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Assessment of biodiversity and environmental quality using macrozoobenthos communities in the seagrass meadow (Gulf of Gdańsk, southern Baltic)

by

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Abstract

This study shows the macrozoobenthic biodiversity and the quality status of the *Zostera marina* meadow in the Gulf of Gdańsk. To our knowledge, this is the first study focused on the assessment of environmental quality based on macrofauna occurring on such a small and specific habitat as a seagrass meadow.

The meadow is dominated by *Zostera marina*, but also *Zanichellia palustris* and *Potamogeton pectinatus* are present. Compared to the soft bottom macrofauna in the southern Baltic, the biodiversity of macrozoobenthos is very high, which is reflected in 33 taxa observed during the whole research, while the mean number of taxa was 12. There were also some taxa found only on the bottom overgrown with vegetation, e.g. *Idotea balthica* or even taxa that are currently rarely observed in the Gulf of Gdańsk, e.g. *Gammarus locusta* or *Gammarus ineaquicauda*. Nineteen percent of the stations were classified into the very good quality status and 50% into the good quality status, so the environmental status of this meadow based on the BQI index is assessed as good. Given these results, this is probably one of the best preserved meadows in the southern Baltic.

Key words: biodiversity, environmental quality, macrozoobenthos, *Zostera marina*, Baltic Sea

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Introduction

Seagrass meadows are among the most valuable and multifunctional habitats in the coastal zone of the Baltic Sea because of their engineering functions (Bonsdorff 1997; Boström et al. 2002; van der Heide et al. 2007). The macrozoobenthic biodiversity of such meadows is much higher than on the bare sand. Furthermore, it has been demonstrated that such meadows improve the environmental conditions (Bonsdorff 1997), even though very few small-scale studies assessing the environmental quality of one specific meadow have been carried out so far. Such studies would be very helpful in the context of the conservation and management of marine resources. The need to develop such strategies has been highlighted in recent decade, mainly because of the increased human impact (Borja et al. 2008). Indices based on macrozoobenthic communities, like the Benthic Quality Index (BQI) (Water Framework Directive 2000; Rosenberg et al. 2004), are among the tools used to monitor the environmental quality status. This makes meadows the most suitable areas for assessing and monitoring the environmental quality (Krause-Jensen et al. 2005), as any changes are immediately detectable. This applies not only to the meadows: they can also be used as reference plots for larger areas, even the whole water bodies.

The distribution range and taxonomic composition of the seagrass meadows in the southern Baltic have changed in recent years. Until the 1980s, their range gradually decreased (Węsławski et al. 2013), but since then a slow regeneration of vascular plants in the Gulf of Gdańsk has been observed.

The latest research shows that the seagrass meadows in the Gulf of Gdańsk are formed mainly by *Zostera marina* L., a protected species, but *Zanichellia palustris* L. and *Potamogeton pectinatus* L. are also abundant (Urbański et al. 2009; Boström et al. 2014). Apart from their biological value, for example, as a shelter for animals and a complex habitat for many species, such meadows are also of economic importance: they are on every diver's list of water areas to be visited, and as an educational example they are second to none. One of these meadows on Długa Mielizna is additionally protected as part of the Natura 2000 Special Area of Conservation (SAC) PLH220032 (Puck Bay and the Hel Peninsula) and Special Protection Area (SPA) PLB220005 (Puck Bay). As a coastal habitat, it is also situated within the Coastal Landscape Park.

In environmental quality assessments, it is very important to obtain unequivocal results regarding a region. Depending on the features tested and the indices used in the Gulf of Gdańsk, its environmental status varies from good to bad (e.g. HELCOM 2009; CIEP 2010; RIEP 2013, Saniewski 2013; HELCOM 2014). Only large monitoring research projects or studies strictly related to sandy bottom indices were carried out (e.g. Osowiecki et al. 2008; 2012; Šiaulys et al. 2011). None of the subsequently published papers describe the benthic fauna inhabiting the seabed covered with macrophytes. Such research usually focuses on soft sea beds which, even though they are the most common type, are not as multifunctional as seagrasses. No studies to date have linked the environmental status with the presence of seagrass. This is only mentioned in papers when environmental quality is being assessed on the basis of the state of macrophytes or when the depth limits for plants are being investigated (Krause-Jensen et al. 2005; Saniewski 2013).

