Bulletin of the Maritime Institute

Gdańsk, 1998, 25, 2

RAJMUND DUBRAWSKI
Department of Maritime Hydrotechnics
Maritime Institute, Gdańsk, Poland

LIDIA KRUK-DOWGIAŁŁO
Marine Biology Centre, PAS, Gdynia, Poland

ASSESSMENT OF THE RATE OF CHANGE OF THE BIOCENOSIS OF THE INNER PUCK BAY

Abstract

For decades, the biocenosis of the inner Puck Bay has been undergoing transformation, which probably at the break of the 60ties and 70ties took an ecologically disadvantageous turn. The negative processes which appeared at that time resulted both from eutrophication and anthropopression. Withdrawal of many animal and plant species was observed. The freed ecological niches were taken up by species which formerly appeared in small numbers. Significant changes of the biocenosis structure took place. In this paper, basing on the formula for the half-period of change, the rate of change of selected components of the ecological formations is calculated. Obtained results may allow to evaluate the processes disrupting the structure of biocenosis under the influence of long term eutrophication and anthropopression.

1. Introduction

The Puck Bay is one of the most often and best investigated water areas in the Polish coastal zone. However, only results of investigations carried out as late as the break of the 60ties and 70ties allow to attempt an assessment of the long term trends and rates of change of main components of the biocenosis.

For the evaluation of phytobenthos changes in the inner Puck Bay (the so-called Puck Lagoon), results of many authors from the years 1957-1996 were used.

The process of transformation of the phytocenosis of the Puck Lagoon was described by qualitative and quantitative investigations - changes of taxonomic composition, quantity of species and biomass [5, 8, 9, 10, 12, 13, 14, 19, 23, 25, 26, 27, 28, 29].

In the analysis of changes of phytobenthos structure, one should not forget about the industrial harvesting of *Furcellaria* in the years 1963-1973. Decision to use this species of algae for the production of agar-agar and algine substances was taken basing on assessments of its biomass [4]. During the exploitation, the quality of the harvested material and processes of regeneration of the algae was monitored [7, 30, 31, 35]. Results of the observations did not indicate that harvesting of *Furcellaria* may influence the future organisation and structure of phytocenosis of the Lagoon. However, it seems that the operation resulted in a significant weakening of the adaptive and biotic potential of the phytocenosis. In effect it was not able to survive through the sudden increase of eutrophication and poisoning of the environment during the second half of the 70ties.

For the evaluation of macro-zoobenthos changes, quantitative data obtained in the period 1962-1996 [1, 16, 17, 21, 34, 36, 37, 41] are used. Only a few works tried to evaluate the reasons of the changes of Puck Bay zoocenoses [22, 42]. Such an attempt was also made by Kotwicki et al. [11] and Wołowicz [38, 39] through investigations of the structure and dynamics of benthos complexes in the zone of discharges into the Bay from the sewage treatment plant at Swarzewo. The causes of the change of phytocenosis, and the influence of these changes on the biocenosis of the water area, also were assessed [14]. However, in this, as in all the other works, the rate of the negative changes was not determined. In effect it was not possible to evaluate the capacity for rebuilding of the biocenosis.

Ichthyofauna was also subjected to significant transformation. Basing on quantitative data concerning fish harvests [20, 32, 33], half periods of disappearance of selected fish species were calculated. It is assumed that the thesis that the stickleback (*Gasterosteus aculeatus*) has a negative influence on the development of the Puck Bay ichthyofauna [32, 33] is true. However, it is not confirmed by data on the biomass of this species. Such data would allow to determine the relationship between the disappearance of some fish species and the development of the formerly marginal stickleback.

Carried out in the past investigations of Puck Bay biocenosis provided quantitative data, basing on which it was possible to determine the half-periods of selected components. Obtained in this way indicators satisfactorily describe the process of biocenosis degradation, the extreme phase of which occurred in the period 1968-1979, and resulted in various disturbances in the next decades.

2. Methodology

Prediction of transformations of the biocenosis, or of its components, is a very complicated low probability task, and requires a database from long term monitoring. In the case of the Puck Bay biocenosis and of its components, phyto- and zoobenthos were investigated several times in the period 1957-1996. Though different methods of sampling and of analysing the results were used, nevertheless they form a data set which provides a chance to carry out some comparisons and gives a basis for predicting the possible transformation of the biocenosis of this water area. Using this platform, an attempt was made to determine the rate of phytobenthos, zoobenthos and ichthyofauna changes, i.e. of changes of these components of the biocenosis, for which quantitative indicators have been obtained in result of several consecutive investigations.

