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SHORT COMMUNICATION

The structure of macrozoobenthic communities as an environmental status indicator in the Gulf of Gdańsk (the Outer Puck Bay)☆

Jan Warzocha*, **Sławomira Gromisz**, **Tycjan Wodzinowski**, **Lena Szymanek**

Department of Fisheries Oceanography and Marine Ecology, National Marine Fisheries Research Institute, Gdynia, Poland

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Summary An attempt is made to use long-term (1979—2014) macrobenthos data series to derive insights on changes in abiotic conditions and on potential effects of long-term macrobenthos variability on food availability for fish and wintering waterfowl. The data were collected from a small embayment, protected as a NATURA 2000 area, functioning as a fishing ground important for the local community and as a site of diverse commercial developments. The analysis showed a drastic reduction of the macrobenthos abundance and biomass, which could have been related to oxygen deficiency; on the other hand, recolonisation processes have also been observed.

The western part of the Gulf of Gdańsk, called the Puck Bay, sheltered by the Hel Peninsula, has been for ages important for local communities as a fishing ground where both freshwater, marine, and migrating species have been harvested. According to the data reported by the fishermen and uploaded to the official data base held by Fisheries Monitoring Centre in Gdynia, the catches are at present dominated by the flounder, a species that feeds mainly on benthic

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* Corresponding author at: Department of Fisheries Oceanography and Marine Ecology, National Marine Fisheries Research Institute, Kołłątaja 1, PL-81-332 Gdynia, Poland. Tel.: +48 587356232; fax: +48 587356110.
E-mail address: janw@mir.gdynia.pl (J. Warzocha).
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invertebrates. The Puck Bay is also an important feeding ground for the wintering waterfowl. In addition, the Bay is protected as a NATURA 2000 area (PLH220032). At the same time, it is affected by intensive human activities and therefore aquatic organisms themselves as well as their contribution to food resources of fish (particularly the flounder) and the wintering waterfowl may be affected by local anthropogenic factors (e.g. effects of a brine-containing sewage discharge, the brine being produced as a result of inland salt deposit leaching to form caverns). The fishermen operating in the Puck Bay suggest that the decline in flounder catches is due to the impoverishment of the food resources consisting of benthic invertebrates. Some opinions hold that the brine produced during salt deposit leaching with treated sewage from the local treatment plant, in progress since 2009, whereby ultimately the brine-containing sewage is released into the Bay, may have resulted in salinity changes and the water column salinity stratification leading to oxygen deficiency in the near-bottom layer. As stipulated by the preconditions of the brine-enriched sewage discharge operation, the salinity of the discharged brine should be equal to that prevalent in the Puck Bay. The area near the brine-containing sewage discharge site has been subjected to monitoring.

This study is not aimed at providing an additional environmental impact assessment, but is an attempt to use the data on macrobenthos assemblages as an indicator of potential environmental changes in the Puck Bay over a large spatio-temporal scale. The motivation lies in a possible synergy created by various anthropogenic and natural factors acting in synchrony, the long-term pressures resulting in a cumulative effect. This in turn may mask the effect of an actual impact of a concrete anthropogenic pressure. In addition, the macrobenthos in the Baltic Sea is an important food source for demersal fish and birds, for which reason long-term studies on the macrobenthic biomass/productivity may aid in addressing the question whether food is a limiting factor for top consumers, e.g. demersal fish and birds.

The macrozoobenthos (alternatively termed the macrobenthos or the macrofauna) is defined as benthic invertebrates retained on a 1 mm mesh size sieve. Compared to, for example, the plankton, the macrobenthos is stable in time and space, as it is composed of long-lived organisms, mostly sessile or with a limited mobility, and inhabiting relatively small areas. Because of this, macrobenthic organisms are exposed, for a relatively long time, to various (also unfavourable) environmental effects prevalent at a given site. For this reason, the macrobenthos is regarded as a good indicator of environmental status, and is particularly useful for the detection of short-term fluctuations of abiotic factors (e.g. oxygen content or salinity) which, on account of their high variability, are difficult to be measured directly.

