



An expert judgement approach to designating ecosystem typology and assessing the health of the Gulf of Gdansk

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Abstract

The Gulf of Gdansk is comprised of a number of different hydro-geo-morphological regimes that represent different ecosystem units - lagoons, bays, river mouths, and sheltered and open coastal areas. Several classifications of the Gulf of Gdansk exist and most of them are based on morphological and/or hydrological parameters (salinity, temperature, nutrients). The classification proposed in this paper places stress on the morphology and dynamics of water masses and thus on bottom sediments.

The Gulf of Gdansk is subjected to different rates of anthropogenic pressure; this means that environmental quality status varies in the different parts of the coast. The following parameters were used in the quality assessments of different hydro-geo-morphological units of the Gulf of Gdansk: 1) sanitary conditions - number of coliform bacteria in a pre-determined volume of water, 2) phytoplankton - species composition, abundance and biomass, 3) macroalgae and angiosperm - species composition and biomass, 4) macrozoobenthos - species richness, composition and biomass, 5) ichthyofauna - information compiled from various sources in the literature, 6) basic hydrographic and hydro-chemical conditions - Secchi depth, temperature, salinity and oxygen.

The quality status of different environmental units, assessed according to criteria proposed by the Water Framework Directive, versus the selected reference period of the 1950s, is assessed in four quality ranges (bad, poor, moderate, and good). This is assuming, as the present authors believe, that high status, which is due to excessive eutrophication, does not exist, even for open Baltic Sea water masses.

1 Introduction

The area selected for identifying natural sub-systems and describing their quality status is the diverse and complex ecosystem of the Gulf of Gdansk. This area has been divided into several sub-systems according to morphology and dynamics. These sub-systems are also considered as “managerial units” where specific action should be taken to combat anthropogenic pressure.

Environmental quality assessment is traditionally based on physical, chemical, and biological parameters. It is usually assessed within administrative borders, and has often not recognized natural borders within the selected ecosystem. This approach is changed significantly in the EU WFD (2000), which requires that natural boundaries should be recognized. The EU WFD also stipulates that ecosystem quality assessments have to be based on measurements of the status of phytoplankton, macrophytobenthos, macrozoobenthos and ichthyofauna. The authors of the current paper also included sanitary conditions of coastal, bathing waters. Sanitary conditions are unsatisfactory in many polluted river mouths in the Baltic and in some areas close to ports and at sewage discharges. This is the biggest concern of both coastal communities and local authorities.

In the authors' opinion, the desired level of ecosystem quality should be the environmental status of the Baltic Sea from the pre-industrial period. Essentially, this refers to the period before the intense development of industry and the advent of agriculture supported by chemical fertilizers, pesticides and herbicides. The prevailing opinion is that this level of environmental quality existed from the time

soon before World War II or even soon after it. Subsequently, the authors propose the 1950s as the reference period. This proposal is supported by other important arguments such as ‘human memories’ of a clean marine environment and a good body of knowledge regarding the Baltic Sea.

2 Materials and methods

A large amount of documentation on the environmental conditions of the Gulf of Gdansk exists in the combined published and unpublished data literature. Historical data regarding the Gulf of Gdansk are available even from the early twentieth century (Lakowitz 1907, 1929) and from the period prior to and immediately following World War II (Demel 1927a & b; Demel, 1935; Bursa et al. 1939, 1947; Wojtusiak et al. 1950). More recent publications are also available (Ciszewski et al. 1991, 1992a & b; Kruk-Dowgiallo 1991, 1996, 1998; Kruk-Dowgiallo & Dubrawski 1998; Osowiecki 1998, 2000; Plinski 1982; Plinski & Wiktor 1987; Plinski & Florczyk 1990; Andrulewicz & Witek 2002).

For the purpose of this paper, the aim of which is to develop a practical approach to the task, provide advice to managers, and meet WFD requirements, the authors have utilized existing knowledge from various sources - published papers, “grey literature”, books and unpublished documentation. The authors believe that utilizing existing knowledge and an expert judgement can be utilised for solving the typology and health assessment problems of the Gulf of Gdansk.

The parameters considered for the different sub-areas (Fig. 1) are presented in Table 1.

| Parameters | Inner coast | | | Outer coast | | Open areas | | |
|-------------------|-------------|----|-----|-------------|---|------------|-----|------|
| | I | II | III | IV | V | VI | VII | VIII |
| Phytoplankton | + | + | + | + | + | + | + | + |
| Macrophytobenthos | + | + | | | | | | |
| Macrozoobenthos | + | + | + | + | + | + | + | + |
| Ichthyofauna | + | + | + | + | + | + | + | + |
| Chemical | + | + | + | + | + | + | + | + |
| Sanitary | + | + | + | | | | | |

Table 1: Parameters considered for the assessment of the quality status of the Gulf of Gdansk.