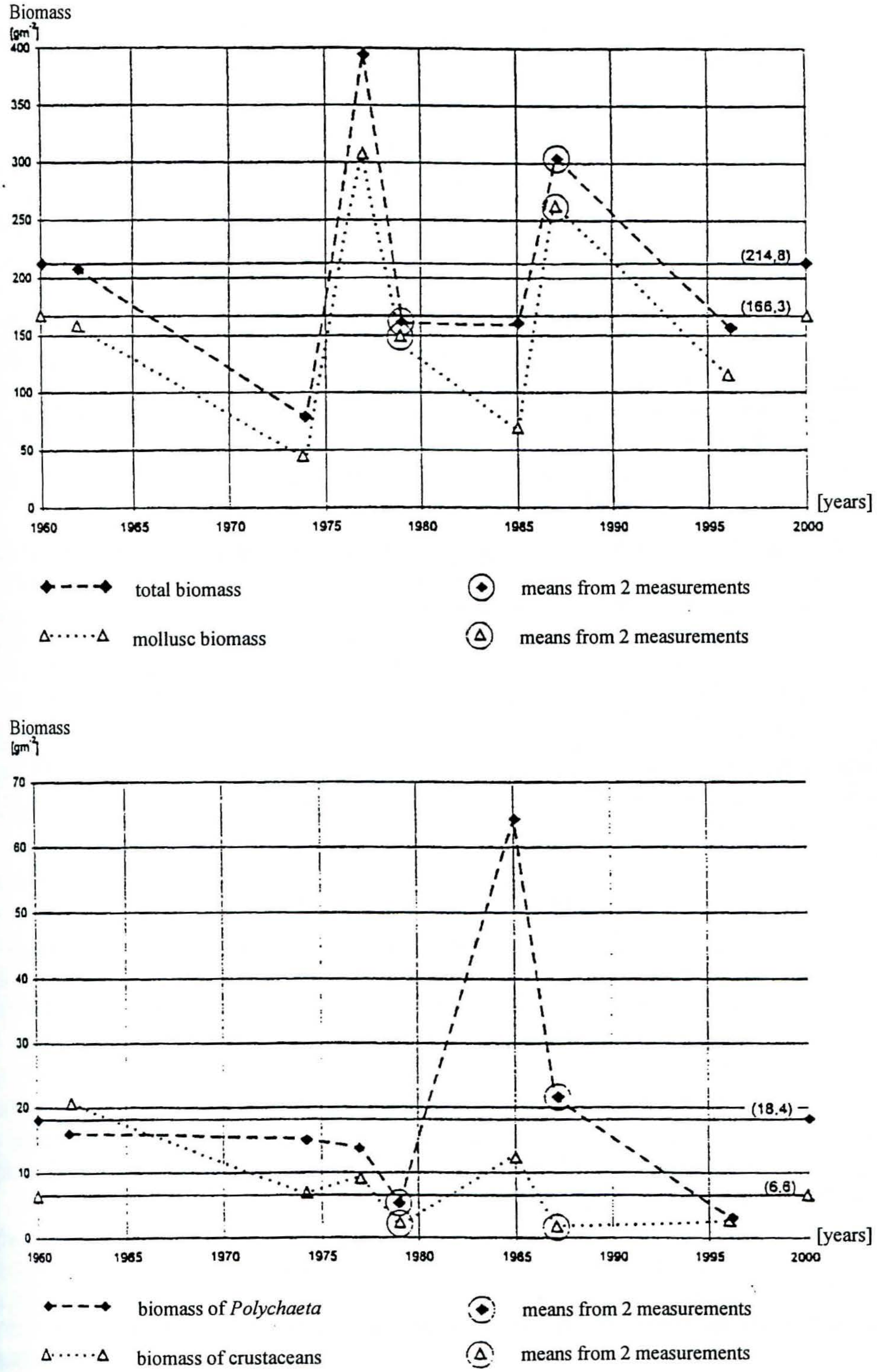

Fig.1. Changes in biomass of macro-zoobenthos and its components in the Puck Lagoon, period 1962-1996

In order to evaluate the rate of change of selected elements of the biocenosis, the formula for the half-period of transformation [24] was used:

$$T = \lg 2 \cdot \frac{t_1 - t_2}{\lg A_1 - \lg A_2}$$

t_1 - t_2 - period (years)

A_1, A_2 - quantitative indicators.

This formula allows to calculate the half-period of change T (in years) basing on the quantitative change of indicator A during the period t_1-t_2. It is assumed that these changes are either linear or exponential. Therefore, the formula is a simplification with respect to the e.g. oscillatory variability of the analysed parameters (biomass, number of taxons, etc.). Nevertheless, hitherto experience shows that the formula can be used as a relatively effective tool for evaluating the rate of change for periods of growth or decrease of analysed parameters of biocenosis [6].

Measurements show that the state of biomass of the phyto- and zoobenthos variability is of a pseudo-sinusoidal character (Fig. 1). Therefore the evaluation of the rate of change of the biomasses was possible only for periods with a stable trend. In a similar way were treated data on the per cent participation of mollusc, *Polychaeta*, crustacean biomass, and the obtained values of half-periods of change gave a satisfactory picture of the directions of reconstruction of the zoobenthos structure.

The half-period of change can be also calculated from the changes in time of the surface area of bottom populated by selected kinds of phytobenthos. Trends of some indicators were additionally determined basing on calculations of the coefficients of regression and correlation within the considered period of time.

3. Rate of change of phytobenthos

Observed in the period 1957-1996 changes in the taxonomic composition of phytobenthos of the Puck Lagoon resulted from partial or complete retreat of many species, which was connected with a reduction of their biomass, and therefore with the reduction of the total phytobenthos biomass, and with a decreased range of underwater meadows.

For the period 1935-1979, the half-period of disappearance of phytobenthos taxons was 53 years [2, 3]. This very high rate of disappearance probably points to a phenomenon known as anthropogenic extinction, however more data are required to confirm this hypothesis.

In the period 1957-1987, phytobenthos biomass decreased very quickly, the half-period of disappearance was about 10 years (Table 1), which directly confirms the growing influence of extra-environmental factors. Analysis of half-periods of change of biomass or of the decrease of areas of occurrence of phytobenthos shows, that they differ significantly for each of the taxons. For example, in case of sea-grass (in the period 1957-1987) the half-period of change (T) was about 13 years, but for *Potamogeton sp.* (in the period 1971-1979) it was only 4 years. For *Furcellaria* *lumbricalis* (period 1957-1984) and *Fucus vesiculosus* (period 1968-1979) it was 5 years. The shortest half-period was obtained for *Zannichellia palustris* (period 1977-1984), and it was only 1 year (Table 1).

