region of Sopot, the region of Gdańsk including Martwa Wisła outlelt (with sewage collector from the Zaspa sewage treatment plant) and the Jelitkowo Stream,
- outlet of the Vistula Cross-Cut with the sewage collector from the East (Wschód) sewage treatment plant.

The volume of discharged into the Gulf river and sewage waters, and of the biogene and bacterial load, decide about the properties of Gulf waters in the coastal zone along stretches of a length of several dozen metres (small streams, melioration ditches) to several dozen kilometres (the Vistula).

In the regions were large loads of pollutants are discharged into the coastal zone, a permanently degraded near field can be distinguished, and a far field where pollution gradually decreases seawards to the level characteristic for the whole Gulf of Gdańsk. It should be stressed that practically the whole seafloor of the Gulf is subjected to varying degrees of degradation due to the pressure of very large loads of pollutants coming from numerous sources, and because of the long term damaging of the natural properties of the bottom. By limiting the flow of pollutants into the Gulf, a relatively quick improvement of water quality in the coastal zone will be obtained. However, improvement of the quality of bottom sediments can be expected only after several years from the moment at which a distinct reduction of biogenes and polluting substances will occur.

4. The state of environment of the Gulf of Gdańsk coastal zone in the period 1994-1995

The environment of the Gulf of Gdańsk is under the influence of river and sewage waters, which are discharged into the coastal waters and propagate mainly in a belt

