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A STUDY ON POLLUTION OF THE PUCK LAGOON AND POSSIBILITY OF RESTORING THE LAGOON'S ORIGINAL ECOLOGICAL STATE

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The main aim of the study was to identify mechanisms causing degradation of the Puck Lagoon's primary environment and to suggest some remedial measures and techniques for its restoration, apart from the newly installed sewage treatment plant near Puck.

Results of the study demonstrate an excessive seasonal development of filamentous brown algae of the family Ectocarpaceae. This excessive growth on the bottom of the Lagoon plays a significant role in eliminating nutrients from the water, limiting the vernal development of plankton, and considerably increasing water transparency, but strongly affecting living conditions of the original benthic macrophytes. In late summer, the brown algae biomass undergoes rapid decomposition and enriches the sediment with organic matter. Sediment analyses revealed no excessive concentration of heavy metals or organic contaminants, their concentrations being usually proportional to the organic matter content.

Experimental seeding of vascular plants and observations on assemblages of sessile fauna and flora indicate that reintroduction of original species and deployment of artificial reefs is feasible and purposeful.

INTRODUCTION

The Puck Lagoon, covering about 104 km^2, is the shallowest, western part of the Gulf of Gdańsk (Figs 1 and 2).

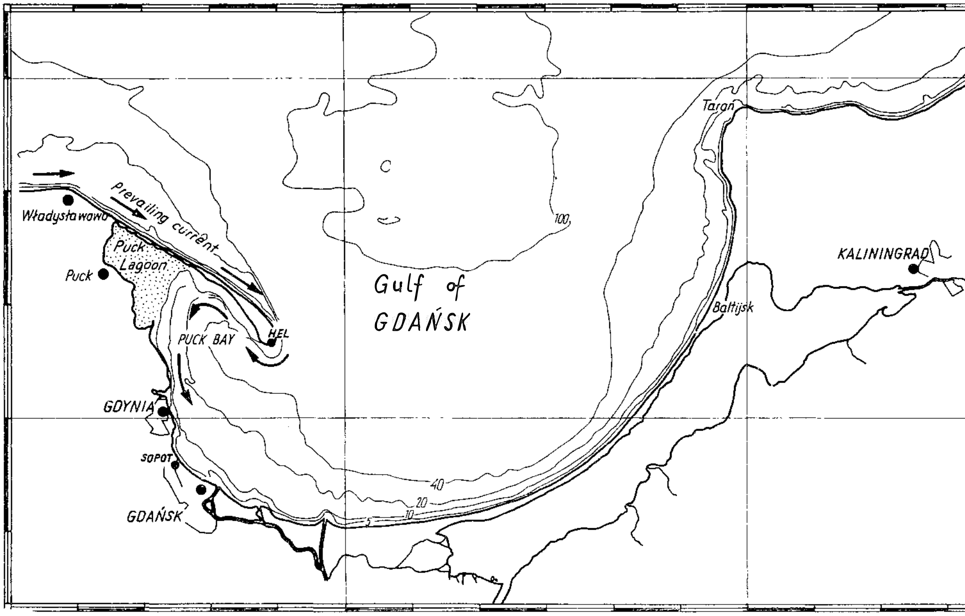

Fig. 1. Location of the study area

The Lagoon is separated from the remainder of the Gulf by an elongated sand bank called the Ryf Mew (Fig. 2) which comes up to the water surface at some locations. The Lagoon's average depth is about 3 m; water exchange with the Gulf of Gdańsk is restricted by the sand bank mentioned.

Until early 1970s, the Puck Lagoon had been an attractive natural environment, a fishing ground, and a tourist attraction. Its bottom was covered with underwater meadows inhabited by an abundant and diverse marine fauna, unique along the Southern Baltic coast (Klekot 1980; Kompowski 1965a, 1965b; Netzel 1963; Romański 1965; Strzyżewska 1969; Żmudziński 1967). The first Polish quantitative marine biological studies were carried out in the Lagoon by Kornaś and Medwiecka-Kornaś (1948), Wojtusiak et al. (1950), and Ciszewski et al. (1962).