The Outer Puck Bay is defined as an area which, by convention, is bordered from the west by an emergent shallow known as the Ryf Mew (the Seagull Sandbar), a hypothetical line connecting the Hel Peninsula terminus with Gdynia constituting the eastern border of the Outer Puck Bay (e.g. Demel, 1935; Słomianko, 1974) (Fig. 1). The maximum water depth is about 56 m and the salinity ranges within 7.2—8.0. The bottom in the inshore zone, down to a depth of several to about 30 m, is covered by sandy and mixed (sand and mud) sediments, muddy sediments prevailing at larger depths. As determined by the loss on ignition (LoI), the organic content in the muddy sediments is up to 17%. The relatively scarce data on the near-bottom dissolved oxygen

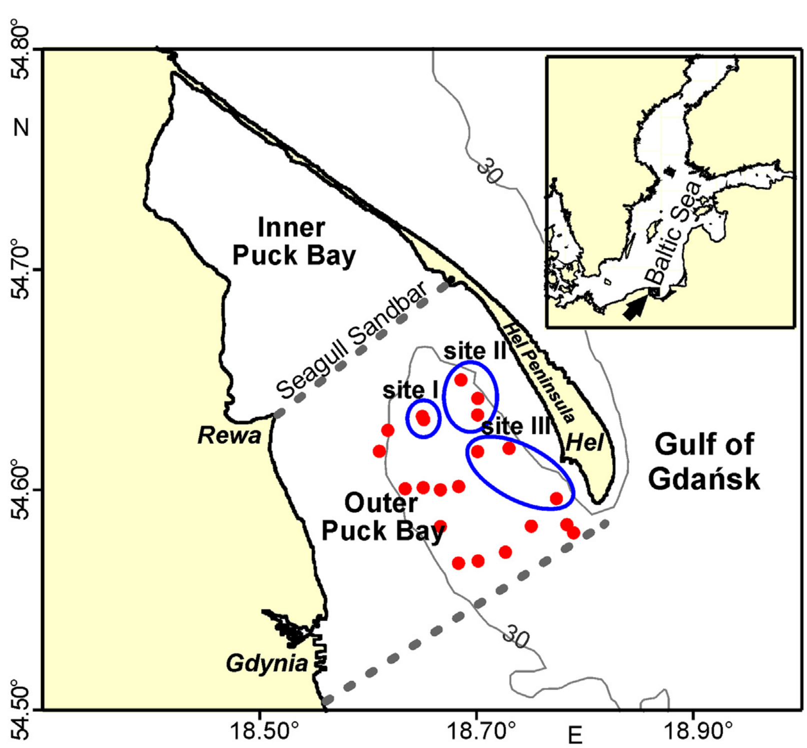

Figure 1 Area of study and distribution of sampling stations in the Outer Puck Bay in 1979—2014. Depth ranges: site I — 30—35 m, site II — 36—40 m, site III — 41—51 m.

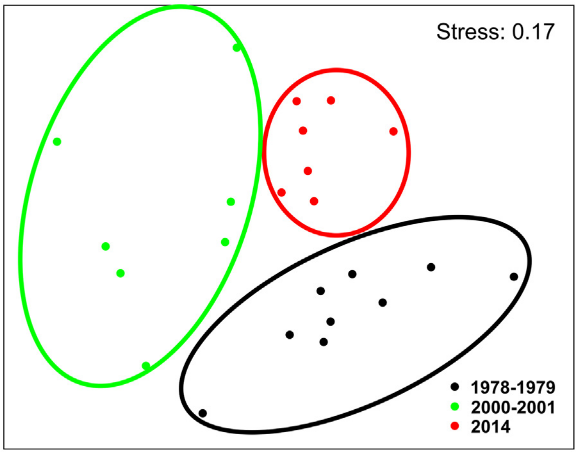

Figure 2 Results of abundance-based non-metric multidimensional scaling.

content indicate hypoxia (e.g. NMFRI database), but are not fully representative due to the lack of systematic long-term measurement series.

Macrobenthos data were collected in 1978—2014 by the National Marine Fisheries Research Institute (NMFRI) within the framework of projects addressing the structure and changes in the macrobenthos within the Polish part of the southern Baltic Sea. The sandy bottom of the Outer Puck Bay showed no changes which could have substantially affected food resources available to the fish or the waterfowl, or which would have been indicative of unfavourable environmental effects (Warzocha et al., unpubl.). Therefore, this study is limited to the muddy bottom of the Outer Puck Bay (Fig. 1). In 1979, 2000 and 2014, samples were collected from several, each time the same, stations distributed so as to cover the entire muddy bottom of the area. In addition, in 2002—2005 and 2007 three sites (marked in Fig. 1 as Sites 1—3), differing in the depth and degree of exposure to waves, were sampled to analyse potential short-term changes. Most samples were collected in summer (June—September); it was only in 1979 that some samples were collected in spring (April) and autumn (October). Therefore, changes in the macrobenthos assemblage are assessed based primarily on the biomass, as its seasonal fluctuations are narrower than those of the abundance. Samples were collected with an 0.1 m^2 Van Veen grab (33 kg weight), a standard gear used in the HELCOM monitoring (e.g. HELCOM, 2014).