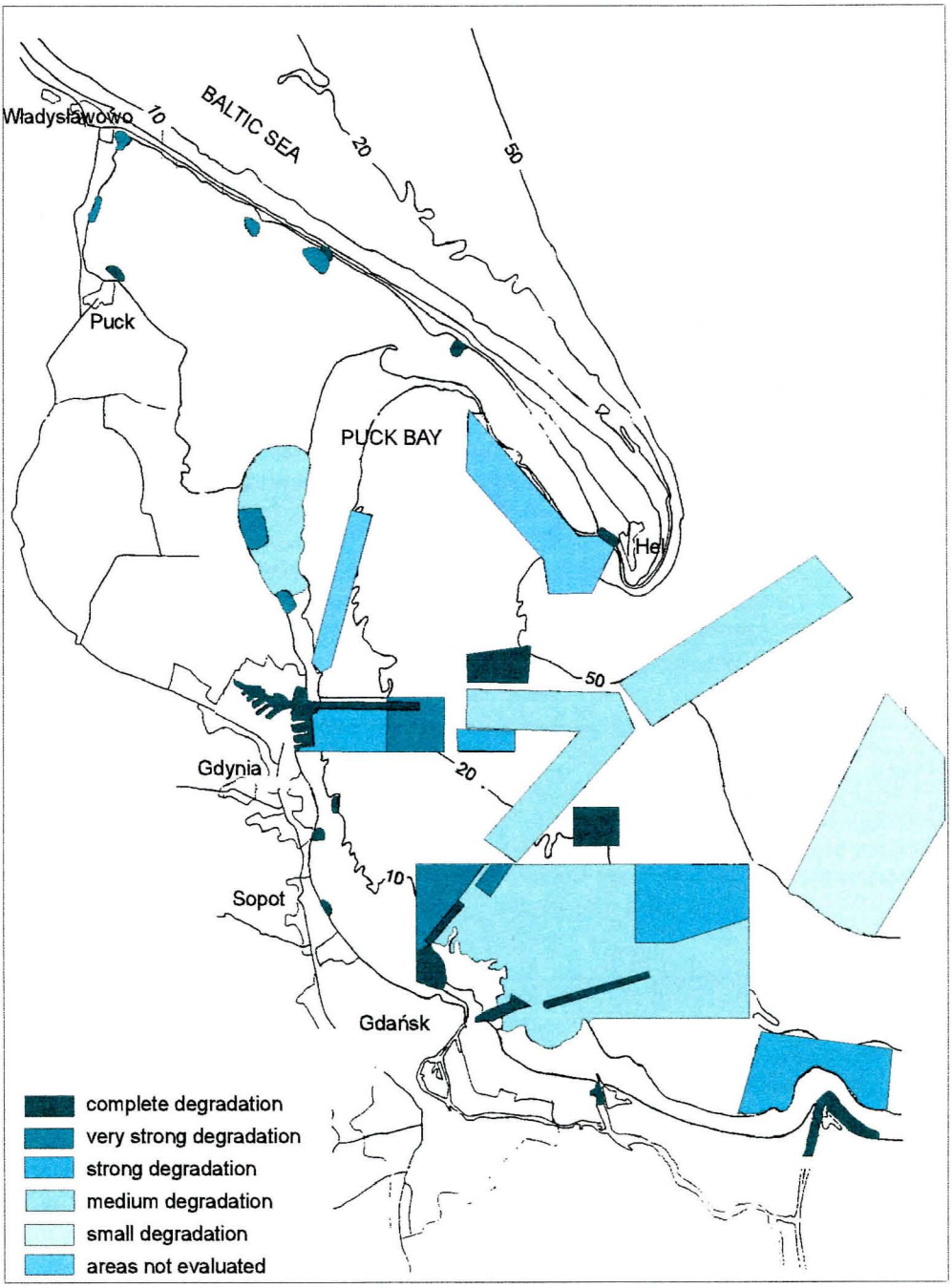

Fig.3. Degree of degradation of bottom sediments in the Gulf of Gdańsk in the years 1994-1995

of 1 km width along the coast. In this zone significant differences in environmental and biocenotic conditions occur due to mixing of waters and substances of river, sewage and marine origin. The hydrodynamic properties of the coastal zone cause a strip-like displacement of chemical and bacterial pollutants and phytoplankton and zooplankton organisms in the Gulf. In this process participate also semi-permanent sea currents and wind currents [45]. Hydrometeorological conditions in the Gulf cause that the basic transport of water and of its components proceeds eastwards. Because of the specific influence of hydrodynamic and polluting factors along the coast from the outer Puck Bay to the Vistula Spit, a varying in space and species differentiated biocenosis of the Gulf's coastal zone has been formed.

The year-long supply of biogenic substances from land [12, 14], which is indicated by the very small seasonal changes of total nitrogen and total phosphorus content in the water, confirms the high level of accumulation of these elements. This is the most significant factor, which stimulates primary production and the loading of the environment by organic matter. During investigations, results indicated distinct eutrophication of the environment (Table 1), which was proven by the total nitrogen and phosphorus content and by water transparency in the summer season of 1995.

Table 1. State of chemical components of coastal environment of the Gulf of Gdańsk in Autumn 1994 and Summer 1995 [28]

Investigated components	Units	Water		Bottom sediments	
		1994	1995	1994	1995
Salinity	‰	6.49	6.49	-	-
Total phosphorus	$\mu mol \cdot dm^{-3}/g^{-1}dm$	1.54	1.72	3.44	2.42
Total nitrogen	$\mu mol \cdot dm^{-3}/g^{-1}dm$	45.14	45.43	14.80	12.00
Nc : Pc	n : 1	29.3:1	26.4:1	4.3:1	4.9:1
Transparency	m	8.3	3.8	-	-
Organic matter	% sm	-	-	2.14	1.28
pH	-log (H)	-	-	7.27	7.18
Eh	mV	-	-	+275	+101
Chlorophyll "a"	$mg*m^{-3}$	0.48	1.82	-	-

The properties of bottom surface sediments (Table 1), indicate their eutrophic character, which increasingly limits the living space of the water area's biocenosis. The content of organic matter and the number of pathogenic bacteria increased, the redox potential became smaller and acidity grew, the content of total nitrogen and total phosphorus increased. Generally, the reduction potential of the bottom deposit environment increased, resulting in a growing deficit of nitrogen salts in the water, and in a restructuring of the macro-zoobenthos sets. Accumulation of "phosphorus in bottom sediments increases the chances for secondary eutrophication, which occurs especially intensely in reduction conditions" [2]. Properties of sediments were changed most strongly in areas of influence of sewage waters discharged from municipal sewage treatment plants [11]. The quality of sandy deposits in the coastal zone of the Gulf of Gdańsk is several times worse than of same deposits along the

open sea coast [25]. The characteristics of the deposits of this zone are worst in the regions of large ports (Fig.3). With distance from the coastline, the quality of deposits decreases, attaining their very worst condition in the belt of muddy deposits. In the Gulf of Gdańsk a process of degradation of the environment of sediments is proceeding, and this is of basic importance to the future, especially in with respect to the macro-zoobenthos of the Gulf. If degradation of bottom sediments will not be stopped, no improvement or rebuilding can be expected of these elements of the biocenosis, which disappeared or were significantly depleted in the past (since mid-seventies).

