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Spatial distribution of biological and physical sediment parameters in the western Gulf of Gdańsk*

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Katarzyna Huzarska

Institute of Oceanology,
Polish Academy of Sciences,
Powstańców Warszawy 55, 81–712 Sopot, Poland;

e-mail: keyla28@gmail.com

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Abstract

The ongoing processes of surface sediments and their biological activity are highly dynamic. Sediment samples for the current study were collected at 48 stations in the Gulf of Gdańsk in May 2006, and the following sediment parameters were analysed: grain size distribution, water volume, permeability, organic matter content, chlorophyll *a* and EPS carbohydrate concentrations. The spatial distributions of the different parameters varied distinctly, which suggested a strongly diversified bottom environment. The results obtained were used to create spatial distribution maps, and statistical analyses of the results showed that the Gulf's bottom can be divided into four areas impacted by different parameters: (1) the inner Puck Bay; (2) the outer Puck Bay; (3) the outer Gulf of Gdańsk; (4) the open sea. Distinct correlations between microbenthic activity, expressed as carbohydrate and chlorophyll concentrations, and sediment physical parameters were noted. The bottom of the Gulf of Gdańsk appeared to be strongly influenced by wave motion. This led to the conclusion that the most dynamic areas are the shallow coastal zones, which play important roles in water purification processes

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and in the proper functioning of the Gulf of Gdańsk ecosystem. This study of the spatial distribution of sediment parameters is the first of its kind, and the widest-ranging study of sediments ever to be conducted in this region.

1. Introduction

Sediment parameters and their spatial distribution have been investigated for decades. Håkanson & Jansson (1983) and Lebo & Reuter (1995) showed that distribution patterns can depend on different physical, biological, chemical and sedimentological processes. The surface sediment layer has been investigated in the greatest detail, because it contains the most freshly-deposited material and its productivity is high. This layer is biologically and chemically very active and is characterized by abundant microbenthic and meiofauna communities (Wetzel 1983). One of the most important activities of the microphytobenthos is primary production, and this is followed by the secretion of mucilage comprised of extracellular polymeric substances (EPS) (Decho 1990, Wingender et al. 1999, Wotton 2002). Together with chloropigments, these secretions are indicators of the biological activity and biomass of the microphytobenthos in sediments (Garrigue 1998, Menden-Deuer & Lessard 2000). Strictly correlated in most cases (Underwood et al. 1995), they can affect the physical properties of sediments (Paterson & Black 1999) as well as some of the processes occurring in the interface between the sediments and the water. This is most evident in intertidal flats, where fine, cohesive material is deposited and in which microphytobenthos is abundant (De Brouwer et al. 1999, Decho 2000, Ziervogel & Forester 2005). The interactions between physical and biological factors are not as obvious, however, and are not well understood in sandy sediments and sub-tidal zones. Sandy sea bottoms, especially those in coastal zones, can play significant roles in natural sewage treatment (Węsławski et al. 2005). Knowledge of sediment conditions and the spatial distribution of various parameters could be key to understanding water purification processes and the magnitude and directions of sediment transport. This, in turn, could supply relevant information in regions where tourism is highly developed; the Gulf of Gdańsk is definitely one such area. Generally speaking, little is known about the spatial distribution of sediment parameters in the Baltic Sea. The only publications on this topic, which focus on sediment conditions and the effect of biogenic factors on them, are from Germany and Sweden (Ziervogel 2003). To date no such studies have been conducted in the Polish part of the Baltic Sea. Moreover, the spatial distribution of sediment properties and microbial activity and the correlation between them have also been underestimated and/or neglected in studies.

The present paper focuses on the spatial differentiation of the biological and physical properties of surface sediments in the Gulf of Gdańsk. This knowledge could be crucial to the acquisition of a better understanding of the processes continually occurring in the study area, and could be used to predict some environmental changes and interactions between sediments and the water column. The significance of the relationships between the biological and physical properties of the sea bottom needs to be evaluated, and the links between microbial activity in and the physical properties of sandy sediments have to be identified. This is especially true of the subtidal areas of seas. Such a wide-ranging study has never yet been conducted in the Gulf of Gdańsk.