3 Results and discussion

3.1 Identification of hydro-geo-morphological units

The Gulf of Gdansk is comprised of a number of different hydro-geo-morphological regimes that represent different ecosystem units. Several classifications of the Gulf of Gdansk exist (Lazarienko & Majewski 1975; Andrulewicz 1996; Nowacki & Jarosz 1998), most of which are based on morphological and/or hydrological parameters (salinity, temperature, nutrients). The classification proposed in this paper is based on the morphology and dynamics of water masses that determine the living conditions of bottom vegetation and fauna as well as the environmental quality of coastal water masses.

Morphology of the Gulf of Gdansk recognizes lagoons, river mouths, and sheltered and open sea areas (Fig. 1). Obvious division based on bathymetry and morphology of the coast is as follows: inner coastal area (0 -10 m), outer coastal area (10 - 20 m), and open areas (>20 m). Therefore, the Gulf of Gdansk can be divided into the following units (Fig. 1):

Inner Coast (0 -10 m)

1. Puck Lagoon (internal Puck Bay) - a shallow, sandy, semi-enclosed water body subjected to strong anthropogenic pressure and inhabited by freshwater and marine species;
2. Sheltered coast of the western Gulf of Gdansk, not dynamic and partly covered by vegetation, under strong anthropogenic pressure;

3. Open coast of the eastern Gulf of Gdansk, very dynamic, lacks vegetation and under strong anthropogenic pressure;
4. Vistula River plume and Vistula Lagoon (including River Pregel) plume – polluted freshwater plumes. Their size and direction depends on wind-driven surface currents.

Outer coast (10 - 20 m)

5. Sheltered outer coast of the Gulf of Gdansk with abundant benthic fauna, under moderate anthropogenic pressure;
6. Open outer coast of the Gulf of Gdansk with abundant benthic fauna, under moderate anthropogenic pressure;

Open areas (> 20 m)

7. Open areas between 20 - 40 m are still under coastal influence, but are also impacted by open seawater masses. Benthic fauna is more abundant as depth increases;
8. Open areas deeper than 40 m - most of these southern Baltic Sea water masses are not under direct coastal influence, the sediments are well oxygenated with a high benthic biomass (particularly between 40 - 60 m.). Bottom sediments become more anoxic and more contaminated as depth increases, therefore benthic biomass decreases towards deep deposition areas (80 -100 m).