Bacterial contamination of water, sediments (Table 2) and of selected organisms in the coastal zone of the Gulf of Gdańsk was very high in the period of observation, indicating a supply of municipal sewage [16, 17, 44]. The sanitary state at the time of investigations, measured by coli NPL, was especially bad in areas of dispersal of waters discharged from sewage treatment plants. This may lead to spreading of infectious (maybe also parasitic) diseases among the hydrobionts and fish of industrial value. The decrease of bacteria production in the sewage water dispersion zones indicates that lowering the self-purification potential of the environment is possible. In effect, organic matter accumulates in the sediments and reduction processes increase, resulting in oxygen deficit in the near-bottom water layer and in sediments of the sea bottom surface. Secondary eutrophication, as the effect of reduced redox potential, increases primary production and supply of organic matter to the sediments. A self-driving eutrophication-production-reduction process is started, which can be stopped only if biogen supply to the Gulf is radically limited. However, stopping the supply is rather not likely since the main source of the biogens (especially of phosphorus) are Vistula waters. Investigations of the biogen load supplied by the Vistula during the last 15 years indicate that there is no possibility of improvement [43, 51]. However, it should be pointed out that a significant reduction has been observed of the phosphorus loads from sewage treatment plants discharging treated waters into the Gulf. However, in the case of the Vistula, even full elimination of phosphorus from municipal sources will not result in a radical reduction of the phosphorus load, since the main source of phosphorus in the river's drainage basin are agricultural areas.

Phytoplankton blooms, which are a resultant of eutrophication, appear over the whole area of the Gulf, and for increasingly long periods cause degradation of this water basin. The possibility of blooming of toxic species is a new danger for hydrobionts, fish and even for man. Methods for evaluating their harmfulness are yet to be worked out, and basics of their development still are not known, therefore predicting the bloomings is impossible. Besides the phytoplankton blooms, the quality of the food base of higher order consumers, especially fish, is deteriorated by the development of epibiontic and parasitic protozoa. The disruption of the trophic system is probably the most significant reason for the reduction or even disappearance of many fish species in the Gulf. Their place is increasingly taken up by useless species, with predominant in the coastal zone stickleback species. The place of retreating vascular plants, especially after the disappearance of red algae and rockweed, is taken up by *Pilayella* and *Ectocarpus* brown algae [5, 22, 23]. This is in accordance with the principle that multiannual vascular plants are pushed out by

one-year plants - the filiform algae, which is typical for highly trophic water areas [24]. In turn with the collapse of the systems of bottom-dwelling animals is connected the development of species only slightly utilised as a food basis (clams). On the bottom, in the coastal zone of the Gulf, predominate *Bivalvia* and *Polychaeta;* however their existence is also endangered due to oxygen deficit and decay processes caused by excessive amounts of organic matter.

Table 2. Some biotic components of the coastal zone of the Gulf of Gdańsk in Autumn 1994 and Summer 1995 [28]

Parameters	Units	1994	1995
Bacteria			
- Coli NPL			
water	NPL/100 cm^3	$23 \div 162*10^2$	$23 \div 23*10^3$
bottom sediments	NPL/1g ·dm	$23*10^2$-$29*10^3$	-
Phytoplankton			
- biomass	$mgC \cdot m^{-3}$	38-95	213-475
- quantity	bln m^{-3}	2.4-8.8	5.3-20.4
Zooplankton			
- no. of taxons	n	27(1)	26
- quantity	$n \cdot m^{-3}$	low	high
Phytobenthos			
- no. of taxons	n	18(1)	15
- participation of brown algae	%	85(1)	90
Macro-zoobenthos			
- no. of taxons	n	28	32
- participation of *Bivalvia*	%	82(1)	89
- participation of *Mytilus trossulus*	%	50	69
- biomass of *Mytilus trossulus*	$g \cdot w \cdot m \cdot m^{-2}$	25.1	263.2

(1) Data from 1992.

Monitoring [28] shows that processes of degradation in the coastal zone have become stabilised and that they proceed in conditions of high eutrophication and of overloading of the environment with organic matter (of mainly authochthonous origin). The characteristics of the environment in this part of the Gulf of Gdańsk depend mainly on seasonal organic matter production and decay, which decide about the state of the environment (water and sediments) and of the biocenoses of the water area. It is evaluated that during the last 30 years eutrophication caused an over threefold growth of loading of the environment with organic matter. This process must be minimised by means of a comprehensive set of technical and biotechnical actions aimed at the restoration of the Gulf.

5. Improvement of the self-purification capacity of the Gulf of Gdańsk waters by changing the quantitative structure of selected components of the biocenosis

A popular and effective method of improving the quality of eutrophicated coastal waters is the utilisation of the natural purification potential of selected native organisms, by providing advantageous conditions of their development, e.g. artificial

reefs [3, 18, 35, 37]. Field experiments showed that use of epiphyte systems is a feasible method for strongly eutrophicated areas of the Gulf's coastal waters.