The sediment sample retrieved was sieved on a 1 mm mesh size sieve and the sieving residue was preserved in 4% formaldehyde. Water salinity and temperature was measured during each sampling event; the dissolved oxygen

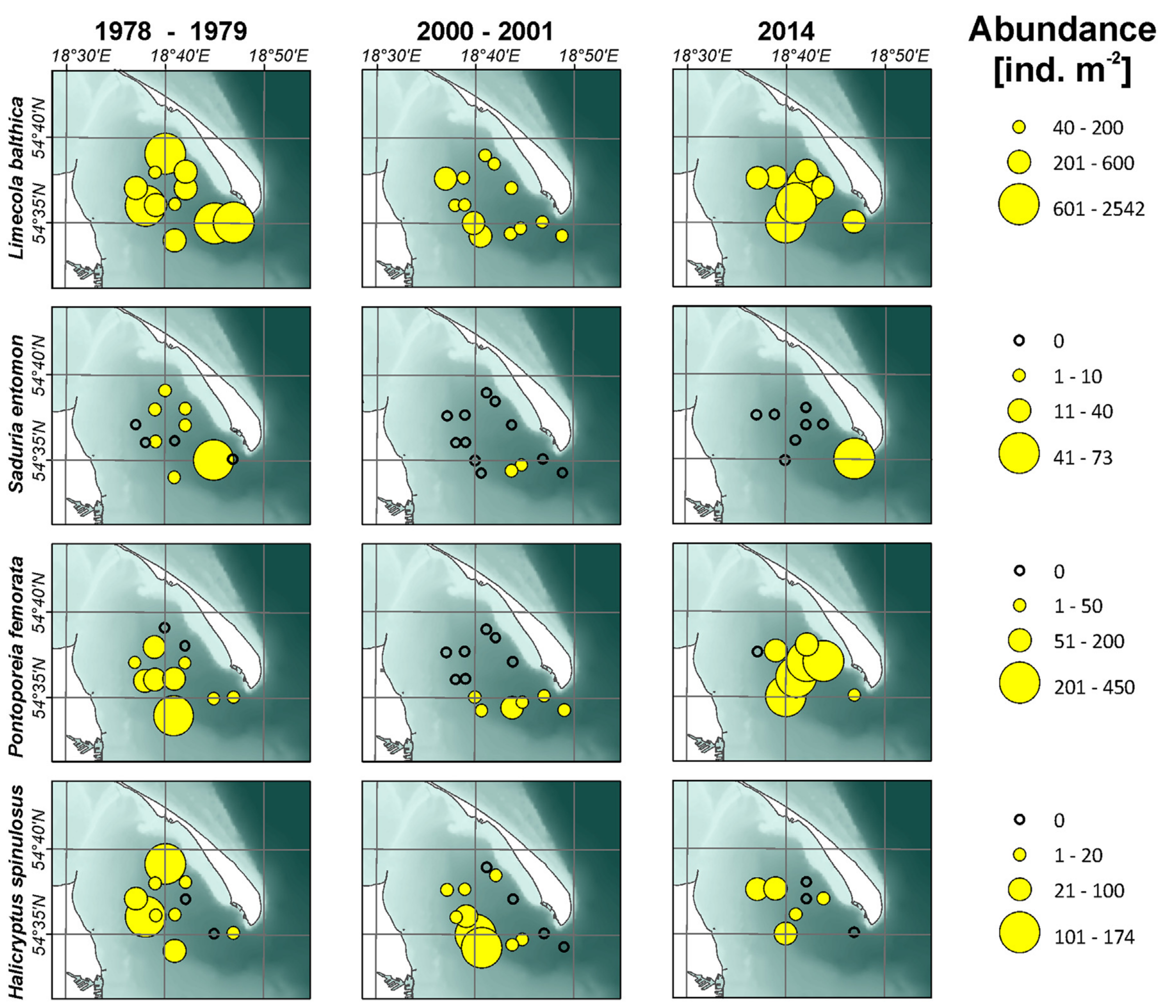

Figure 3 Changes in abundance of the four dominant species occurring in all the periods analysed.