The objectives of this study were to describe the taxonomic diversity of macrofauna in the seagrass meadows on Długa Mielizna, to show the influence of vascular plants on the diversity, and to compare the macrozoobenthic diversity on two types of seabed: sand covered with vascular plants and bare sand. An additional objective was to define the environmental status of this meadow and to show how the presence of vascular plants make it superior to a bare sandy bottom.

Materials and methods

Collection and analysis of samples

Macrozoobenthos samples were collected in July 2008 by divers at 16 stations on Długa Mielizna – a sandy shoal along the Hel Peninsula (Puck Bay), on a sandy bottom covered with vascular plants and on bare sand in the close proximity to a vegetated area. The bottom water temperature and salinity were measured at each station. In the first case, plants cut just above the sediments together with the fauna living on them were collected with a modified Kautsky net (20 × 20 cm, 500 μm mesh) (Plants), whereas plants with epifauna and infauna were collected with a corer (internal diameter 10 cm) inserted into the sediment to a depth of ca 30 cm (Plants + sand). Bare sand samples were collected with a corer only (Sand). Four samples were collected at each station: two Kautsky nets, one core with plants and one without plants.

All samples were passed through a 1 mm sieve and preserved in formaldehyde (4%) as described in the HELCOM guidelines (HELCOM Combine 2014). Macrophytes and macrofauna were identified, counted (only animals) and weighed (in both cases wet mass was measured). Nematoda, Oligochaeta, Hydrobiidae, *Marenzelleria* spp., *Jaera* spp. and Insecta were not identified to the species level. All mollusks were weighed with their shells. In the case of Bryozoa and *Amphibalanus improvisus,* only the presence of these organisms was noted, so they were not used in the calculation of the environmental status indices. The abundance and biomass were calculated per 1 m^2. The Kautsky net samples were used only for the number of taxa, their frequency, abundance and biomass analysis. The frequency of each taxon was first calculated from the data. When calculating the proportion of a taxon in the mean abundance and biomass, only taxa contributing >10% were taken into account; the other taxa were placed in the "others" category.

Indices

All indices were calculated only for the cores (Plants + sand and Sand). Nematoda, fish larvae and eggs, fish, *Mysis relicta, Praunus flexuosus* and *Piscicola pojmanskae*, and juveniles were not taken into account in these calculations, because they are all accidental taxa. The Shannon-Weaver index based on log e (Magurran 2004) and the Pielou index (Heip 1974) were calculated. The environmental status index BQI (Benthic Quality Status) was calculated according to the formula from Blomqvist et al. (2006):

$$BQI = \left[\sum_{i=1}^{S}\left(\frac{N_i}{N_{tot}} * s_i\right)\right] * \log_{10}(S+1) * \left(\frac{N_{tot}}{N_{tot}+5}\right)$$

where:

N_i – taxon abundance,
N_{tot} – total abundance at a station,
S – species richness at a given station,
S_i – sensitivity assigned by earlier research or by experts (Table 1).

Sensitivity values were 1, 5, 10 and 15, where 1 = "tolerant to environmental changes" and 15 = "a very sensitive taxon".

Environmental status classes were defined by dividing the whole set of values obtained into five equal ranges. For the final quality assessment, only one result from each station was selected – the worst one. The statistical analysis (Mann-Whitney *U* tests) was carried out using STATISTICA 10 (StatSoft, Poland). The map was drawn using ArcGIS 10.2. Some of the GIS layers used for map drawing were obtained from the GIS Center of the University of Gdańsk.