Best for water de-eutrophication and for pollution removal are green algae of *Enteromorpha* type and biofiltrators: mussel *Mytilus trossulus* and barnacles *Balanus improvisus*. Especially high purification efficiency of the barnacle systems is obtained when they are exposed on artificial reefs.

5.1. Improvement of potential of *Enteromorpha* macro-algae

Increasing the population of macro-algae is a highly promising method of limiting excessive concentrations of biogenes and heavy metals in the coastal zone of the Gulf [30, 34, 36]. The proposed solution consists in an effective use of reefs - plantations of green algae, *Enteromorpha,* mainly, placed in areas where municipal waste is discharged into the Gulf. Plantations of these macro-algae have the following advantages: a short trophic chain, short time of development of populations and short time of exposition, ability to develop effectively in direct neighbourhood of points of discharge of the waste waters, the use of species which naturally are present in the water area, high productivity [37].

An experimental *Enteromorpha* plantation was placed near the discharge from the Dębogórze sewage treatment plant. Results of the experiment show that in conditions of direct influence of municipal waste waters on the Gulf environment, *Enteromorpha* macro-algae develop with high intensity [29]. The experiment allowed also to determine the optimum distance at which the artificial reefs should be placed from the waste water outlet, i.e. 150 to 300 m., and water depth of up to 1 m., which ensures effective growth of macro-algae (Table 3). The best substratum, ensuring most effective growth of the algae and allowing their easy removal, was selected, and the technical method of suspending the reefs in the water was developed. It was also found that the effectiveness of the reefs and the rates of growth can be improved by using substrata with previously implanted spores of the algae. Implantation of net substrata with *Enteromorpha* spores increases algae biomass growth by 2 to 4 times in comparison with natural substrata (stones) or 2 to 3 times in comparison with non-implanted substrata (Table 3). There is no risk of domination of the *Enteromorpha* algae due to starting their plantations on artificial reefs, since at present they constitute only 3.6% of the total phytobenthos biomass of the Gulf [28].

The use of artificial substrata may result in a multiple increase of the biomass of macro-algae in comparison with natural communities, which will result in the reduction of the amount of biogenes in the water. *Enteromorpha* algae are characterised by intense photosynthesis in strongly eutrophicated waters - during 24 hours they remove from the water 4.7 to 14.1 g of nitrogen per 1 m^2 of net substratum. Though the algae assimilate biogenes only for about 5 months in a year, they can be an excellent competitor in catching biogenes for the excessively developing phytoplankton, and in distinction from the phytoplankton, macro-algae can be relatively easily removed from the water with fragments of the artificial reefs, and the growth of their biomass can be easily controlled and limited. However, removing thalluses of the algae from the reefs is not planned, since this could disturb the development and destabilise the plantations. Observations of obtained macro-algae sets have

shown that they will form a natural feed and habitat for I-st order consumers (crustaceans), providing good conditions for their development, and this in turn will have an advantageous influence on the development of ichtiophauna in the coastal zone [15, 31].

Table 3. *Enteromorpha sp.* biomass ($g \cdot dm^{*}dm^{-2}$) on net reefs in the Gulf of Gdańsk, near sewage water discharge at Mechelinki, at stations M., M_1 and M_2, in the period 11.05 to 11.07. 95 [29]

Depth of net suspension [m]	Distance from sewage plant collector [m]				
	(M) - 150		(M_2) - 300		(M_1) - 500
	"clean" nets	"implanted" nets	"clean" nets	"implanted" nets	"clean" nets
0.1	6.5	14.64	6.9	22.42	14.5
1.0	3.47	4.52	-	-	-
1.3-1.5	2.27	2.3	7.48	5.64	-
2.5	-	-	no growth	no growth	1.08

"clean" nets - not implanted with *Enteromorpha* spores.
"implanted" nets - implanted with *Enteromorpha* spores.

5.2. Increase of biofiltrator set potential

In the scale of the whole Gulf of Gdańsk, the use of biotechnical techniques can bring at most an improvement of the order of several per cent only, when calculated in terms of the amount of accumulated organic matter in the form of suspensions and compounds of nitrogen and phosphorus. The use of biotechnical methods will however have significant results in microscale, i.e. in respect to the most degraded areas, at the outlets of waste water collectors, of rivers, streams etc. This conclusion is confirmed by experiments with biofiltrators in the area of waste water dissipation at Mechelinki [15, 46].