Since mid-70s, the Puck Lagoon environment has been subject to continuous unfavourable changes (Błędzki and Kruk-Dowgiałło 1983; Kruk-Dowgiałło unpubl. manuscript; Legeżyńska and Wiktor 1981; Morawski 1982; Pliński 1982, 1986; Pliński and Wiktor 1987; Wenne and Wiktor 1982) which resulted in:

- a mass development of the filamentous brown algae *Pilayella litorralis* Kjellm. and *Ectocarpus sp.;*
- a disappearance of the following two plant species dominant in the area: *Fucus vesiculosus* L. and *Furcellaria lumbricalis* Huds. Lamour.:

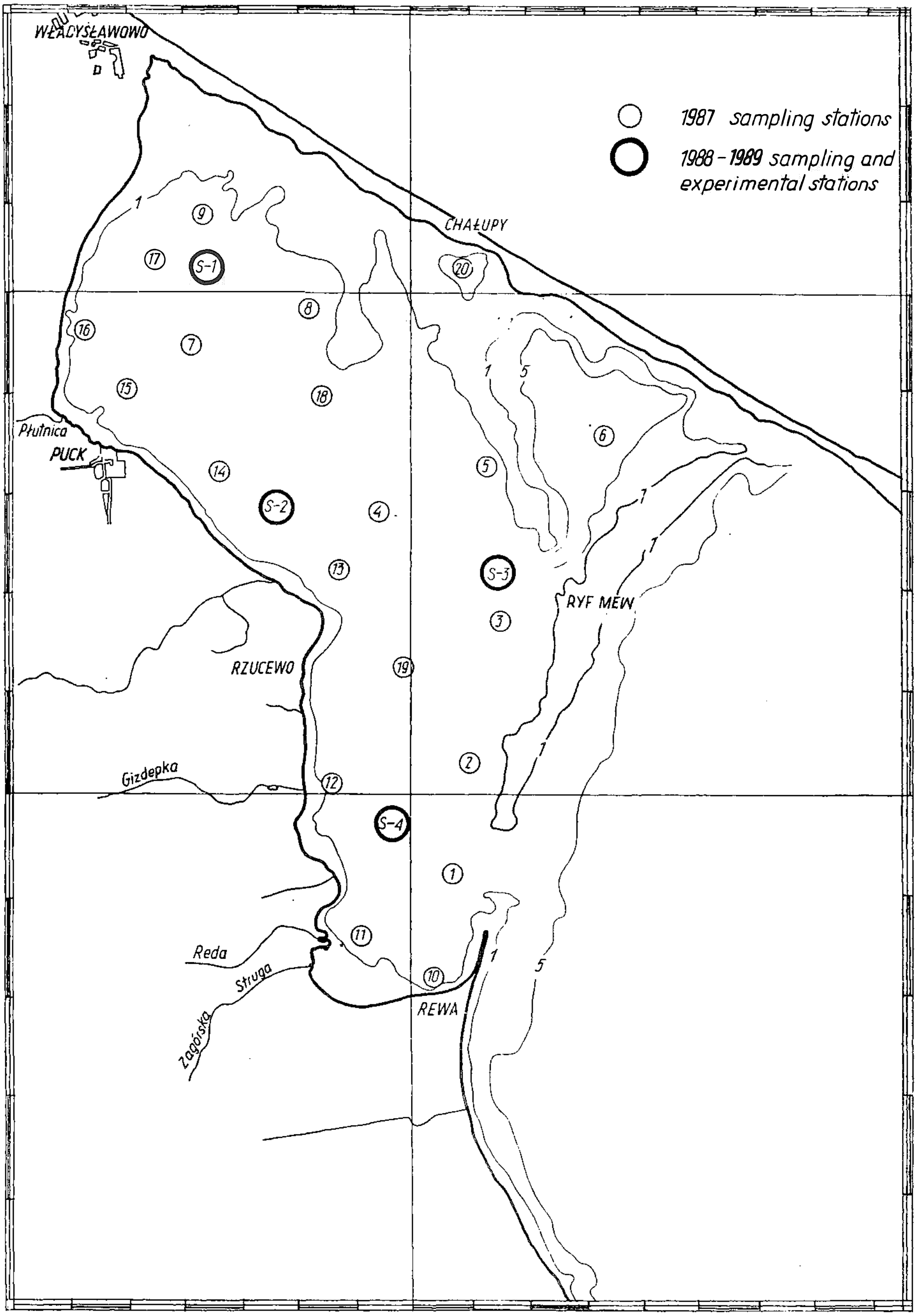

Fig. 2. Location of sampling stations in the Puck Lagoon

- a significant reduction of the natural habitat of vascular plants (*Cormophyta*) and the almost total depletion of *Zostera marina* L.;
- distinct structural changes in the bottom fauna: an increase in the abundance and biomass of the Bivalvia and Polychaeta on the one hand, and a decrease in the abundance and biomass of the Crustacea and Gastropoda on the other;
- a deterioration of spawning conditions for the most important commercial fish species: *Perca fluviatilis* L., *Rutilus rutilus* L., *Coregonus lavaretus* L., *Abramis brama* L., *Belone belone* L.;
- a significant reduction in abundances of some of non-commercial fish species: *Nerophis ophidion* L., *Syngnathus typhle* L., *Spinachia spinachia* L., and *Pungitius pungitius* L., and the concurrent mass occurrence of *Gasterosteus aculeatus* L.;
- an increased bacterial contamination of anthropogenous origin;
- mass mortality of the eel and flatfish in the '80s.

Many explanations have been invoked as to the causes of such drastic negative changes; some of them point to a single cause, e.g. trace metals or an organic poison, but nearly all the changes have had an anthropogenous origin.