content in the near-bottom water was determined during few cruises on board a larger craft. The analyses presented make also use of long-term oxygen data available in the NMFRI data base. The salinity and temperature did not change substantially during the period of study, hence their potential effects were disregarded in this study. The sediment organic matter content (LoI) was determined by combusting a sediment sample at 500°C. The macrobenthos was sorted under a stereomicroscope, identified to the lowest taxon possible, and dried on a blotting paper. Individuals belonging to the same taxon/species were weighed together. The Bivalvia were weighed with shells, without water in the mantle cavity. The abundance is expressed as the number of individuals per m^2, the biomass being expressed as formalin wet weight per m^2.

Numerical data treatment (MDS) was carried out using the PRIMER software package.

The taxonomic composition of the macrozoobenthos on the muddy bottom of the Outer Puck Bay in 1979 was typical of this bottom type in the Gulf of Gdańsk above the halocline (e.g. Mulicki, 1937; Warzocha, 1995). Characteristic of the community is the relatively low number of species and a strong dominance, particularly in the biomass, of the bivalve *Limecola balthica*. The remaining species typical of the community included *Saduria entomon*, *Pontoporeia femorata* and *Diastylis rathkei* as well as the priapulid *Halicryptus spinulosus*. Within 1979—2014, no species was observed to disappear, while in 2000, the presence of a new taxon, the polychaete *Marenzelleria* was recorded. Nonetheless, because of the strong domination of the Baltic tellinid *L. balthica*, no substantial effect of the new polychaete immigrant on the total macrozoobenthic biomass could be observed. No information has been so far provided on the importance of *Marenzelleria* as a food item for organisms at higher trophic levels in the Gulf of Gdańsk. However, according to observations in other areas (e.g. Šiaulys et al., 2012; Winkler, 1996), a potential role of this species in the food of demersal fish in the Puck Bay, cannot be ruled out.

Results of abundance-based non-metric multidimensional scaling (MDS) are shown in Fig. 2. Samples from 1979, 2000 and 2014 were separated into three distinct groups, which points to substantial differences in the macrobenthic community structure between the periods compared. Figs. 3 and 4 illustrate this differences in the community structure by showing distribution, abundance and biomass of dominant species in the three time periods compared.

Whereas in 1979 all the species were present throughout the entire muddy bottom of the outer Puck Bay, drastic changes in distribution, abundance and biomass (Figs. 3 and 4) were observed in 2000. A new assemblage on the deeper (depth exceeding 30 m) muddy bottom appeared, totally lacking the crustaceans *S. entomon*, *P. femorata* and *D.*