The above data point to a very high rate of degradation of the Puck Bay area in the period 1957-1987. For the period of complete disappearance of *Fucus vesiculosus* (1968-1979), the half-period of decrease of *Furcellaria lumbricalis* was 1.1 years, and of sea grass - 4.9 years. These values confirm that destruction of the main species of the underwater meadows of the Puck Bay proceeded simultaneously, and that the disappearance of *Furcellaria lumbricalis*, until 1973 harvested on industrial scale, was of decidedly anthropogenic character. Calculations of half-periods of change of biomass or of change of area of habitation until 1966, showed similar trends as for the period 1957-1987. The values of half-periods of change indicate the decreases in production of the various phytobenthos species, show the differences in resistance of the species to the increasing trophics and toxicity of the environment. It is also possible that climatic factors had some influence on the changes, especially the heavy winters of 1969/1970 and 1979/1980, during which the Puck Bay was covered by ice for an exceptionally long time [18]. One of the reasons for the devastation of the phytocenoses and for the sudden disappearance of the remnants of *Fucus vesiculosus* and *Furcellaria lumbricalis* at the beginning of the 80ties could have been the discharge of waste water from Mechelinki under the ice cover and the long term decay of bottom sediments connected with oxygen deficit.

Without considering the biomass of *Pilayella* and *Ectocarpus*, the remaining biomass of phytobenthos after 1979 was only a tenth of the biomass present in the period 1957-1968. At the same time the biomass of the *Pilayella* and *Ectocarpus* decreased by a, and after 1979 they formed over 50% of the phytobenthos biomass and shaped the environmental and biocenotic conditions of the water basin.

After 1984 an increasing participation of *Pilayella* and *Ectocarpus* is observed, reaching the central part of the Bay up to 80% of the phytobenthos biomass. In the period 1979-1984, the half-period of change indicates brown algae biomass increases of 6 years, which confirms that they have taken a permanent position in the structure of Puck Bay biocenosis after anthropogenic destruction or pushing out of conventional competitors, such as *Furcellaria lumbricalis* and *Fucus vesiculosus*.

Carried in the years 1987-1996 investigations of the state of the Puck Bay phytobenthos show that the phytocenosis structure is markedly out of balance and that *Pilayella* and *Ectocarpus* predominate, while the productivity of phytobenthos is low and the biomass of multi-annual plants is limited - in that of the typical for the Puck Bay sea grass (*Zostera marina*).

Changes in the area of occurrence of plants, measured by the half-period of disappearance confirm that the original phytal system broke down by 1987, and the development of species which survived the period of catastrophe. In the period 1987-1996 the range of sea grass, especially *Zannichella palustris* increased. The position of *Pilayella* and *Ectocarpus* consolidated in the total biomass, though the biomass of the brown algae themselves significantly decreased - maybe due to the increased number of phytoplankton bloomings and depletion of phosphorus in the water. It may be also the result of self-limitation caused by the decrease of

Table 1. Half-periods of change of biomass and of the range of phytobenthos in the Puck Lagoon [3, 4, 8, 12, 15, 25, 26, 29]

Year of investigation	Biomass [thous.t mm]	Half-period of change [*T* - years]
	Total phytobenthos	
1957 (1)	65.0	
1968-71 (2)	84.0	
1977 (4)	17.6	3.3
1984 (5)	10.2	8.8
1987 (7)	12.5	10.6
1996 (8)	13.9	+26.8; -9.9
	Fucus vesiculosus	
1957 (1)	4.47	
1968 (3)	6.26	+2.26
1969-71 (2)	5.17	-10.0
1979 (6)	0	-1.6; -5.4
1984 (5)	0	
	Furcellaria lumbricalis	
1957 (1)	11.5	
1968 (3)	7.8	
1969-71 (2)	8.8	-35.4
1977 (4)	0.3	-1.4
1979 (6)	0.01	-1.4; -3.2
1984 (5)	0	-5.0
	Pilayella and Ectocarpus	
1977 (4)	6.1	
1984 (5)	13.6	+6.0
1996 (8)	6.99	-12.2

Year of investigation	Range of occurrence [km^2]	Half-period of change [*T* - years]
	Zostera marina	
1957 (1)	48.2	
1969-71 (2)	17.1	
1977 (4)	13.0	
1979 (6)	3.6	-1.0; -13.6
1984 (5)	18.5	+2.1
1987 (7)	1.3	
1996 (8)	6.3	+3.9; -7.7; -13.2
	Zannichella palustris	
1969-71 (2)	5.0	
1977 (4)	33.6	+3.2
1979 (6)	5.7	
1984 (5)	0.1	-1.0
1987 (7)	6.8	+0.5
1996 (8)	83.7	+1.2; +14.4
	Potamogeton sp.	
1969-71 (2)	38.5	
1977 (4)	11.7	-4.7
1979 (6)	6.7	-2.5; -3.7
1996 (8)	24.0	+9.2
	Pilayella and Ectocarpus	
1977 (4)	28.7	
1979 (6)	18.4	-3.1
1984 (5)	21.1	+2.5
1987 (7)	24.0	+20.8
1996 (8)	86.0	+4.8; +7.6

water transparency or of the toxic influence of products of decay of organic matter in bottom sediments. It seems that species which completely disappeared from the Puck Bay area will never return, because their habitats became destroyed, especially due to changed properties of the bottom surface and because their niches became taken up by the present dominants. The rates of disappearance of *Fucus vesiculosus* and *Furcellaria lumbricalis* were very high, clearly pointing to the cumulative negative influence of anthropogenic and environmental factors, stronger than the resistance of these species.