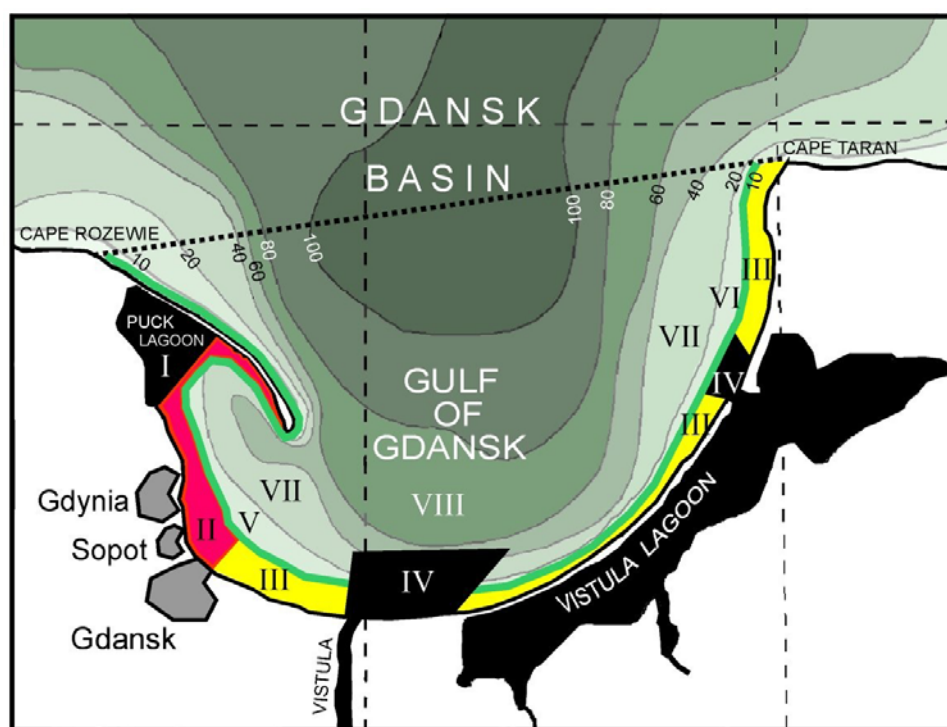


Figure 1: Divisions into natural sub-systems or typology in the Gulf of Gdansk

3.2 Environmental quality assessment

Sanitary conditions

Determinations of the sanitary conditions of the coastal waters of the Gulf of Gdansk are based on coliform bacteria measurements. These are supplemented occasionally with determinations of *Salmonella* and *Shigella*. Nearly all of the Gulf of Gdansk beaches were closed to bathing in the 1980s, but the sanitary state of these sites has been improving systematically since the 1990s and presently less than 25% are closed (WIOS 1999-2002). Efforts at both the local and national levels to improve sanitary conditions have focused primarily on constructing sewage treatment plants in coastal and watershed areas. However, the sanitary conditions of the Vistula River and its plume as well as the Vistula Lagoon and some places close to sewage outfalls remain unsatisfactory and require further effort. In general, coliform bacteria concentrations decrease from coastal to open sea areas,

i.e., from the Puck Bay to the open Gulf of Gdansk and from the Vistula River mouth to offshore areas (Czerwinska & Dubrawski 1998).

Phytoplankton

The nutrient accumulation process in the open coastal areas of the Gulf of Gdansk is similar during the winter season, as is the development of blooms during the spring and summer seasons. Thus, the productivity and composition of phytoplankton throughout the year in the Gulf of Gdansk is similar. However, the Puck Lagoon has different nutrient utilization dynamics - filamentous alga blooms develop in early spring and later form thick algal mats on the bottom of the lagoon.

Flagellate and Dinophyceae have dominated the abundance and biomass of the phytoplankton in the Gulf of Gdansk since the 1980s. An increase of approximately one hundred-fold in the overall abundance of phytoplankton and a ten-fold increase in diatoms confirm that the trophic state of the gulf was higher in the 1980s than in the 1970s. The phytoplankton bloom period, which is longer in comparison to that of the 1920s, has a negative impact on the gulf environment. This is especially true of blooms of potentially toxic species such as *Aphanizomenon flos-aquae*, *Nodularia spumigena*, *Dinophysis acuminata* and *Dinophysis norvegica* (Niemkiewicz & Wrzolek 1998).

Persistent, strong phytoplankton blooms enrich water and bottom sediments with significant amounts of autochthonous organic material and nutrients, which in turn intensify the process of internal eutrophication and generate blooms in the following year (Kruk-Dowgiallo & Dubrawski 1998).

Macrophytobenthos

There is an impressive amount of documentation for the changes in phytobenthic communities caused by anthropogenic pressure over the last twenty five years (Kruk-Dowgiallo 1991, 1996, 1998; Kruk-Dowgiallo & Dubrawski 1998; Plinski 1982; 1990; Plinski & Wiktor 1987; Plinski & Floreczyk 1989). Macrophytobenthos is a good indicator of the ecological status of waters where bottom flora occurs; this applies above all to the Puck Lagoon and the sheltered coastal zone of the western part of the Gulf of Gdansk.

In the Puck Bay, algae and vascular plants occur together. The underwater meadows that cover the bottom of this basin are the largest of their kind in the Polish coastal zone and are a unique feature of this area. The vascular plants that occur in the Puck Lagoon include *Zostera marina*, *Potamogeton pectinatus* and *P. filiformis*, *Myriophyllum spicatum*, *Ranunculus baudotii*, and *Zannichellia palustris*. The algae here include the rare species *Chara baltica* and *Tolypella nidifica*.

The sandy-stony bottom of the sheltered coastal zone of the western part of the Gulf of Gdansk is dominated by algae, including the red algae *Furcellaria lumbricalis*, which is now rare in the Gulf of Gdansk.

Changes in the phytobenthos have been observed since the mid 1970s, especially in the Puck Lagoon. These have included the following:

- disappearance of the algae *Fucus vesiculosus* and *Furcellaria lumbricalis* that dominated until the late 1960s and many other non-dominant species - this has led to the deterioration of the quality of underwater meadows;
- decreasing size of bottom areas overgrown by *Zostera marina* and *Potamogeton spp.* and declines in their biomass;
- distinct domination (of up to 70%) in the overall biomass of one group of vegetation, the so-called filamentous brown algae *Pilayella littoralis* and *Ectocarpus siliculosus* - the domination of this species fell to 30% in the 1990s;
- decided decline in the overall phytobenthos biomass.