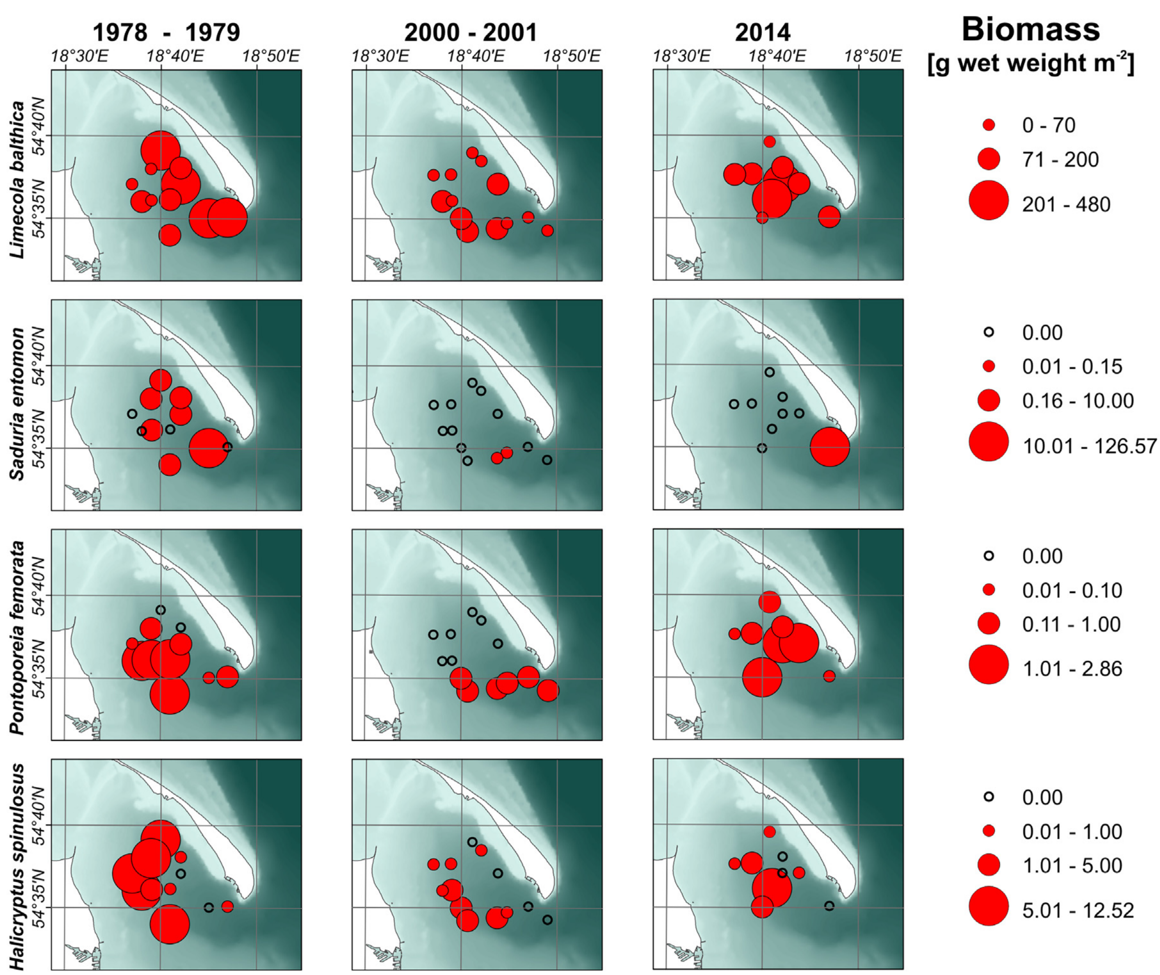

Figure 4 Changes in biomass of the four dominant species occurring in all the periods analysed.

rathkei, and including the sparsely occurring bivalve *L. balthica* only (Figs. 3 and 4). The most drastic reduction in the abundance and biomass of the macrofauna was observed in the deeper and sheltered regions (Figs. 1 and 5; sites II and III).

Subsequent years witnessed recolonisation of the muddy bottom; the data demonstrate gradual re-appearance of the key species (except *S. entomon*) as well as an increase in the macrozoobenthic abundance and biomass (Figs. 3—5). However, the structure of the recovering community changed. From among the species occurring in the area in 1979, it was only the bivalve *L. balthica* and the crustacean *P. femorata* that recovered or exceeded their former abundance and biomass throughout the entire area of study. The contribution of polychaetes (mainly *Marenzelleria* but also *Hediste diversicolor*) to the total abundance increased compared to 1979 (Fig. 5).

A considerable increase in the crustacean contribution to the macrobenthic abundance was due to the numerous individuals of *P. femorata* appearing on the bottom. However, the crustacean contribution to the total macrobenthic biomass did not reach the values recorded in 1979, because the bottom had not been recolonised by *S. entomon*, formerly a substantial contributor to the total macrozoobenthic biomass (Fig. 4). In 2014, the species was recorded only at the easternmost sampling station, basically beyond the border of the area adjacent to the Hel Peninsula (Figs. 3 and 4). Of the crustaceans, *P. femorata* was abundant in 2014, but only in the eastern, deepest part of the area. Only single individuals of another crustacean, *D. rathkei*, were recorded. On the other hand, no clear differences in the distribution of *H. spinulosus* were observed within the period of study. However, as the species occurs at low abundances anyway, the