Table 1

Sensitivity of taxa used for calculating the Benthic Quality Index (BQI), where 1 = tolerant and 15 = very sensitive

Sensitivity value (S_i)	Taxa
1	Oligochaeta, Insecta larvae ind.
5	all polychaetes, Hydrobiidae, *Macoma balthica*
10	*Amphibalanus improvisus, Cyathura carinata, Idotea chelipes, Idotea granulosa, Jaera* spp.*, Corophium multisetosum,* all gammarids, *Theodoxus fluviatilis, Cerastoderma glaucum, Mya arenaria, Mytilus edulis*
15	*Idotea balthica, Bathyporeia pilosa, Crangon crangon*

Results

Bottom waters

The water temperature ranged from 17.0 to 21.1°C. The salinity, however, was basically constant – 6.9 or 7.0 at all the sampling stations.

Taxonomic diversity

Flora

The flora at the stations was dominated by *Z. marina* (with the biomass up to 2000 g m^{-2}), but *Z. palustris* and *P. pectinatus* were also present. There was only one station (J13), located very close to the coast, where *Z. marina* was not observed and *P. pectinatus* was the dominant plant. *Z. palustris* was dominant at 25% of the sampling stations – these were situated in the central-southern part of the meadow. There were also filamentous algae attached to vascular plants, mostly from the family *Ectocarpaceae* and *Cladophora* spp., although their biomass was relatively low – no more than 133 g m^{-2}.

Macrozoobenthos

A total of 33 taxa from 9 phyla were identified in the study area (Table 2). Four taxa – Oligochaeta, *Hediste diversicolor,* Hydrobiidae and *Mya arenaria* – were very frequent on both bare sandy bottom and vegetation-covered bottom (frequency >50%). A large number of taxa were also observed on the vegetation-covered bottom only; 13 species of benthic invertebrates and unidentified fish were recorded only in the vascular plant samples (such animals were not present on the sandy bottom).

Table 2

Frequency of occurrence (%) of taxa on Długa Mielizna on bare sand (Sand), vegetation-covered sand (Plants + sand) and on plants (Plants) (**in bold – taxa observed only in places with plants**)

Species	Sand	Plants + sand	Plants
Nematoda	7	75	76
Oligochaeta	53	100	82
***Piscicola pojmanskae* Bielecki, 1994**	**0**	**0**	**29**
Hediste diversicolor (O. F. Müller, 1776)	87	100	82
Marenzelleria spp. Mesnil, 1896	40	81	12
Pygospio elegans Claparéde, 1863	80	94	12
***Amphibalanus improvisus* (Darwin, 1854)**	**0**	**13**	**29**
***Mysis relicta* Lovén, 1862**	**0**	**0**	**6**
***Praunus flexuosus* (Müller, 1776)**	**0**	**0**	**6**
Cyathura carinata (Krøyer, 1847)	13	19	6
***Idotea balthica* (Pallas, 1772)**	**0**	**13**	**100**
Idotea chelipes (Pallas, 1766)	27	94	100
***Idotea granulosa* Rathke, 1843**	**0**	**13**	**41**
***Idotea* juv.**	**0**	**25**	**100**
***Jaera* spp. Leach, 1814**	**0**	**6**	**35**
Bathyporeia pilosa Lindström, 1855	7	0	0
Corophium multisetosum Stock, 1952	20	13	6
***Gammarus inaequicauda* Stock, 1966**	**0**	**0**	**6**
Gammarus locusta (Linnaeus, 1758)	7	13	41
***Gammarus oceanicus* Segerstråle, 1947**	**0**	**0**	**18**
***Gammarus zaddachi* Sexton, 1912**	**0**	**25**	**53**
Gammarus tigrinus Sexton, 1939	13	25	29
***Gammarus salinus* Spooner, 1947**	**0**	**50**	**88**
***Gammarus* spp. Fabricius, 1775**	**0**	**0**	**12**
Gammarus juv.	7	44	100
Crangon crangon (Linnaeus, 1758)	7	6	6
Insecta larvae ind.	7	81	88
***Theodoxus fluviatilis* (Linnaeus, 1758)**	**0**	**6**	**6**
Hydrobiidae Stimpson, 1865	100	100	100
Cerastoderma glaucum (Bruguiére,1789)	20	81	65
Macoma balthica (Linnaeus, 1758)	67	81	24
Mya arenaria Linnaeus, 1758	80	100	53
Mytilus edulis Linnaeus, 1758	27	94	100
Einhornia (Electra) crustulenta (Pallas, 1766)	7	0	24
fish eggs and larvae	**0**	**0**	**12**
Gobiidae	**0**	**0**	**24**
Total number of taxa	19	24	31

Hydrobiidae were dominant in all the Sand and Plants + sand samples (Fig. 1). In the epifaunal community (Plants), this dominance was not so pronounced, so the epifaunal community is more balanced in this respect. With regard to the biomass, Bivalvia – *M. arenaria* and *M. edulis* – are clearly dominant in every sample, because of the large weight of shells (Fig. 2).