2. Study area

The Gulf of Gdańsk is located in the southern part of the Baltic Sea. The northern border is a line extending between Cape Rozewie and Cape Taran on the Sambian Peninsula (Figure 1). The four sub-regions of the Gulf are: (1) the shallow (maximum depth 10 m) inner Puck Bay, closed off by the submerged sandbank known as 'Ryf Mew'; (2) the deeper (maximum depth 54 m) outer Puck Bay, with a more diversified bottom morphology, extending eastwards to a line between Hel and the Orłowo Cape; (3) the Gulf of Gdańsk proper (average depth 70 m), which is significantly impacted by riverine input from the mouth of the River Vistula; (4) the open sea, which is dominated by the open sea circulation and processes (Majewski 1990,

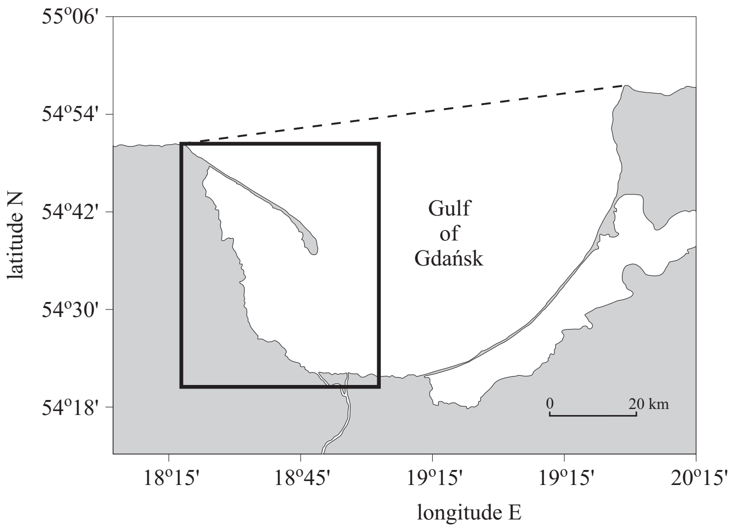

Figure 1. Location of the study area in the Gulf of Gdańsk, dashed black line – northern boundary of the Gulf of Gdańsk, black rectangle – study area

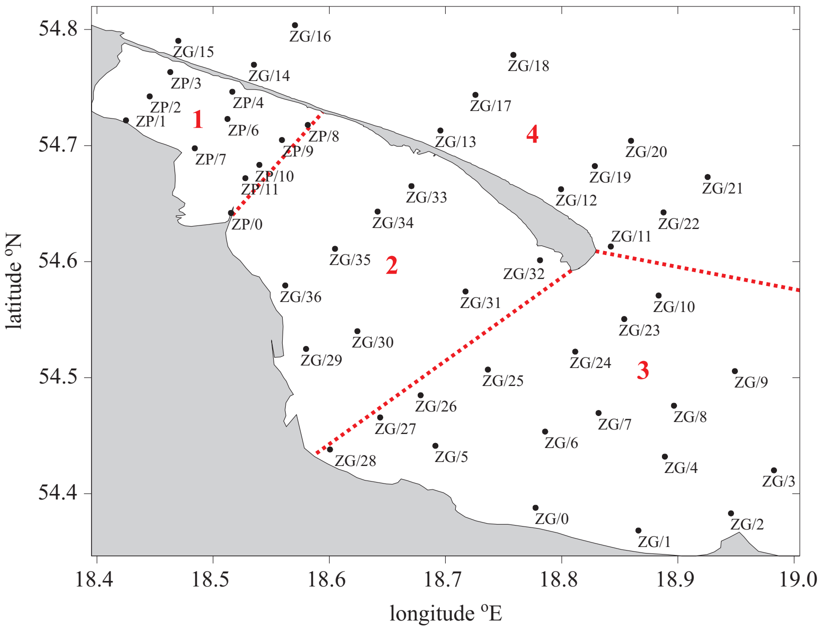

Figure 2. Sampling station locations and division of study area (dotted red lines); ZG – samples collected with Van Veen grab from r/v 'Oceania', ZP – samples collected by diver from pontoon, 1 – inner Puck Bay, 2 – outer Puck Bay, 3 – Gulf of Gdańsk proper, 4 – open sea