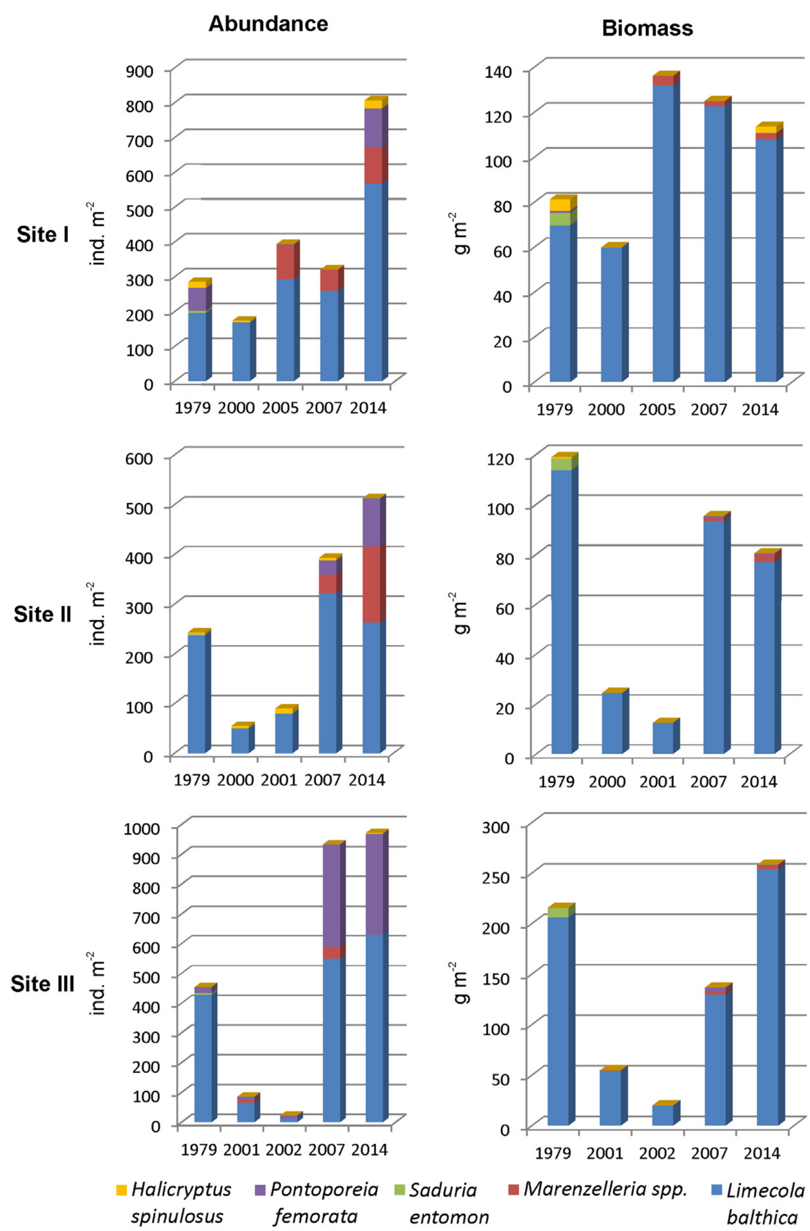

Figure 5 Changes in total macrobenthic abundance and biomass, and in abundance and biomass of individual taxa, at three sites differing in depth and exposure to wave action. Depth ranges: site I — 30—35 m, site II — 36—40 m, site III — 41—51 m.

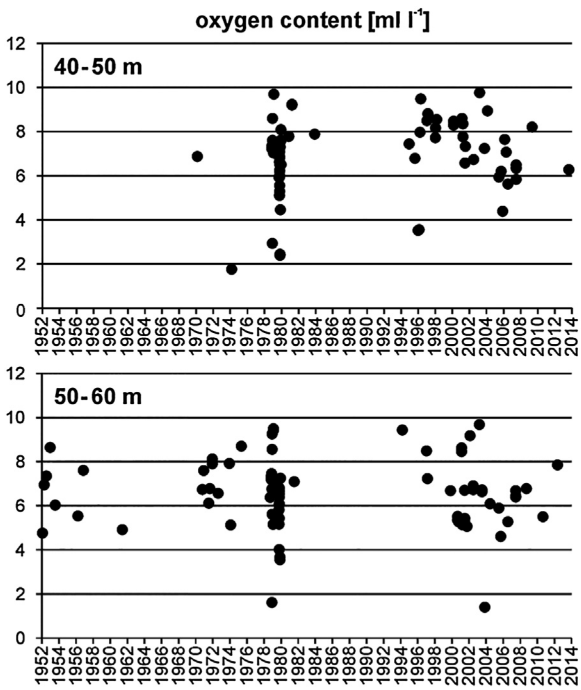

Figure 6 Dissolved oxygen contents in the near-bottom water layer in 1952—2014.