The number of taxa, the abundance and the total biomass are higher for the vegetation-covered bottom than for the bare sand. The differences are statistically significant (Fig. 3). The mean number of taxa was seven for the sandy bottom (Sand) and twelve for the vegetation-covered bottom (Plants + sand).

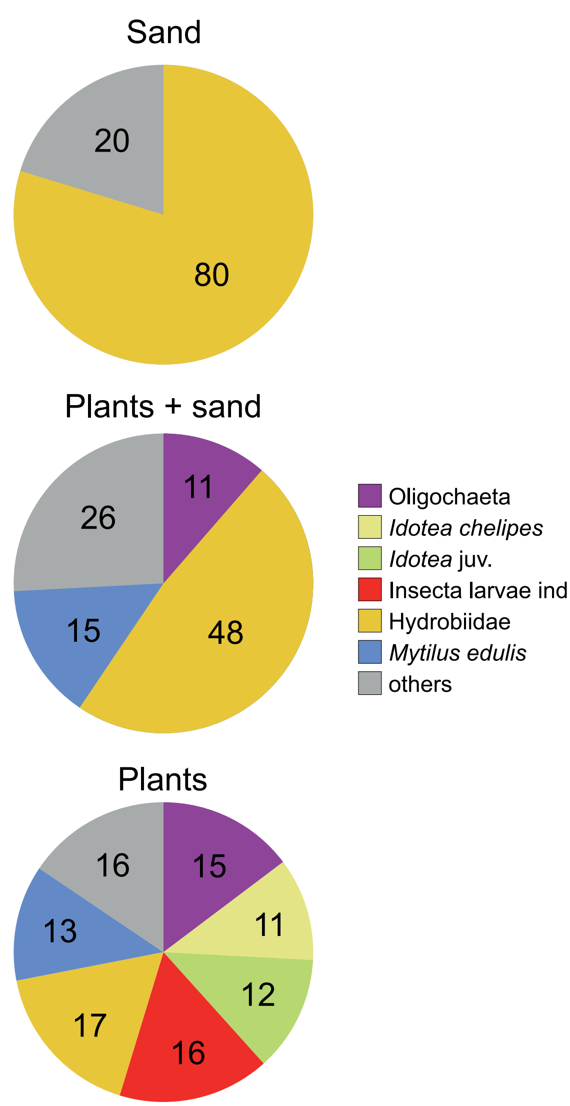

Figure 1

Percentage of each taxon in the mean abundance on different substrates (others – <10%)