4. Rate of change of macro-zoobenthos

In the period of maximum eutrophication and restructuring of plant systems in the Puck Bay in the 70ties, a small (ca. 7%) decrease of zoobenthos biomass took place (Table 3). The development of bottom zoocenoses in the 80ties proceeded in different conditions (smaller eutrophication). The next decrease in zoobenthos biomass, observed in the 90ties, may be related with a periodicity in the development of zoocenoses, as well as from the influence of short term climatic changes at the beginning of the decade, which are manifested by a significant increase of water temperature.

The total biomass of zoobenthos of the Puck Lagoon depends mainly on the state of the mollusc biomass, the participation of which was ca. 77.5% in the period 1962-1996, reaching a maximum of about 90% at the end of the 70ties. The strong relationship between the mollusc biomass and the toatl zoobenthos biomass of the water area is confirmed by the high coefficient of correlation, equal to +0.976 (Table 2).

Table 2. Coefficients of regression and correlation between total biomass and biomass of the components of the Puck Lagoon, period 1962-1996

Investigated system (biomass a/biomass b)	Coefficients of regression		Coefficient of correlation	Significance of correlation
	a	b		
Total/*Mollusca*	-0.522	0.808	0.976	0.001
Total/ *Polychaeta*	-0.6534	0.077	0.809	0.01
Total/*Crustacea*	-	-	0.180	n.i.
Mollusca/Polychaeta	-5.914	0.092	0.803	0.01
Mollusca/Crustacea	-	-	-0.090	n.i.
Polychaeta/Crustacea	-	-	0.203	n.i.

The high coefficient of correlation points also to a dependence between the occurrence of molluscs and *Polychaeta* and the trophic state of environment (the nearbottom layer of water and bottom surface sediments). These organisms take up different niches and do not compete for food, and occur in largest numbers in regions intensely supplied by organic matter. The hitherto, long term loading of the Puck Bay sediment environment with organic matter has significantly decre-ased the biomass of *Polychaeta*. In the future, this may cause further reduction of this group and maybe also an invasive development of *Marenzellaria viridis*. The species has already become dominant over large areas of the Baltic coastal zone and in the Vistula Lagoon. This would be a continuation of the process of reduction of biodiversity and irreversible restructuring of the biocenosis of the water area. The increased trophy of near-bottom waters did not result in a reduction of mollusc biomass.

However, certain changes in the predominance of mollusc species were observed. Reasons of this phenomenon are yet to be defined, maybe the change is due to a cyclic variability of biotic potential of the species, which may become more distinct when environmental and anthropogenic disturbances are superposed. In the period 1968-1996, the biomass of crustaceans varied from 20.6 $gm.^{-2}$ (1962) to 0.3 gm^{-2} (1986-87), at an average of 6.6 gm^{-2} (Fig. 1). The half-period of disappearance was about 11 years which points to a significant rate of degradation of this group of animals. The calculated values of disappearance of *Polychaeta* and crustaceans for the period s of disappearance of *Furcellaria lumbricalis* and *Fucus vesiculosus* are 6.6 and 3.1 years respectively (Tables 3 and 4). These data confirm the significant relationships between the crustaceans and the phytal system of the water area. Destroying of the phytal system was the main cause of the reduction of the animals. This formation is the most change and most endangered zoobenthos group in the Puck Bay.

The biomass of *Polychaeta* varied in the period 1962-1996 between 2.8 gm^{-2} (1992) and 64.4 gm^{-2} (1984-85), and the average value was 18.4 gm^{-2}. In the period 1962-1977 the biomass of *Polychaeta* stayed at a relatively stable level of 13.8-16.2 gm^{-2}, and gradually decreased until 1996, showing however sudden large increases in 1984(5) and 1987. The general trend of *Polychaeta* biomass was negative, and for the analysed 30 year period the half-period of disappearance was T=-13.4 years. The good state of the food base of *Polychaeta* in the Puck Bay should facilitate the development of these animals however, the sudden intense development and the general negative trend show that the biocenosis is strongly out of balance and that a strong influence of extra-environmental factors is present. Changes in *Polychaeta* biomass were connected with changes in the total zoobenthos biomass and in the biomass of molluscs (Table 2) as the high values of coefficients of correlation show. The dynamics of the total zoobenthos biomass of the Puck Bay depend mainly on the changes of the predominant components - molluscs and *Polychaeta*, and the state of these is subjected to cyclic interelated variations. The level of development of both these groups of animals is shaped by the same factors, in effect their productivity and biotic potential reach extreme states at the same time. Due to the disappearance of crustaceans, the food bas of fish has become strongly reduced, which probably is one of the reasons for the changes in fish populations.

The half-periods of change (Table 3) show the rate of decrease of the biomass of total zoobenthos, molluscs, *Polychaeta* and crustaceans. The general trend of biomass change in the period 1962-1996 is negative, determined mainly by a slow reduction of mollusc biomass (T=72 years). In the same period the rate of decrease of *Polychaeta* and crustacean biomass was about 6 times larger (T=12 years). Half-periods of change calculated for similar sub-periods confirm the simultaneousness and synchronism of variations of the biomass of analysed zoobenthos components (Table 3).