Additionally, the vertical range of occurrence of bottom vegetation in the Gulf of Gdansk declined significantly from a depth of 25 m in 1885 (Lakowitz 1907) to 6 m in the 1990s (Kruk-Dowgiallo 1998).

Eutrophication has been intensifying steadily since the 1950s; one result has been the disappearance of the occurrence of the perennial alga *Fucus vesiculosus* and *Furcellaria lumbricalis* in the gulf. These species do not reproduce generatively, which is very disadvantageous to survival when negative changes occur in environmental conditions. Due to this, they began to be replaced by the abundant development of filamentous brown algae, mainly *Pilayella littoralis*. These species employ various reproduction strategies depending on environmental conditions; this attests to the powerful regenerative capacity of the filamentous brown algae. Thanks to this ability, these algae beat other species, including phytoplankton, in competition for nutrients in the Puck Bay, where environmental conditions have been changing continuously since the 1950s.

Macrozoobenthos

The benthic fauna of the Gulf of Gdansk is relatively well documented in the scientific literature as it is close to scientific centres and is accessible to researchers. The first negative changes were observed here in the 1960s and were related to the restructuring of the macrophytes composition in shallow areas. Although changes in various parts of the Gulf of Gdansk were complex and sometimes divergent due to significantly diverse environmental conditions in the area, they were related primarily to taxonomic composition and structure, abundance, and biomass distribution. In general, however, these changes did not fully correspond with conceptual models that describe processes occurring in benthic macrofauna communities under the influence of marine eutrophication (Osowiecki 2000).

It is reasonable to assume that the continuous process of eutrophication and pollution is the primary factor responsible for changes in the Gulf of Gdansk macrozoobenthos. Sediments that were overloaded with organic matter underwent a structural transformation that prompted adaptive changes in the composition of the benthic fauna. The macrophytes meadows that grew on the sandy bottom and that were so common in the shallow zone of the Puck Bay (western part of the Gulf) in the 1960s are now practically extinct. They have been replaced by sandy-silt and silt sediments, which create more favourable conditions for the development of deposit feeders that tolerate greater degrees of environmental pollution.

The quantitative and qualitative changes that have occurred in the macrozoobenthos during the last decades are significant, but definitely not as spectacular as those that have occurred in the phytobenthos and sediments. Some non-indigenous species appeared in the Gulf of Gdansk in the 1990s, although it has not been confirmed if any of them have succeeded in mass-colonizing the region, except a case of a polychaete *Marenzelleria viridis* in the Vistula Lagoon where it constitutes up to 95% of a total macrozoobenthos biomass (Zmudzinski 1994).

Ichthyofauna

The fish occurring in the Gulf of Gdansk include marine, diadromous, and freshwater species of commercial importance such as *Platichthys flesus*, *Clupea harengus*, *Salmo salar*, *Anquilla anquilla*, *Stizostedion liciopercas* and *Perca fluviatilis*. The coastal areas provide habitats for many small species and the young stages of non-commercial fish species. This includes some protected species such as the small goby and sand goby, as well as “pest fish” such as *Gasterosteus aculeatus* and *Neogobius melanostomus*. The latter has widened significantly its area of distribution in the coastal zone in recent years (Jackowski 2002). The coastal zone is the location of the feeding grounds of many species of commercial fish and the spawning grounds of herring. The spawning migration route of salmonids also passes through this zone.

In the first half of the 1960s *Anquilla anquilla* and *Esox lucius* dominated catches made in the inner Puck Bay. In the 1970s, *Rutilus rutilus* began to occur on a massive scale (Ciszewski et al. 1992a; Skora 1993a). Due to the destruction of the natural spawning sites and feeding grounds of freshwater fish and overfishing, the current commercial significance of roach and perch is minimal. Eutrophication and pollution in the Puck Lagoon has resulted in the following:

- the decreased size of underwater meadows has caused the disappearance of herbivorous fish species (pike, roach, perch);
- the limited range of occurrence of the unique species *Nerophis ophidion*, *Syngnathus typhle*, *Spinachia spinachia* and *Coryphopterus flavescens*;
- the expansion of species from the stickleback and goby families. The biomass of the three-spined stickleback currently stands at nearly 98% of the overall fish biomass in the Puck Bay (Skora 1993).
- the area of occurrence of the new species round goby *Neogobius melanostomus* is expanding;
- *Acipenser sturio* has become extinct (Skora 1993), and serious limitations are being placed on local populations of *Coregonus lavaretus* and *Vimba vimba*.