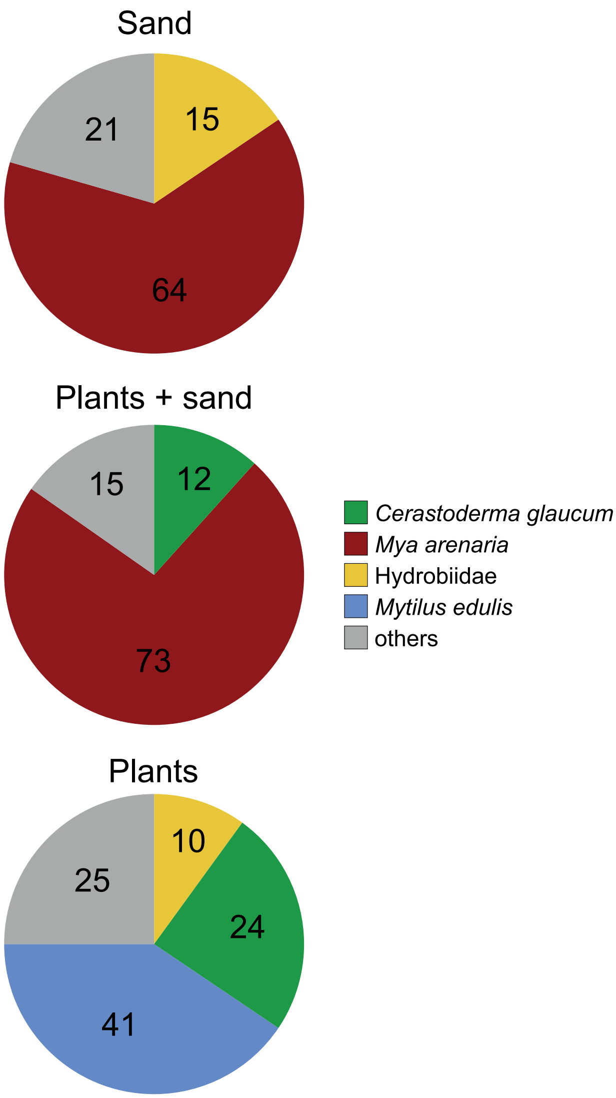

Figure 2

Percentage of each taxon in the mean biomass on different substrates (others – <10%)

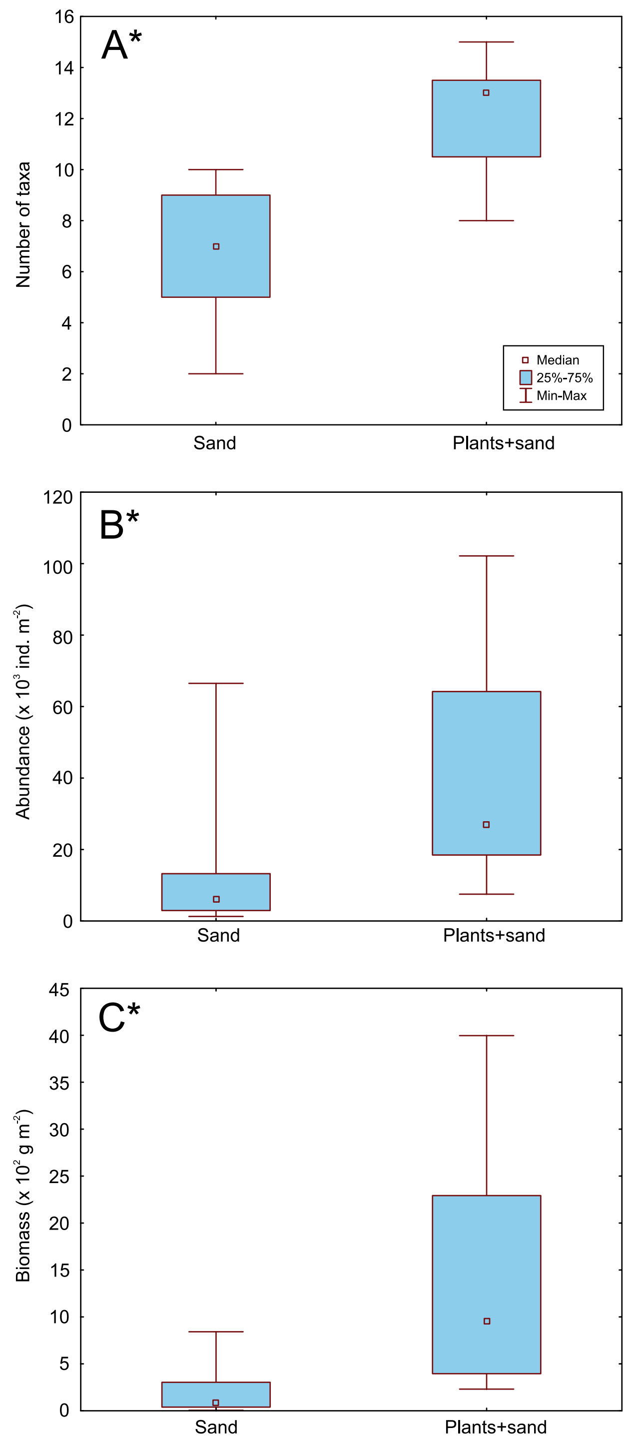

Figure 3

The number of taxa (A), abundance (B) and biomass (C) on bare sand (Sand) and on the bottom covered with vascular plants (Plants + sand) (the asterisk indicates statistically significant differences: $p<0.05$)