Table 3. Half-periods of change of macro-zoobenthos biomass in the Puck Lagoon, during the period 1962-1996 [1, 16, 17, 21, 34, 36, 37, 40, 41]

Year of investigation	Biomass (g m^{-2})	Half-period of change (T - years)							
					Total				
1962-63 (1)	213.0								
1974 (2)	78.1	-8.3							
1977 (3)	395.2		+1.3						
1977-78 (4)	151.6								
1997-79 (5)	171.5								
1984-85 (6)	157.9			-6.0					
1986-87 (7)	214.7								
1987 (8)	396.0				+2.2			+10.2	
1996 (9)	156.8					-6.7	-14.2		-75.4
					Bivalvia				
1962-63	156.7								
1974	45.4	-6.6							
1977	308.0		+1.1						
1977-78	137.3								
1977-79	145.5								
1984-85	67.0			-3.6					
1986-87	193.4								
1987	332.8				+1.3			+4.4	
1996	113.6					-5.7	-13.1		-72.6
					Polychaeta				
1962-63	16.2								
1974	15.2								
1977	13.9								
1977-78	4.7	-8.3							
1977-79	6.2								
1984-85	64.4		+1.8						
1986-87	9.7			-0.7					
1987	33.0								
1996	2.8				-1.4	-2.5	-13.4		
					Crustacea				
1962-63	20.6								
1974	7.0								
1977	9.4								
1977-78	2.0								
1977-79	1.8	-4.8							
1984-85	12.9		+2.5						
1986-87	0.2			-0.3					
1987	3.2								
1996	2.6				+2.7	-5.1	-11.3		

Half-periods of change were also calculated basing on the percentage of participation of biomass of molluscs, *Polychaeta* and crustaceans in the total biomass of the water area. Results (Table 4) confirm that changes in the mollusc group proceed rather slowly, and that their maximum state was reached at the end of the 70ties. In the last decade (1987-1996), a distinct decrease of participation of mollusc biomass in the total biomass is apparent. The average participation of mollusc biomass was 77%, and was close to the initial value. Together with the decrease of participation of *Polychaeta* and crustacean biomasses, this confirms that degradation of other groups of zoobenthos organisms is progressing.

Table 4. Half-period of change of the percentage participation of mollusc, *Polychaeta* and crustacean biomass in the total zoobenthos biomass of the Puck Lagoon in the period 1968-1996 [1, 16, 17, 21, 34, 36, 37, 40, 41]

Year of inevstigation	Per cent participation in total biomass	Half-period of change (*T* - years)					
		Bivalvia					
1962-63 (1)	73.7						
1974 (2)	58.1	-3.1					
1977 (3)	77.9						
1977-78 (4)	90.6						
1977-79 (5)	90.0		+6.3				
1984-85 (6)	42.4			-6.4			
1986-87 (7)	90.1				+1.8		
1987 (8)	81.5						
1996 (9)	73.0					-4.0	
		Polychaeta					
1962-63	7.3						
1974	19.5	+8.5					
1977	3.5						
1977-78	3.1						
1977-79	3.8		-1.7				
1984-85	40.8			+2.0			
1986-87	4.5						
1987	8.4						
1966	1.8				-2.7	-16.7	
		Crustacea					
1962-63	6.1						
1974	9.0	+21.2					
1977	2.4						
1977-78	1.3						
1977-79	1.1		-1.0				
1984-85	6.1			+5.2			
1986-87	0.1						
1987	0.8				-1.0		
1996	1.7					-6.5	-18.5

The average participation of *Polychaeta* biomass was 10%, and in 1996 this participation decreased over 5 times. The same happened with the participation of crustacean biomass, the average value of which was 3.2%, and in 1996 it was over 2 times smaller. The values of half-periods of change of of the percentage participation of biomass of zoobenthos components provide a similarly good picture of the dynamics of biocenotic processes as the values for biomass change. At the same time they give a clearer description of the state of zoocenosis structure of the water basin and of the direction of its transformation.

5. Rate of change of ichthyofauna

Changes in the structure and areas of occurence of phytobenthos - underwater meadows - have largely influenced the habitat and spawning conditions for the fish in the Puck Lagoon. Fish from the stickleback family adapted themselves best to the new conditions, and their quantity started to grow systematically. On the other hand, quantities in other species decreased, because they were more vulnerable to anthropogenic influences, and also because they were destroyed by the sticklebacks which fed on their fry and spawn.

At the time when *Fucus vesiculosus* and *Furcellaria lumbricalis* suddenly retreated (Table 1), garfish and lavaret disappeared completely and perch, eel and pike numbers markedly decreased (Table 5). Formerly, this last species controlled the numbers of the sticklebacks, and when finally pike nearly completely disappeared (1982), stickleback attained an absolutely quantitatively predominant position in the Puck Bay ichthyofauna. Therefore, the basis for the observed changes in Puck Lagoon ichthyofauna was certainly the depletion of natural plant systems, and next the inter-species interactions and competition, which was won by the species best adapted to the new environmental conditions.

The kept up influence of anthropogenic factors and simultaneous increased competition resulted in retreat of many fish species, and the order in which the species retreated depended on the resistance of the species and on the magnitude of the biotic potential. These fish species which retreated earliest practically have no chance to return to the Bay, unless the existing environmental and biocenotic conditions change. Because of that, even intense stocking with fry cannot at present rebuild the initial herds of these fish species.