Chemical parameters

The most important sources of nutrient pollution in the Gulf of Gdansk region are the Vistula River, the Vistula Lagoon, waste treatment plants, some industries in Gdansk and Gdynia, and atmospheric fallout. The average river load of the Vistula River amounts 120,000 tons of total nitrogen per year and 7,000 tons of total phosphorus per year ((Andrulewicz & Witek 2002; IMGW 1994-2002).

The enhancement of nutrient concentrations is noted during the winter period, this enables the occurrence of the spring phytoplankton bloom (Trzosinska 1994, Lysiak-Pastuszek 2000) and further phytoplankton blooms throughout the summer season. Oxygen depletion occurs in the deepest parts of the Gulf of Gdansk, usually below 80 meters (Trzosinska & Lysiak-Pastuszek 1996).

4 Results and discussion

According to the author's judgement the present quality status of the identified ecosystem units of the Gulf of Gdansk assessed in light of the historical reference period (1950s) and according the quality scale proposed in the WFD is presented in Table 2.

| Inner coast (0-10 m) | | | Outer coast (10-20 m) | | Open areas | | |
|----------------------|------|----------|-----------------------|-------------------|-------------------|------|------|
| I | II | III | IV | V | VI | VII | VIII |
| bad | poor | moderate | bad | moderate /good | moderate /good | good | good |

Table 2: Estimated quality or health status versus the reference period (1950).

The following are the justification of the quality grades:

- **I. Puck Lagoon – Bad.** More than 75% of the underwater meadows have disappeared and fish landings have diminished by more than 75%;
- **II. Sheltered coast of the western Gulf of Gdansk - Poor.** Diminished depth range of vascular plants (from 25 to 6 m), poor sanitary conditions, and excessive algal blooms.
- **III. Open coast of the eastern Gulf of Gdansk – Moderate.** Sanitary conditions, although acceptable for bathing, are at the low end of the acceptance range, prolonged algal blooms deteriorate the aesthetic conditions of these coastal waters;
- **IV - Vistula River and Vistula Lagoon plumes – Bad.** Poor sanitary conditions and high nutrient concentrations.

- **V and VI - Sheltered outer coast and open outer coast (10-20m) - Moderate/ Good.** No significant changes noted apart from enhanced blooms. Abundant bottom fauna, good sediment and sanitary conditions.
- **VII and VIII - Open areas between 20 m to 40 m and further to the open sea – Good.** No changes noticed apart from changes in the trophic status in comparison with those of the 1950s. Abundant and diversified bottom fauna, good sanitary conditions.

5 Conclusions

Identifying natural sub-systems (ecological units or typology) is the first step necessary in effective management. In total, there were eight ecosystem sub-units identified in the Gulf of Gdansk, but only those sub-units which are situated close to the coast are being proposed for management actions.

These sub-units represent different quality grades resulting from anthropogenic pressure and their natural abilities to absorb this pressure. These grades, versus environmental status of reference period 1950s, are “bad”, “poor”, “moderate”, and “good”. The quality status of “high” has not even been given to the open waters of the Gulf of Gdansk, due to the excessive eutrophication phenomenon.

In order to improve the environmental or ecosystem quality status of the Gulf of Gdansk, the following recommendations/actions are proposed:

- **Area I - Puck Lagoon:** restore the underwater meadows by reintroducing vascular plants and macroalgae (e.g. *Fucus vesiculosus*, *Furcellaria lumbricalis*), restoring spawning grounds and reintroducing selected commercial fish species;
- **Area II - Sheltered coast:** further improve sanitary conditions through more effective sewage treatment and further reduce nutrient loads;
- **Area III - Open coast:** further reduce nutrient loads;
- **Area IV - Vistula River and Vistula Lagoon plumes:** reduce the use of nutrients in the Vistula and Pregel River watersheds, construct sewage treatment facilities and promote effective purification of sewage;

No action is needed in outer and in open of the Gulf of Gdansk **areas V-VIII**. Actions taken in areas I-IV should have a positive impact in areas V-VIII.

The results of this approach regarding typology and a health assessment of the Gulf of Gdansk should be developed further and discussed in open forums to generate and promote general acceptance.

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