The objective of the experiments was to increase the rates of growth on the artificial substrata in order to obtain in the waters of the area an animal set rich in mussel and barnacle larvae. The juvenile animal set was then transferred to the area requiring biopurification, in which natural reproduction of the larvae and their settling on the bottom is impossible or difficult (M). After taking such sets from the regions of stations M_3 and M_4, their species composition and biomass growth were investigated in order to evaluate their ability to adapt to a degraded environment.

It was found that exposition of the substrate - fishing nets - in areas with relatively numerous larvae quickens the rate of formation of biofiltrator sets. Acclimatisation of the transferred animal sets in the degraded environment was good, and they immediately began to function, which was shown by quick growth of biomass. It also appeared that water in the coastal zone contains enough food for biofiltrators settled on the artificial substrata.

Mussels (and barnacles) grow much slower than macro-algae, and their filtration efficiency is highest for at least 1 year old specimens of about 1.5 cm length.

However, due to their long biological cycle (mussels live up to 5 years), accumulated in them biogens and contaminants may be catched in their tissue or shells for up to 4 years. Mussel sets effectively developed on artificial reefs distributed close to discharges from sewage treatment plants, at a distance of 300 to 500 m and at 2 to 5 m water depth. In June 1994, at water flow of about 3.4 cm/s, during 1 hour they caught from the water about 27.5 kg of suspended matter, 0.6 kg of total nitrogen and 0.25 kg of total phosphorus (Table 4) [15, 46]. Besides, the investigations also showed that mussels can be used for removing bacterial pollution from the environment, which would help to improve the sanitary conditions in the coastal waters of the Gulf. Biofiltrators growing on artificial substrata, after about 1.5 year of exposure, i.e. after the set becomes stabilised, should not be removed from the Gulf, but transferred to deeper regions, e.g. to areas of dumping dredged spoil, where after placing on the bottom they will enrich the sea bottom fauna in degraded regions.

Table 4. Quantity, biomass and effectiveness of biofiltration of animal sets exposed on net reefs in the area of sewage water discharge at Mechelinki in the years 1993-1994 [15, 46]

Dates of investigations	Time of exposure	Dominant species	Quantity	Biomass	Effectiveness of biofiltration		
					total suspension	total phosphorus	total nitrogen
	[days]	[%]	[thous. m^{-2}]	[kg·w·m^{-2}/m^2]	[g·h^{-1}·m^{-2}]		
Station M_1 - 500 m from collector							
09.1994	330	barnacles - 90	317.0	11.3	+100	+2.1	+4.1
09.1995	690	mussels - 74	172.0	19.2	+150	+5.8	-13.6
Station M_2 - 300 m from collector							
09.1994	90	barnacles - 98	241.0	7.8	+300	+5.6	+11.8
09.1995	450	mussels - 99	1524.0	2.3	+220	+11.2	-8.7

(+) intake, (-) discharge of investigated components by the animal set.

There is no risk in increasing the biomass of biofiltrators due to the advantageous conditions provided by artificial reefs, since in the sixties their biomass was larger by 15 thous. t m.m. than the present biomass. Therefore, if it is assumed that that was the natural size of the population, then there is a quite large reserve for increasing the quantity of these organisms [53].

Long term observation and investigations of the development of these sets allowed to determine their influence on the water environment. Barnacle sets (practically single-year) and mussel sets (multi-annual) removed mineral and organic suspensions, micro- and nanoplankton, and even colloidal matter from the water. Coastal waters of the Gulf of Gdańsk are rich in organic matter and biogens. Because of that biofiltrator sets quickly reached maximum development and maximum biomass. Suspended matter, from which food was filtered out, was

agglutinated and deposited in sea bottom sediments. Organic components left in the bottom were chemically and biologically mineralised after being used for food by mud eaters. In this way, sets growing on the reefs in areas of sewage matter supply, initiated self-purification processes and enhanced them to a very high level in comparison with the initial state. In the second year of exposure, the initially one- or two-species sets were joined by many species of crustaceans and fish, and in result biodiversity increased and a specific biocenosis developed in an earlier degraded region.

6. Biotechnical system of supporting purification of the Gulf of Gdańsk coastal waters

Experimental investigations carried out in the Gulf's environment provide a basis for the preparation of the important biotechnical element of the system of protection and restoration of the Gulf of Gdańsk biocenosis. It was found that:

- in the Gulf's environment there still exist possibilities of renewing the biocenosis using authochthonous organisms;
- effective operation of artificial reefs requires that they are built in such a way that growth of both biofiltrators and *Enteromorpha* macro-algae is possible;
- the use of artificial reefs with both algae and biofiltrators in eutrophicated areas requires that in order to decrease competition for settling surface, different types of substratum should be used for the algae and the biofiltrators;
- the algae and biofiltrator sets, besides removing biogens and pollutants from the environment, due to the decrease of biogen and organic matter concentrations and of bacterial pollution are very important for the development of environmental conditions in the water column. They also are an excellent habitat for bottom-living animals and for fish, of which some use the reefs for spawning. They also are a basis for maintaining and even increasing the biodiversity of the Gulf of Gdańsk ecosystem.