Indices

The Shannon index H' showed that the greatest diversity of taxa is on the vegetation-covered bottom – this difference was statistically significant (Fig. 4). The maximum was 2.3 on the vegetation-covered bottom, whereas it ranged from 0.1 to 1.6 on the sandy bottom. The Pielou index J' of species evenness did not exhibit such differences, although the range of values on Sand was quite wide.

There were statistically significant differences in BQI between the two types of bottom (Fig. 5), with higher values on Plants + sand (3.1 – 8.4) and lower values on Sand (2.6 –5.8). The station with the best environmental status had a high number of taxa

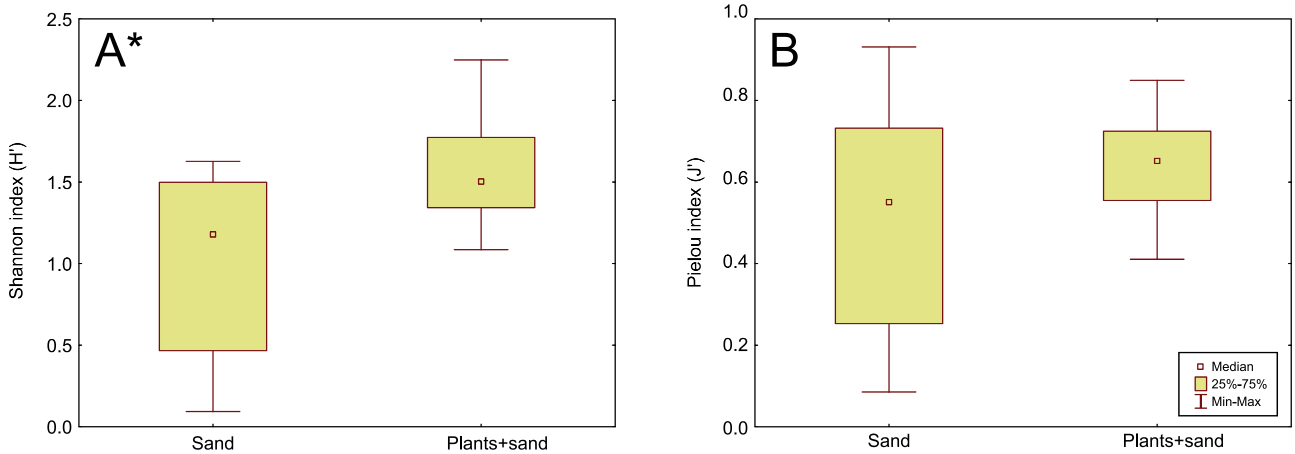

Figure 4

Values of H′ (A) and J′ (B) on bare sand (Sand) and on the bottom covered with vascular plants (Plants + sand) (the asterisk indicates statistically significant differences: $p<0.05$)

(15, including 6 species of Crustacea) and a high abundance – around 23 000 ind. m^{-2} (Plants + sand).

The class ranges were defined on the basis of all the results from Długa Mielizna, (Table 3). Three stations (19%) were assigned to the "very good" class, eight stations (50%) were of "good" quality, four stations (25%) were "moderate" and one station (6%) was "poor"; none were classified as "bad". A map of environmental quality of the study area was drawn on the basis of these results (Fig. 6). It shows the distribution of quality classes over the whole area. The poor and moderate quality stations are situated in the southern part of Długa Mielizna.