Nowacki 1993). These divisions are illustrated in Figure 2. Puck Bay is the shallowest (mean depth 5 m) of the areas, and the processes occurring there are similar to those in the coastal zones. Sunlight reaches to the bottom, and the entire water column is mixed. Thus, this area is rather uniform in water temperature, oxygen content and nutrient content, both horizontally and vertically. There is an underwater rubbish dump located centrally at the bottom of the outer Puck Bay. This anthropogenic muddy upper sediment layer can significantly affect the environmental conditions in this area. The third region, the inner Gulf of Gdańsk, is impacted by waters from the River Vistula. Riverine input and the mixing of fresh and brackish waters give rise to very specific environmental conditions there. The bottom morphology and bottom currents generated by the Vistula mouth are unique to this region. The open sea area, located to the north and north-east of the Hel Peninsula, is characterized by much greater depths; as a result, the bottom is affected only by bottom currents, and the water column is stratified throughout the year. The Gulf of Gdańsk was formed mainly by the last continental glacier during the Vistula glaciation period, by deglaciation in this region, and later by sea activity. The Gulf of Gdańsk lies in the temperate zone, and the prevailing (40–50%) winds are from the west or south-west (Cyberski & Szefler 1993). The average water level in the Gulf of Gdańsk is correlated with seasonal fluctuations throughout the Baltic Sea; levels are lower from February to June ($\sim$470 cm) and higher from July to December ($\sim$560 cm). Currents are determined by winds, and can vary even on short temporal and small spatial scales (Kowalik 1990). Because of this strong variability, the flow pattern for this region is irregular and non-uniform, and is very difficult to measure and interpret (Robakiewicz 2009). Current direction and intensity are strongly related to wind direction, duration and speed and to shoreline shapes. Currents flow parallel to the shore in shallow coastal zones, and current speeds in these zones are frequently less than 50 cm s^{-1} (Kowalik 1990). Surface and bottom currents are equally dependent on winds, but their directions and speeds can differ distinctly.

3. Material and methods

3.1. Sampling

The investigation was based on sampling performed at 48 stations located in the Gulf of Gdańsk (Figure 1) during a r/v 'Oceania' cruise in the deeper parts of the gulf, and during a pontoon expedition in the shallow parts of the Puck Bay in May 2006. Sediment samples were collected with a Van Veen grab during the r/v 'Oceania' cruise, and by a diver during the pontoon expedition. Water depth was recorded at each sampling station (Table 1), and these are illustrated on the map in Figure 3a. The sediment surface samples collected for determinations of basic sediment parameters, chlorophyll *a* concentrations and EPS carbohydrate concentrations were frozen and stored in the dark until analysis. Sediment cores (5 cm long, 3.6 cm diameter) were collected to measure permeability and were analysed within a few hours of collection.

3.2. Sediment parameters

The following parameters were analysed in all of the sediment samples collected: (1) grain size distribution – in sandy sediments this was determined by sieving and in fine sediments with the pipette method; (2) water volume was determined as the difference between wet and dry weight after the sediments had been dried at 60°C for 24 h; (3) organic matter content was determined as the loss on ignition (LOI): the difference between dry and ignited weight after the sediments had been ignited in ceramic crucibles at 450°C for 24 h was then calculated as a percentage.

Table 1. Sampling station coordinates and water depths

Sampling station	Longitude °N	Latitude °E	Water depth [m]
ZG/0	54.3872	18.7770	−8
ZG/1	54.3675	18.8652	−13
ZG/2	54.3823	18.9445	−16
ZG/3	54.4195	18.9813	−37
ZG/4	54.4313	18.8878	−27
ZG/5	54.4407	18.6912	−12
ZG/6	54.4530	18.7852	−21
ZG/7	54.4690	18.8310	−29
ZG/8	54.4753	18.8957	−62
ZG/9	54.5052	18.9478	−68
ZG/10	54.5705	18.8825	−69
ZG/11	54.6128	18.8415	−45
ZG/12	54.6623	18.7988	−15
ZG/13	54.7130	18.6955	−20
ZG/14	54.7698	18.5357	−12
ZG/15	54.7905	18.4708	−12
ZG/16	54.8040	18.5708	−20
ZG/17	54.7438	18.7255	−28
ZG/18	54.7783	18.7580	−81
ZG/19	54.6823	18.8278	−77
ZG/20	54.7042	18.8588	−26
ZG/21	54.6728	18.9245	−85
ZG/22	54.6423	18.8867	−80
ZG/23	54.5502	18.8530	−71
ZG/24	54.5220	18.8110	−35
ZG/25	54.5065	18.7362	−31
ZG/26	54.4843	18.6785	−15
ZG/27	54.4652	18.6438	−12
ZG/28	54.4375	18.6008	−8
ZG/29	54.5243	18.5803	−7
ZG/30	54.5397	18.6243	−22
ZG/31	54.5740	18.7170	−51
ZG/32	54.6010	18.7808	−48
ZG/33	54.6650	18.6707	−28
ZG/34	54.6430	18.6417	−34
ZG/35	54.6108	18.6052	−23
ZG/36	54.5792	18.5625	−11
ZP/0	54.6418	18.5160	−0.5