Table 5. Half-periods of decrease of fish catches in the Puck Bay [33]

Species	Period of investigations [years]	Size of catches [t/year]	Half-period of change [*T* - years]
Total catches	1978-1983	570-130	-4.7
Garfish (*Belone belone*)	1964-1974	45-0	-1.8
Pike (*Esox lucius*)	1972-1982	49-0	-1.8
Lavaret (*Coregonus lavaretus*)	1969-1974	4.5-0	-2.3
Perch (*Perca fluviatilis*)	1968-1980	43-0	-2.2
Roach (*Rutilus rutilus*)	1982-1987	190-0	-0.66
Eel (*Anquilla anquilla*)	1977-1978	7.5-2.5	-0.63

The discussed species disappeared from the Puck Lagoon very quickly (Table 5). In the period 1964-1987 completely disappeared: garfish ($T=1.8$), pike ($T=1.8$), perch ($T=2.2$), roach ($T=0.66$). Eel catches decreased by a factor of 3 in the years 1977-78 at $T=0.63$. These data point to catastrophic changes which took place in the Puck Bay in the period 1968-1979, and which started with the disappearance of *Fucus vesiculosus* and *Furcellaria lumbricalis*.

In the mid 70ties when the biomass of *Fucus* and *Furcellaria* decreased by about 60% (Table 1), the process of retreat of garfish and lavaret also began (Table 5). Together with the decreasing area of underwater meadows, the biomass of perch decreased to zero (1980). After *Fucus* and *Furcellaria* completely disappeared, the process of total destruction of the perch population started, certainly facilitated by the building of a fish-pass on the Płutnica river.

At the time when the pike population came close to zero, the process of reduction began in the roach herd, which practically disappeared during the period 1982-1987. One should look for reasons of lower eel catches in other conditions than just the ones which occur in the Puck Bay. It may be worth mentioning that catches of eels have decreased in all lagoons and coastal lakes, which may point to causes located outside the Baltic Sea.

6. Summary

After 1945, with the increasing eutrophication of the Puck Bay environment, its biocenosis was subjected to evolutionary and climatic changes, reaching within some components a close to climax state (rooted plants). In the initial stage of growth of eutrophication, toxication of the environment also caused increased biological production of the water area. After the limits of acceleration were exceeded, the phenomenon of selective slowing down of the development of vulnerable, low resistant species appeared. This was accompanied by the development of species characterised by a wide spectrum of adaptive capacities and highly resistant to anthropogenic influences. These resistant species survived the period of eutrophication and toxication and then started to predominate in the biomass of the Bay.

The process of disruption of the Puck Bay biocenosis was observed as early as the end of the 50ties, and it accelerated in the 70ties. This resulted in complete disappearance of *Fucus vesiculosus* (1968-1979) and *Furcellaria lumbricalis* (by 1984), and then indigenous species which formerly occurred only marginally started to develop. No new plant or animal species appeared, just some phyto- and zoobenthos and ichthyofauna species which all the time were present, but their biomass was small, started to predominate. Many rare species disappeared, and in effect the biodiversity of the water area decreased.

The influence of the specific conditions of the Bay and of the long term eutrophication and toxication finally shaped the now existing biocenosis. At present it is in a rather unstable state, which is proved by the phytoplankton blooms and massive appearances of plankton and benthos animal organisms. The biocenosis in its present form is resistant to the influence of the complex of factors which generated it. When these factors stop to act may cause further transformation. However, at the present level of knowledge about processes of degradation it is impossible to predict the direction of these changes.

As it has been already stressed, the degradative transformation of the Puck Bay biocenosis was initiated by the complete disappearance of *Fucus vesiculosus* and *Furcellaria lumbricalis*, and by a significant limitation of the area covered with sea grass (*Zostera marina*). In effect many other bottom plants and animals, and also fish species, disappeared, and the process proceeded very quickly (Fig. 2).

In the poor phytocenosis annual brown algae *Pilayella* and *Ectocarpus* and the relatively tough plant species typical for muddy bottom started to dominate. In the zoocenosis very large oscillations of total biomass and of the biomass of molluscs occurred, at a distinct predominance of these last. At the same time a significant decrease of *Polychaeta* and *Crustacea* biomass took place.

Limitation of habitat area, stronger competition of sticklebacks and also disappearance of crustaceans are the main reasons of the disappearance of many fish species. The half-period of disappearance of *Fucus vesiculosus* and *Furcellaria lumbricalis* was equal to about 5 years, and the process ended in the years 1979-1984. Since that moment native phytobenthos species (*Zannichella palustris*, *Potamogeton sp.*) started to develop at an average half-period of increase of about 10 years. The very quick rate of decrease of crustacean biomass (ca 11 years) should be stressed. This formation is most endangered and most difficult to rebuild, because the initial phytal system has been destroyed. A large number of fish species has also disappeared, and the rate at which this process progressed was very high, ranging between 0.6 years (roach, eel) and 2 years (garfish, pike, lavaret, perch). Due to the deep and violent changes in the Puck Lagoon biocenosis in the 70ties, the present structure and organisation are very significantly different from what they were in the initial stage. Chances for rebuilding the former rich and very diversified biocenosis of the Puck Lagoon are steadily becoming smaller because of the deep negative changes of the bottom sediment environment in that water area and because the existing biocenosis becomes stabilised. The use of the half-period of change (increase/decrease) for evaluating the transformation of the components of Puck Lagoon biocenosis, allowed to determine the rate at which these changes proceed, and to determine the basis for predicting developments.

One of the conclusions to be drawn from the analysis of realised investigations of Puck Lagoon biocenosis is that a comprehensive system of biological monitoring should be developed, which would take into account the basic, generally accepted quantitative indicators of the state of the biocenosis and its components, and of the relationships between the main groups of hydrobionts of the Puck Lagoon area.