Taking into account the present trophic state of the Gulf's waters and the assessments of mussel biomass at the beginning of the 60ties, it is concluded that the mussel stock in the coastal zone can be restored. It is assumed that net reefs should be placed in the coastal zone, on which barnacle/mussel and green algae sets with accompanying flora and fauna will develop. Investigations in the area of Mechelinki and other experiments show that "minibiocenoses" with high biodiversity can be formed. It is designed to install 30 net reefs in the first stage of biotechnical activities (Table 5). Developing on them bio-growth units will undergo quantitative changes of biomass and species composition. Removal and utilisation of species forming the bio-growth units is not planned, since it is assumed that they will form a biological barrier protecting the outer part of the Gulf, which will not disturb the ecological balance of the region. Monitoring of the dynamics of species and of the environment of neighbouring water areas will allow to evaluate their influence on the environment and biocenoses, and to control the process by quick removal (in case of negative influence) or by maintaining the development (if the influence proves positive).

Table 5. Biotechnical system for supporting purification of the Gulf of Gdańsk coastal waters

Number of net modules	Dominant species [%]	Active surface [thous. m^2]	Optimum biomass [t·w·m]	Effect of purification	
				Total suspension [tons/ season]	Total phosphorus [tons/ season]
Inner Puck Bay					
13	mussel - 90	7.9	78	309	11
Outer Puck Bay					
4	mussel - 70	3.5	35	116	4
Gulf of Gdańsk					
14	mussel - 50	10.0	100	332	13

The present state of strong eutrophication and degradation of the biocenoses, and the development of reduction processes (e.g. the decrease of the range and resources of authochthonous species) results in the unstable ecological equilibrium of the Gulf. We are fully aware that in these conditions large scale implementation of biotechnical methods of purification of the environment, even if only authochthonous species are used, may generate biocenotic changes difficult to predict at the present stage.

7. Main directions of the system for protecting and restoring the biocenoses of the Gulf of Gdańsk

The proposed by the IEP system is based to a large extent on already implemented programmes. They are supplemented by necessary environmental actions, which will enable and quicken the processes of protecting and revitalising the biocenoses. The actions building up the system should be carried out on land - in order to limit discharges of pollutants, and in the Gulf - to improve the efficiency of ecosystem functioning (Fig. 4 and 5).

Among the land-based, pollutant discharge limiting actions, actions which should be carried out in national scale are distinguished, *inter alia* limiting the flow of pollutants into the Vistula, and actions which can and should be carried out within the boundaries of the Gdańsk Voivodship. Problems of pollutant discharges into the Gulf by means of the Vistula and from atmosphere are complex, originate over the whole area of Poland and even neighbouring countries, and therefore can be solved only in at least national scale.

Among actions which could be realised by the Voivodship on land, the following are considered most important:

- modernisation of sewage treatment plants to increase their treatment efficiency;

- starting biological treatment with simultaneous precipitation of phosphorus in the Dębogórze and Wschód (East) sewage treatment plants;
- use of a system of intermediate treatment plants connected to main treatment plants;
- lightening the weight of biogens in the inner Puck Bay by leading the discharge pipe from the Swarzewo sewage treatment plant into the open sea near Władysławowo;
- development and implementation of a sanitary protection programme for the catchment area of the Gulf.

The following actions, enhancing the functioning of the ecosystem (Fig. 4 and 5) should be carried out in the Gulf of Gdańsk:

- implementation of the developed at the Institute of Environmental Protection programme of recultivating the Puck Bay [27];
- implementation of the developed at the IEP programme of biotechnical actions in the Gulf of Gdańsk (IEP, 1996);