The studies presented, coordinated by the Department of Water Ecology, Institute of Environment Protection, and undertaken after a sewage treatment plant had been installed near Puck, are aimed at describing the current state of the Lagoon to identify the mechanism of degradation and to work out a multi-faceted plan of ecotechnological measures such that would make a fast restoration of the Lagoon's original environment possible.

The work was carried out at two stages:

1. A study on the current condition of the biocoenosis and the extent of pollution in the Puck Lagoon (1987);
2. A study on the mechanism of environmental degradation and an experimental approach towards restoration of the original biocoenosis (1988–1989).

As the work was interdisciplinary in its character, the following institutions were involved in additional tasks: Institute of Oceanology of the Polish Academy of Sciences, Sopot; Institute of Meteorology and Water Management, Maritime Branch, Gdynia; Medical Academy, Gdańsk; State Geological Institute, Sopot; N. Copernicus University, Toruń; Veterinary Hygaene Research Station, Gdańsk.

MATERIALS AND METHODS

In 1987, samples were collected from 18 monitoring stations (Fig. 2) with the aim to describe the biotic and abiotic environmental factors in the Puck Lagoon at the time. The following parameters were measured or estimated: temperature; water transparency; dissolved oxygen and nutrients; fallout of pollutants from the atmosphere; trace metals in water, sediments, and in marine organisms; aromatic fraction content in sediment; chlorophyll *a*; phyto- and zooplankton; phyto- and zoobenthos.