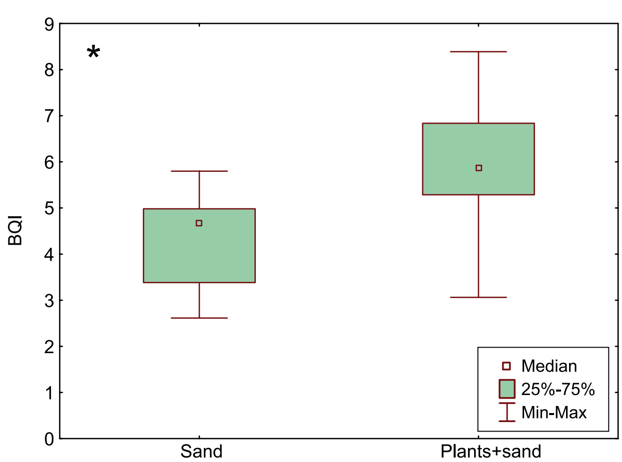

Figure 5

Benthic Quality Index (BQI) on bare sand (Sand) and on the bottom covered with vascular plants (Plants + sand) (the asterisk indicates statistically significant differences: $p<0.05$)

Discussion

Z. marina is very sensitive to eutrophication and environmental changes (Boström et al. 2014), so its presence on Długa Mielizna can be regarded as an indicator of good quality. In some samples, leaves with seeds were found, so the seagrass meadow on Długa Mielizna can be regarded as well-formed and valuable. The low abundance of filamentous algae on Długa Mielizna, probably due to animal grazing, is also helpful in developing the good quality of the meadow.

With regard to the taxonomic diversity of macrozoobenthos, the number of taxa recorded in this study (33) was very high for such a limited area. This is the same number of taxa as that found in the Puck Lagoon (Legeżyńska & Wiktor 1981; Janas & Kendzierska 2014). In their study of seagrass meadows, Janas & Kendzierska (2014) found only 20 taxa, while Kotwicki (1997) reported only 13 taxa in the coastal waters off Gdynia where seagrass meadows may occur. On the other hand, the few studies conducted only on the sandy bottom in the coastal waters of Puck Bay all report a lower number of taxa, ranging from 15 to 25 (Herra & Wiktor 1985; Kotwicki 1997; Kotwicki et al. 1999). The dominance of Hydrobiidae observed in these studies is typical of sandy bottoms at this depth (Bick & Zettler 1994; Boström & Bonsdorff 1997; Osowiecki 1998; Kotwicki et al. 1999; Włodarska-Kowalczuk et al. 2010). This shows that the seagrass meadow is a complex habitat, suitable for various kinds of animals, not only those associated with plants. Lavesque et al. (2009) demonstrated a high level of diversity in the seagrass meadow in Arcachon Bay –

Table 3

Class ranges on bare sand (Sand) and on the vegetation-covered bottom (Plants + sand)

	Class range				
Sand	5.8-4.6	4.5-3.4	3.3-2.2	2.1-1.0	<1
Plants+sand	8.4-6.7	6.6-5.0	4.9-3.3	3.2-1.6	<1.6
	Very good	Good	Moderate	Poor	Bad

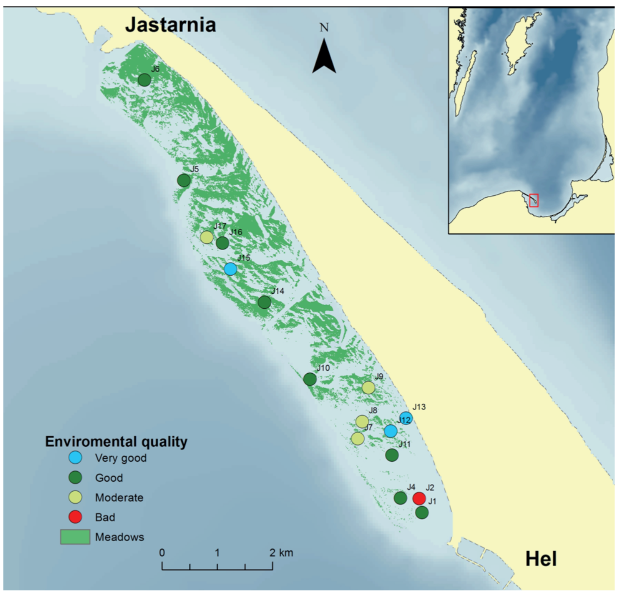

Figure 6

Environmental quality on Długa Mielizna based on the Benthic Quality Index (BQI)

30 taxa – which is very similar to that in Puck Bay.