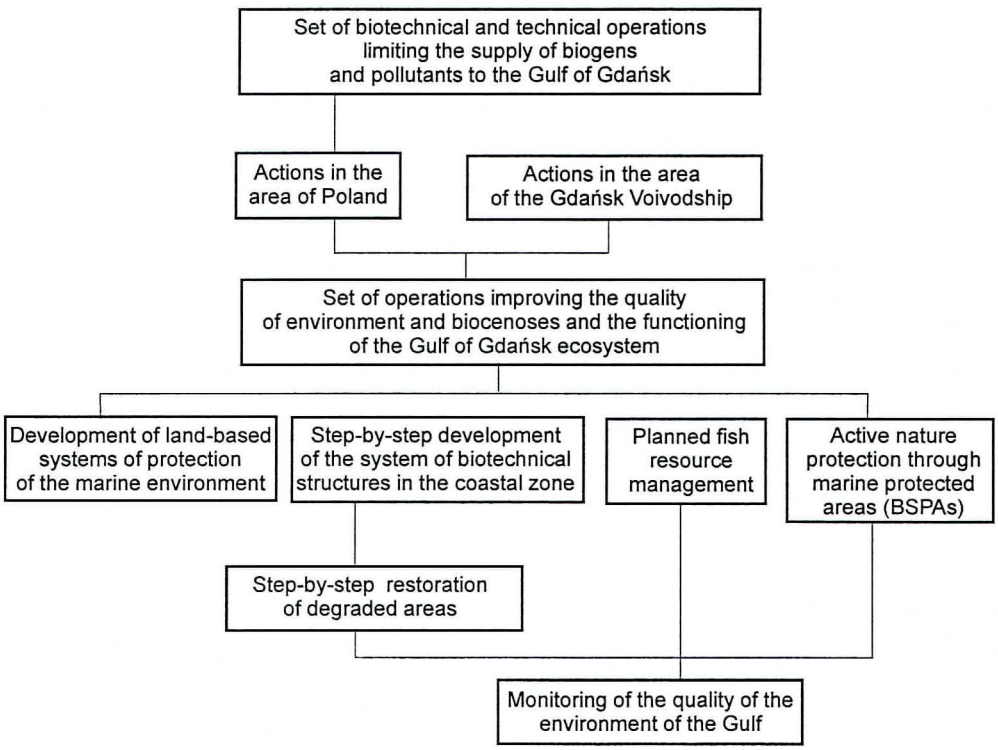

Fig.4. Basic elements of the system for protecting and restoring the biocenosis of the Gulf of Gdańsk