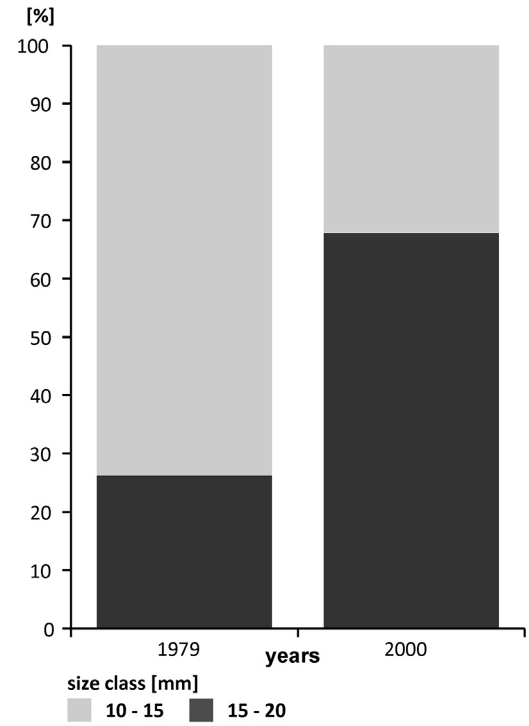

Figure 7 Contribution of two *Limecola balthica* size classes, most abundant in the samples, to the species' population in 1979 and 2000.

values of abundance and biomass reported may not have been consistent.

Noteworthy are the abundances and biomasses of *L. balthica* in 2014, much higher than those found in 1979. One may thus conclude that the environmental conditions were not favourable for the macrobenthos as early as in 1979. The available dissolved oxygen content values at the time (Fig. 6) may suggest that relatively low abundances and biomasses in 1979 were caused by hypoxia.

The nature of changes in the structure of macrozoobenthic communities, a rapid faunal reduction followed by recolonisations, changes in the dominance structure (an increased contribution of polychaetes and a reduced share of crustaceans) point to periodic oxygen deficiencies in the near-bottom water layer (Pearson and Rosenberg, 1978; Rumohr et al., 1996). The role of hypoxia is suggested also by the available data on oxygen content (Fig. 6), the high organic load (maximum about 17%), and results of chemical sediment assays regarding, e.g. the presence of methane (Brodecka et al., 2013; Reindl and Bolałek, 2012). The abundance and biomass of macrobenthos at muddy bottom in the eastern part of the Outer Puck Bay was found to be reduced as early as in the 1990s (Janas and Szaniawska, 1996; Janas et al., 2004; Włodarska-Kowalczuk et al., 1996). The authors mentioned ascribed the changes they observed to oxygen deficiency and the resultant presence of hydrogen sulphide in the sediment. Studies carried out in 2000 showed reduction in the number of species, abundance and biomass on almost the entire area of the muddy bottom in the outer Puck Bay (Warzocha et al., 2001).

Information from shallower areas (30—35 m) with a muddy bottom, where the macrozoobenthos had been reduced by 2000, shows *L. balthica* to have survived at abundances sufficient for the analysis of the population structure used as an indicator of the condition at the study site (Fig. 7). The analysis demonstrated that in 1979 the population included much more numerous younger individuals, whereas the contribution of the oldest individuals increased after the reduction of the population size in 2000. The change in the size structure of the bivalve population constituting an important fish diet item may have also impacted the predators' food resources (e.g. Barnes et al., 2010).

Summing up: The structure of the muddy bottom macrobenthos in the Outer Puck Bay has been undergoing substantial changes in the several recent decades. A drastic reduction of the fauna observed in the area in 2000 may have been indicative of oxygen deficiency in the near-bottom water. The re-appearance of the species following the reduction did not lead to any complete recovery of the community, which may suggest a permanent alteration of sediment characteristics.

Changes in the biomass observed (particularly the reduction in the crustacean biomass) may have adverse consequences for food availability for higher trophic levels, although the biomass of the bivalve *Limecola balthica*, one of the major diet components for the flounder and sea ducks, has recovered in recent years. On the other hand, preliminary observations indicate a change in the size structure of the bivalve population resulting from a higher mortality of younger individuals, in the periods when reduction of macrofauna was observed. The polychaete *Marenzelleria*, a new immigrant, changed the community structure, but did not affect the total macrozoobenthos biomass in any substantial way.