Studies of the sandy bottom show that the waters off Kuźnica (close to our study area) are among the species-richest areas of the six areas investigated by Osowiecki (1998) in the Gulf of Gdańsk. The abundance reported in the study by Osowiecki ranged from 12000 to 13500 ind. m^{-2}. These figures correspond with those at many stations on Długa Mielizna in 2008. One of the reasons for this situation is the stabilization of environmental conditions due to the presence of seagrass and the protection of animals provided by leaves, e.g. against strong water currents (Boström & Bonsdorff 2000). There were 13 taxa living exclusively among seagrasses. Comparing these results with the study conducted by Smoła (2012) in a seagrass meadow near Gdynia, four of these 13 taxa were present only on the seagrass on Długa Mielizna; the four other taxa were also recorded by Smoła. We can conclude that this meadow is also more valuable than other meadows in Puck Bay, due to the occurrence of very rare species, such as *I. balthica* and *G. inaequicauda*.

The uniqueness of these 13 taxa on the vegetation-covered bottom is corroborated by the research of Boström & Bonsdorff (1997), where taxa such as *T. fluviatilis*, *E. crustulenta* or *Idotea* spp. were found only in the meadows, and not on the bare sand. Among the plants, Kendzierska et al. (2014) found a species of leech (*P. pojmanskae*), described in the Gulf of Gdańsk for the first time and not observed in other areas. However, there was a small number of non-indigenous taxa in our studies. The fact that there were only four of them (*Marenzelleria* spp., *A. improvisus*, *G. tigrinus* and *M. arenaria*), compared to eight taxa reported in the study by Janas & Kendzierska (2014), demonstrates the natural character and good stability of this habitat.

Similar differences between the underwater meadow and the bare sandy bottom, demonstrated in this work, have been also found in other parts of Europe, for example in Norwegian waters (Frederiksen et al. 2010). Those authors found twice as many organisms on the vegetation-covered seabed compared to the sandy bottom. The number of species off the coasts of Norway (113) is much higher than in Puck Bay, but at least 35 of them were represented by a single specimen.

It can be concluded that the environmental status of Długa Mielizna is good. This result is rather better than that obtained in other researches, e.g. Korpinen et al. (2013), which shows that the whole Gulf of Gdańsk is an area subject to moderate or strong human impact, especially the bottom habitats. In this case, the importance of seagrass as an indicator is even greater, because it can be regarded as an indication of good habitat quality. It may be objected that seagrasses and animals living among them are not good indicators for this area, because the bay freezes over every winter. However, Jankowska et al. (2014) showed that the meadows in the Gulf of Gdańsk are among those that do not decay during winter, so they are present throughout the year.

All the above arguments show that the presence of vascular plants is essential for good environmental quality. They not only enhance the complexity and beauty of the seascape, but also the biodiversity of species living among the leaves and in the sediment. Bare sand as a habitat is more likely to be destroyed and fragmented, for example, by an unexpectedly powerful wave, which renders such an unstable habitat vulnerable to sudden changes. Many studies have shown that habitats with vascular plants are much more valuable: they have a higher degree of biodiversity with greater abundance and environmental quality (Boström & Bonsdorff 1997;

2000). A more stable and diverse habitat with more species makes seagrass meadows more useful for environmental quality research than bare sand. This study has demonstrated that seagrass meadows are inhabited by diverse benthic communities with many crustaceans that are sensitive to disturbances. Changes in their environment can thus be more easily monitored than in the benthic communities on the bare sand. These results can be very useful for further studies, either for comparison with other regions of the Baltic, or as historical, reference data for future work in the same region.

Conclusions

The taxonomic diversity of macrozoobenthos in the seagrass meadow on Długa Mielizna is very high (33 taxa). There are also statistically significant differences in the number of taxa, abundance and biomass as well as the Shannon and Benthic Quality Indices between bare sand and bottom covered with vascular plants in favor of seagrasses.

The environmental quality of Długa Mielizna, assessed using the benthic fauna, is good.

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