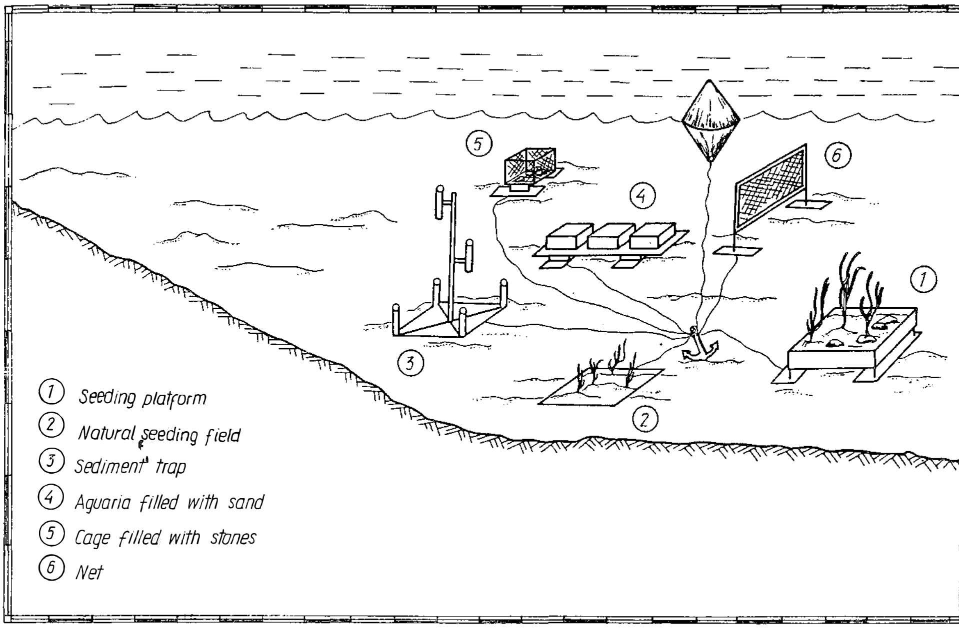

Fig. 3. Experimental constructions installed on the Puck Lagoon bottom

In 1988, the sampling programme was limited to 4 stations (Fig. 2) and included not only the temperature, water transparency, dissolved oxygen and nutrients, but also redox potential; pH; trace metals in water, sediment, and marine organisms; fallout of pollutants from the atmosphere; aromatic fraction content in sediments; and bacteria. The generally applied methods of measurements and assays were employed.

Apart from the measurements listed above, a number of experiments were carried out. At the beginning of the growth season, the following objects were placed on the bottom of the Puck Lagoon (Fig. 3):

- sand-filled platforms seeded with vascular plants (*Zostera marina, Potamogeton perfoliatus* L., and *Zannichellia palustris* L.);
- stones with attached algae (*Cladophora* sp., *Enteromorpha* sp., *Furcellaria lumbricalis*);
- sand-filled aquaria to estimate the rate of colonization by marine fauna;
- sediment traps to estimate the rate of organic matter sedimentation;
- netting-covered rectangles to estimate the colonization rate by marine organisms.

The constructions made of stones, timber, netting, metal, and glass served to estimate the extent and rate of sessile fauna and flora growth.

Four experimental stations were monitored, the methods used involving sampling and underwater observations performed by divers.

RESULTS AND DISCUSSION

Results of measurements carried out in 1987 portray the hydrochemical conditions of the Puck Lagoon (Table 1). Typical seasonal changes of water temperature, with characteristic small differences between the surface and bottom layers (up to 1°C at most) were revealed. Water transparency remained good (4–5 m, that is generally down to the bottom) throughout the entire growth season. Water oxygenation from May until October varied from 90 to 127% in the surface layer and from 70 to 125% near the bottom (Andrulewicz unpubl. manuscript).

Table 1

Average nutrient concentrations (μmol/dm^3) in the Puck Lagoon water (June—October 1987) (after Andrulewicz unpubl. manuscript)

	Surface	Bottom
P_{tot}	0.97	0.92
PO_4-P	0.22	0.27
P_{org}	0.76	0.65
N_{tot}	13.50	10.09
NO_3-N	0.35	0.43
NO_2-N	0.13	0.16
NH_4-N	0.39	0.55
N_{org}	9.69	9.08

In 1988, chemical assays of the water column yielded data similar to those of the preceding year: water transparency was generally good and nutrient concentrations were relatively low in comparison with those in the Gulf of Gdańsk or the open. Baltic (Andrulewicz unpubl. manuscript).

Divers observed an excessively high production of the Ectocarpaceae in the Puck Lagoon (Andrulewicz, unpubl. manuscript; Ciszewski unpubl. manuscript).

In March and April, when the water temperature rose to about 8°C, 40–80% of the Puck Lagoon bottom were usually covered with an about 10-cm thick layer of the Ectocarpaceae. In June/July, the Ectocarpaceae usually withered and gradually decomposed owing to favourable oxygen conditions in the near-bottom water layer. At the end of this period, the Ectocarpaceae layer was deposited in the form of a dark 1-cm thick sediment layer. In September, almost the entire Ectocarpaceae biomass usually decomposed and formed a very thin deposit in the upper part of the bottom sediment, some of the material penetrating deeper in the sediment.

Sediment analyses (Pempkowiak unpubl. manuscript; Szefer et al. unpubl. manuscript) showed a rather low heavy metal content, proportional to the organic matter content. The levels of some heavy metals detected in selected organisms from thePuck Lagoon are presented in Table 2.