Presented in this paper half-periods of change support this conclusion, since there is a high level of agreement of the rates of change between the plant and animal systems in comparable periods of investigation.

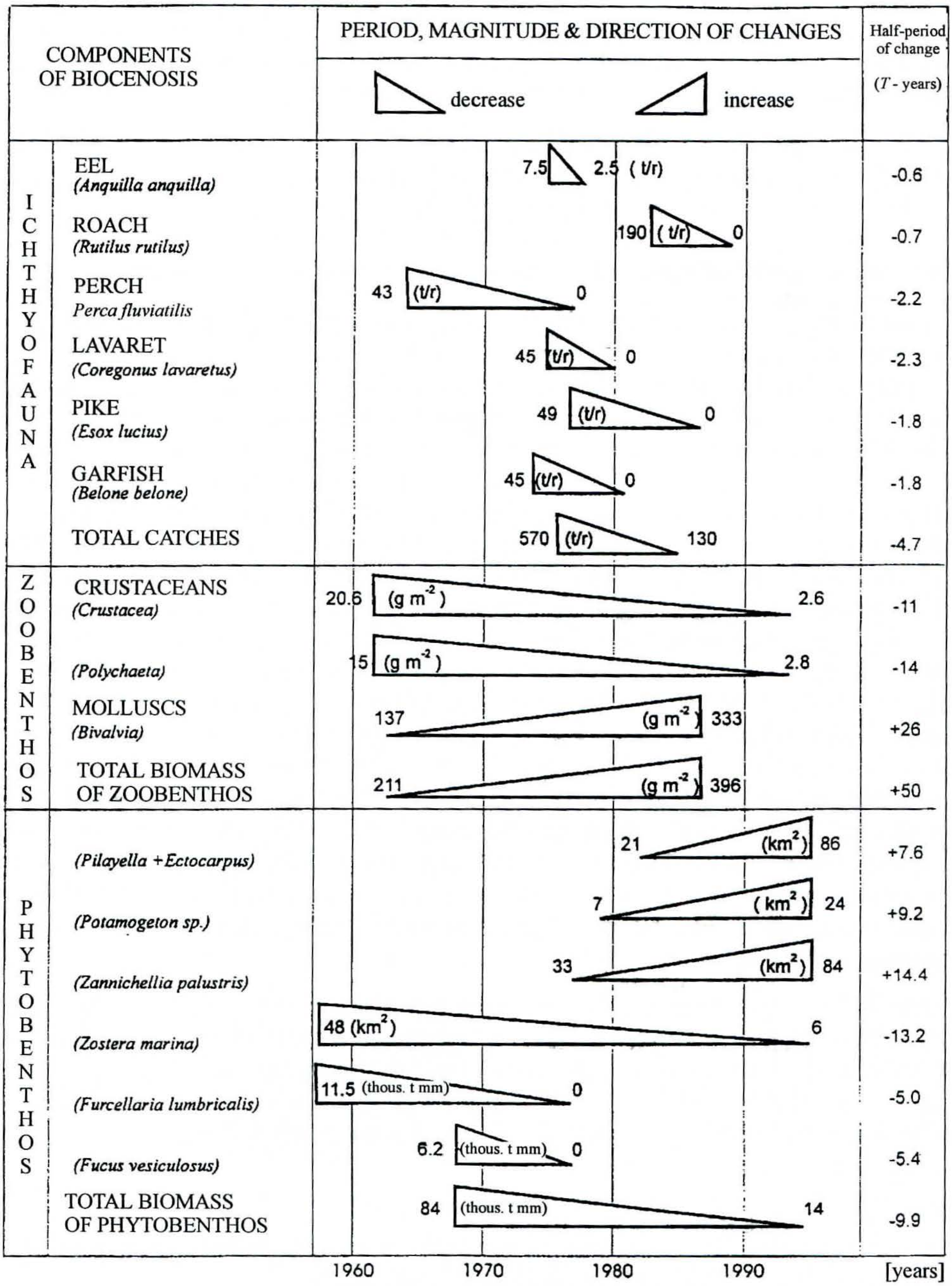

Fig.2. Diagram of biocenotic changes in the Puck Lagoon, period 1957-1996

Literature

[1] Błędzki L., Kruk-Dowgiałło L., 1983, *Multiannual changes in the structure of Puck Bay benthos*, "Człowiek i Środowisko" 7/1-2. (In Polish).

[2] Bursa A., 1935, *Settked algae in Polish Baltic coastal waters*. Bull Acad. Sc. Lettres. Ser. B. Sc.nat (1). (In Polish).

[3] Ciszewski P., Ciszewska I., Kruk-Dowgiałło L., Błędzki L., 1979, 1980, *A study on the shaping of the natural environment of the Coastal Landscape Park*, Parts I & II. Prace IKŚ. Gdańsk. (In Polish).

[4] Ciszewski P., Demel K., Ringer Z., Szatybełko M., 1962, *Resources of Furcellaria lumbricalis in the Puck Bay, evaluated by free diving*, Prace MIR 11A. (In Polish).

[5] Ciszewski P. et al., 1992; *Trends of long-term alternations of the Puck Bay ecosystem*. Stud. i Mater. Ocean 60. Biologia Morza 8.

[6] Dubrawski R., 1992, *Characteristic of environment degradation processes in the Puck Bay and main directions of ecological investigations aiming at recultivation of the Bay,* Bull. Mar. Inst. Vol. 19 No. 2.