Conclusions

Long-term changes in the distribution and structure of the macrozoobenthos occurring on the muddy bottom of the outer Puck Bay point towards adverse effects of abiotic conditions, most probably oxygen deficiency resulting from eutrophication, on the functioning of the benthic community. Those effects may impinge, permanently or periodically, upon the availability of food for demersal fish and wintering waterfowl. As the adverse drastic changes, especially in the abundance and biomass of crustaceans, have been observed since 2000, it would be difficult to directly relate them to an impact of a concrete anthropogenic intervention, except for the discharge of sewage which, in progress for many years, has doubtless induced an increase in the area's trophic status and sediment organic load. In light of the data collected, it appears important to combine the environmental impact assessment of a development and the relevant monitoring data with results of long-term research.

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References

Barnes, C., Maxwell, D., Reuman, D.C., Jennings, S., 2010. Global patterns in predator—prey size relationships reveal size dependency of trophic transfer efficiency. Ecology 91 (1), 222—232.

Brodecka, A., Majewski, P., Bolałek, J., Klusek, Z., 2013. Geochemical and acoustic evidence for the occurrence of methane in sediments of the Polish sector of the southern Baltic Sea. Oceanologia 55 (4), 951—978, http://dx.doi.org/10.5697/oc.55-4.951.

Demel, K., 1935. Investigations on the bottom fauna and its occurrence in the southern Baltic. Arch. Hydrob. Ryb. IX (3—4), 237—311, (in Polish).

HELCOM, 2014. Manual for the Marine Monitoring in the COMBINE Programme of HELCOM. Soft bottom macrozoobenthos. Annex C-8, 277—287.

Janas, U., Szaniawska, A., 1996. The influence of hydrogen sulphide on macrofaunal biodiversity in the Gulf of Gdańsk. Oceanologia 38 (1), 127—142.

Janas, U., Wocial, J., Szaniawska, A., 2004. Seasonal and annual changes in macrozoobenthic populations of the Gulf of Gdańsk with respect to hypoxia and H_2S. Oceanologia 46 (1), 85—102.

Mulicki, Z., 1937. Note of the quantitative distribution of the bottom fauna near the Polish coast of Baltic. Bull. Stac. Mor. Helu 1, 74—101, (in Polish).

Pearson, T.H., Rosenberg, R., 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanogr. Mar. Biol. Ann. Rev. 16, 229—311.

Reindl, A.R., Bolałek, J., 2012. Methane flux from sediment into near-bottom water in the coastal area of the Puck Bay (southern Baltic). Oceanol. Hydrobiol. Stud. 41 (3), 40—47.

Rumohr, H., Bonsdorff, E., Pearson, T.H., 1996. Zoobenthic succession in Baltic sedimentary habitats. Arch. Fish. Mar. Res. 44 (3), 179—214.

Šiaulys, A., Daunys, D., Bučas, M., Bacevičius, E., 2012. Mapping an ecosystem service: a quantitative approach to derive fish feeding ground maps. Oceanologia 54 (3), 491—505, http://dx.doi.org/10.5697/oc.54-3.491.

Słomianko, P., 1974. Physical condition of the region. Perspective of the economic development of the region. Stud. i Mater. Oceanol. 5, 7—30, (in Polish).

Warzocha, J., 1995. Classification and structure of macrofaunal communities in the southern Baltic. Arch. Fish. Mar. Res. 42 (3), 225—237.

Warzocha, J., Grelowski, A., Bolałek, J., Białkowska, I., 2001. The response of soft bottom benthic macrofauna to environmental changes in the Gulf of Gdańsk in 2000—2001. In: 3rd Int. Symp. "Functioning of coastal ecosystems in various geographical regions", 19—22 June 2001, Gdynia, Poland, (abstracts), p. 72.

Winkler, H.M., 1996. Is the polychaete *Marenzelleria viridis* an important food item for fish? In: Proc. of the 13th Symposium of the Baltic Marine Biologists. 147—151.

Włodarska-Kowalczuk, M., Janas, U., Szaniawska, A., 1996. Hydrogen sulphide and other factors influencing the macrobenthic community structure in the Gulf of Gdańsk. Oceanologia 38 (3), 379—394.