Table 2

Average heavy metal contents (μg/g dry weight) in selected organisms from the Puck Lagoon (after Szefer et al. unpubl. manuscript)

Metal	*Pillayella littoralis*	*Zostera marina*	*Mytilus* 15–20 mm	*edulis* 25–30 mm
Cobalt	3.0	0.7	1.0	1.0
Cadmium	2.0	1.1	3.4	4.8
Nickel	7.1	1.6	9,0	5.3
Lead	13.1	3.5	3.9	3.4
Copper	6.8	6.1	21.7	20.0
Zinc	122.0	116.0	268.0	274.0

Concentrations of aromatic compounds in sediments were not very high and were proportional to the organic matter content.

Generally, the Puck Lagoon has a relatively high suspended matter sedimentation rate (an average of 5–15 g/m^2d during the period of study). Sedimentation was more intensive in the southern part of the Lagoon. Sediments in the southern part were found to contain higher amounts of organic matter, trace metals, and aromatic fractions.

Values of pH were higher on the artificial bottom (7.45–7.74) than on the natural one (7.20–7.30). Eh values varied considerably: from −300 to −200 mV on the natural bottom and from +80 to −120 mV on the artificial one (Andrulewicz unpubl. manuscript). The values indicate that the conditions of the platforms deployed (artificial bottom) and on the natural bottom of the Lagoon were markedly different.

Microbiological examination of water and sediments at the sites of experiments showed the genera *Pseudomonas* and *Aeromonas,* fish pathogenes, to be the dominating population (Grawiński et al., unpubl., manuscript).

Intensive fouling by sessile fauna on all the objects deployed was particularly pronounced in the southern part of the Lagoon (Ciszewska unpubl. manuscript). Stones were the most intensely fouled objects. *Mytilus edulis* grew best on any stone substrata, whereas *Balanus improvisus* preferred iron substrata and *Electra crustulenta* showed a preference to netting and metal objects.

An experiment involving seeding of a few vascular plant species on sand-filled platforms placed on the bottom of the Puck Lagoon was aimed at finding out if any possibility of restoring the primary state of underwater meadows in the basin existed. The results obtained reveal that only one of the 13 specimens planted failed to develop during the 118-day experiment (June – October 1988). *Zostera marina* grew best on all the experimental platforms and increased by 13 internodes on the average, which equals to 2.3 internodes per a single 30-day period. *Z. marina* did not occur on the natural bottom in that area of the Lagoon. *Zannichellia palustris* and *Potamogeton perfoliatus* grew equally well on the experimental platforms, the latter species producing some winter buds at the end of the growth period (in October). Although growth of those plants on the natural bottom was affected by the Ectocarpaceae, seeding activities in the shallower (less than 1.5 m depth) parts of the Lagoon produced encouraging results.

CONCLUSIONS

1. The studies of the Puck Lagoon described revealed its high water transparency, low nutrient contents in water, and low concentrations of trace metals in sediments and water. Concentrations of Cd, Mn, and Ni in aquatic animals and plants did not show significant variations within the last 10 years. *Pilayella littoralis,* a brown alga of the family Ectocarpaceae, is likely to be the major biotic factor responsible for the Puck Lagoon degradation.

2. The very intensive development of the Ectocarpaceae affects other components of the biocoenosis of the area investigated. The Ectocarpaceae growth causes nutrient depletion and prevents algal blooms in the water column, which is a positive effect. The intensive growth of the *Ectocarpaceae* has also a negative impact on the phytobenthos as the algae cover the vascular plants (*Cormophyta*) and form a thick thallus layer on the bottom, thus hindering photosynthesis by restricting light penetration. They may also interfere with fish spawning, and – after the fry have hatched – may inhibit the latter's migration to the water column. Decomposition of the algae has enriched the formerly sandy bottom with organic matter, which has its consequences in the quantitative and qualitative parameters of the zoobenthos.

3. To assist in restoration of the Puck Lagoon's environment, a number of remedial measures are suggested, e.g.:

– setting up experimental fields located in some areas of the bottom and seeding them with vascular plants. These experimental fields introduced initially in small areas would then gradually spread. Since the vascular plants propagate rapidly, the seedlings can be spaced widely apart;

– intensification of natural reproduction of commercial fish species by providing artificial spawning areas (fascine reefs, strips of seeded bottom) and artificial stocking.

4. Certain biological and chemical processes taking place in the Puck Lagoon point to its potential for recovery when assisted by some biotechnological activities.

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