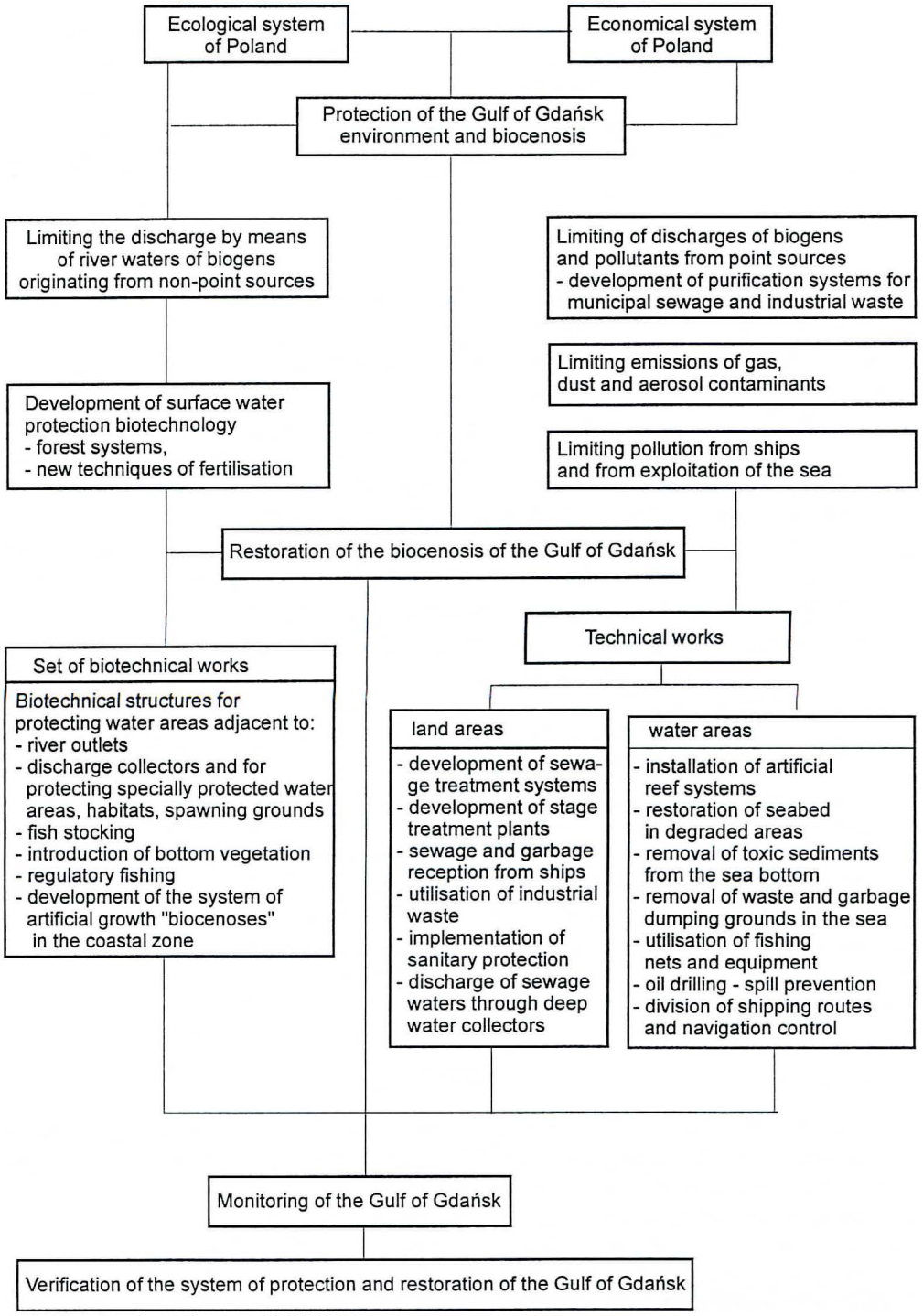

Fig.5. Diagram of the system of protection and restoration of the Gulf of Gdańsk biocenosis

- implementation of the developed at the Institute of Fishery progamme of renewal and restoration of fish resources in the Southern Baltic, therefore also in the Gulf of Gdańsk [15, 46];
- systematic implementation of the programme of functioning of active nature protection in marine protected areas - BSPA-HELCOM [Marine Biology Centre 1997, 25];
- installing a regional data bank for ecology, protection and renewal of the Gulf's biocenosis;
- development of the principles of conduct and of safety standards for sustainable management of the coastal zone.

In the framework of the main directions of the action programme there are numerous specific actions to be carried out. Among them are:

1. restoration by stages of the environment and of the biocenoses of the Gulf, which will cover the areas of river and stream outlets, waste water collectors, underwater collectors, bottom areas degraded after sand nourishment, garbage dumping grounds, and specially protected areas;
2. use of biotechnical, gradually introduced structures, i.e. of artificial reef systems in the coastal zone of the Gulf, in that in the regions of dumping grounds and river and collector outlets;
3. planned fish resource management, including such problems as methods of renewing spawning grounds and habitats of fishes, fish restocking of the water area, actualisation of fishing laws and decreasing illegal fishing, marking coastal areas in which, until bacterial and parasitic pollution is eliminated, fishing should be prohibited [16, 17];
4. in order that active nature protection in the designated marine protected areas may start functioning, an inventory and valorisation of these areas should be carried out, and the legal framework for nature protection in these areas must be developed and installed, and specific forms of protection and recultivation actions will have to be introduced;
5. development of the principles of conduct and of safety standards for sustainable management of the coastal zone (ICZM).

8. Summary

Degradation of the marine environment has been proceeding for many years, so the process of its restoration also will have to take some time. A distinct effect of improvement of the Gulf's environment may be expected after one or two years from the moment the system will begin to be implemented. This will depend on the efficiency of introducing the elements of the system. Realisation of some of the actions, such as modernisation or extension of sewage treatment plants, requires also high investment and time. Introduction of artificial reef systems is also divided into stages.

The introduction of artificial reefs and gradual decreasing of the supply of biogens into the Gulf will not result in an immediate improvement of the state of environment. However, this does not mean that no advantageous processes will proceed in the environment, enhancing processes of self-purification and regeneration of the biocenosis. Monitoring should provide information about all changes, and should form the basis for any corrections and improvements. After the elements of the system will become operative, the following positive changes in the functioning of the Gulf's ecosystem may be expected:

- intensification of self-purification processes in the regions of municipal waste discharge (due to artificial reefs and limiting the inflow of wastes);
- increased biodiversity - especially in presently degraded regions, such as municipal waste outlets;
- decrease of phytoplankton blooming, both due to decreased biogen supply, and to competition of macro-algae;
- growth of the fish population through providing advantageous habitats and spawning areas;
- elimination of bacterial and virus contamination in market fish, which will improve the attractiveness of the region for tourism;
- elimination of the contamination of waters and sediments, which will allow touristic utilisation of the Gulf and will allow to obtain profits, a part of which could be used for financing further actions.

The final implementation of the presented in this paper system for protecting and restoring the biocenosis of the Gulf of Gdańsk should provide measurable ecological and economical advantages for the Gdańsk region.

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