[7] Kentzer T., Borowczyk E., Szczepkowska E., 1976, *Increase of algae under influence of pollution of the Baltic Sea*, Stud. i Mat. Ocean. No. 15. (In Polish).

[8] Klekot L., 1980, *Qualitative investigations of the underwater meadows of the Puck Bay,* "Oceanologia" No. 12. (In Polish).

[9] Kornaś J., 1957, *Bottom vegetation of the Polish part of the Baltic Sea - state of investigations and propositions of their development,* Wiad. Bot. t. I, A. (In Polish).

[10] Kornaś, J., Medwecka-Kornaś A., 1948, *Underwater plant systems of the Gulf of Gdańsk,* PAU. Rozpr. Wydz. Mat.-Przyr. 73B. (in Polish).

[11] Kotwicki S., Miłosek A., Szymelfenig M., Witkowski A., Wołowicz M., 1993, *The structure and dynamics of benthos systems in the coastal zone in the neighbourhood of the sewage treatment plant at Swarzewo*, Arch. Ochr. Środ., No. 3-4.

[12] Kruk-Dowgiałło L., 1991, *Long-term changes in the structure of underwater meadows in the Puck Lagoon*, Proc. 11th BMB [in:] Acta Icht. Et Pisc. Suppl. XXI.

[13] Kruk-Dowgiałło L., 1994, *Distribution and biomass of phytobenthos in the Puck Lagoon, summer 1987* [in:] *Puck Bay - chances for restoration,* IOŚ ,Warszawa. (In Polish).

[14] Kruk-Dowgiałło L., 1994b, *Causes of changes in the structure of bottom vegetation in the Puck Bay and possibilities of controlling the vegetation* [in:] *Problems of protection of the natural environment of the Baltic Sea and coastal areas,* IOŚ, Warszawa. (In Polish).

[15] Kruk-Dowgiałło L., Dubrawski R., 1998, *The Gulf of Gdańsk. State of environment in 1994 and 1995*, IOŚ, Warszawa (in printing). (In Polish).

[16] Legeżyńska E., 1988, *Zoobenthos*, Inst. Ocean. Gdańsk Univ. (manuscript). (In Polish).

[17] Legeżyńska E., Wiktor K., 1981, *Bottom fauna of the Puck Bay proper,* Zesz. Nauk. Gdańsk Univ., ser. Oceanografia 8. (In Polish).

[18] Majewski A., 1987, *Characteristic of watres* [in:] *Southern Baltic,* Ed. B. Augustyński. Wyd. PAN, Wrocław. (In Polish).

[19] Medwecka-Kornaś A., 1951, *Plant systems in the marine environment,* "Wszechświat" 8-9. (In Polish).

[20] Morawski M.S. , 1982, *Changes in the structure of ichthyofauna in the coastal waters of the Gulf of Gdańsk in the period 1964-1979,* Stud. i Mat. Ocean. 39, Biologia Morza 6. (In Polish).

[21] Osowiecki A., 1994, *Distribution and biomass of macro-zoobenthos of the Puck Lagoon, Summer 1987* [in:] *Puck Bay. Possibilities of restoration,* IOŚ, Warszawa. (In Polish).

[22] Ostrowski J., 1985, *Influence of pollution on the zoobenthos of the Gulf of Gdańsk, with special attention given to indicator species,* Studia MIR, t. 26. (In Polish).

[23] Piasecki D., 1979, *Degradation and restoration of the Puck Bay* [in:] Reports of the Committee of Marine Res. Polish Ac. of Sci. (In Polish).

[24] Piotrowski J., 1971, *The application of metabolic and excretion kinetics to problems of industrial toxicology.* Washington.

[25] Pliński M., 1982, *Distribution and biomass of the Puck Lagoon phytobenthos,* Stud. i Mat. Ocean. 39. Biologia Morza 6. (In Polish).

[26] Pliński M., 1986, *Changes in the quantitative and qualitative composition of the Puck Bay phytobenthos in the period 1977-1984,* Zesz. Nauk. UG. Oceanografia 12. (In Polish).

[27] Pliński M., Florczyk I., Manasterska M., 1989, *Long term changes in the composition of phytobenthos from the Gulf of Gdańsk (Southern Baltic).* Proceedings of the 21st EMBS. "Oceanologia", PAN IO, Gdańsk 14-19 Sept.

[28] Pliński, M., Wiktor K., 1987, *Contemporary changes in coastal biocenoses of the Gdańsk Bay (South Baltic).* Pol. Arch. Hydrobiol. 34, 1.

[29] Przybyłek R., 1968, *Investigations on the methods of restoring marine plants (Fucus vesiculosus and Furcellaria lumbricalis) in the Puck Bay, including methods of their reproduction,* KZSR OR in Gdynia 14/18-ZZ/68, Part I (manuscript). (In Polish).

[30] Przybyłek R., 1969, *Investigations on the methods of restoring marine plants (Fucus vesiculosus* and *Furcellaria lumbricalis) in the Puck Bay, including methods of their reproduction,* KZSR OR in Gdynia W.ZZ-9/69, Part II (manuscript). (In Polish).

[31] Siedler W., 1969, *An attempt at evaluating the composition and biomass of bottom vegetation of the Puck Bay,* "Technika i Gospodarka Morsk"a, R 19. (In Polish).

[32] Skóra K. E., 1992, *Fishery* [in:] *Marine pollution.* Stud. iMat. Oceanol. KBN PAN 61. (In Polish).