Sampling station	Longitude °N	Latitude °E	Water depth [m]
ZP/1	54.7218	18.4260	−2.1
ZP/2	54.7425	18.4463	−2.7
ZP/3	54.7635	18.4640	−1
ZP/4	54.7465	18.5172	−1.4
ZP/6	54.7230	18.5130	−2.2
ZP/7	54.6977	18.4850	−4.2
ZP/8	54.7178	18.5818	−0.8
ZP/9	54.7048	18.5597	−0.4
ZP/10	54.6833	18.5403	−0.6
ZP/11	54.6718	18.5283	−0.5

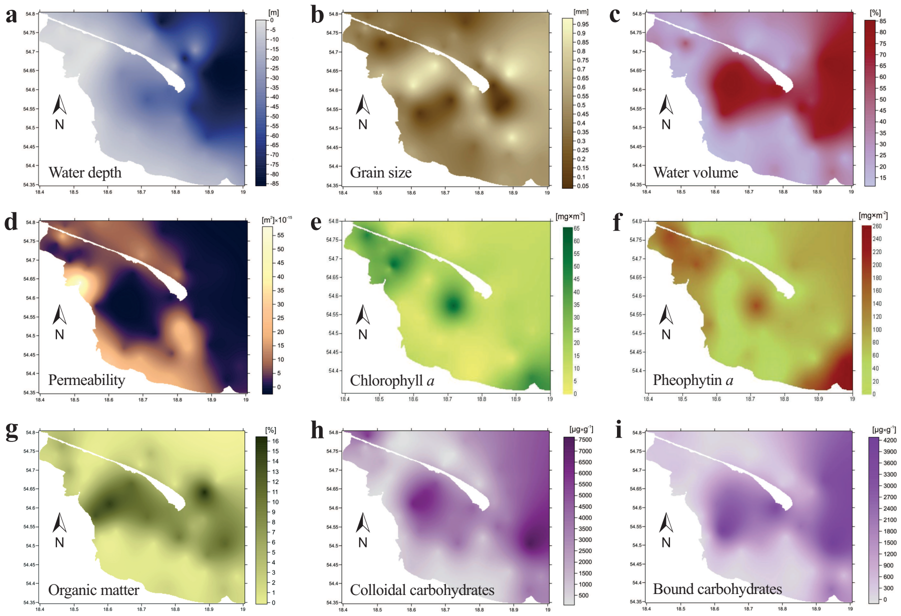

Figure 3. Spatial distribution of sediment parameters in the Gulf of Gdańsk; a) water depth, b) grain size distribution, c) water volume, d) permeability, e) chlorophyll *a* concentration, f) phaeophytin *a* concentration, g) organic matter content, h) colloidal carbohydrates, i) bound carbohydrate

3.3. Carbohydrate concentration

Carbohydrate concentrations were determined by phenol-sulphuric acid assay (Dubois et al. 1956, Underwood et al. 1995). D-glucose dilutions were used as the standard. Two fractions were analysed: (1) water extractable – determined as colloidal carbohydrates, and (2) EDTA extractable – determined as bound carbohydrates.

3.3.1. Colloidal fraction

1 ml of Milli-Q water was added to test tubes containing 100 mg of lyophilized sediment. 0.5 ml 5% phenol, followed immediately by 2.5 ml of conc. (minimum 95%) H_2SO_4, were added to the samples and cooled at room temperature for at least 30 min. Absorbance was recorded at 485 nm on a spectrophotometer calibrated with Milli-Q water.

3.3.2. Bound fraction

200 mg of lyophilized sediment was transferred to centrifuge tubes to which 4 ml 100 mM Na_2EDTA were added. The samples were stirred with a vortex, left in a 25°C water bath for 30 min, and then centrifuged at

4000 g for 15 min. 1 ml of the supernatant was transferred to the test tubes and treated with 5% phenol and concentrated H_2SO_4 as above for the total fraction. Absorbance was recorded at 485 nm. The carbohydrate concentrations were calculated as a function of absorbance and sediment weight.

3.4. Chlorophyll *a*

Sediment samples frozen at $-20°C$ were mixed with 90% acetone (1.5 cm^3 acetone per cm^3 of sediment sample) and stored in dark, cold conditions for 24 h, transferred to test tubes and centrifuged at 9200 rpm for 30 min. The supernatant was transferred to a 1 cm glass spectrophotometric cuvette for the absorbance measurement. The spectrophotometer was calibrated with 90% acetone. Absorbance measurements were done in two steps: (1) chlorophyll *a* was measured at a wavelength of 750 nm and turbidity at a wavelength of 665 nm; (2) phaeophytin, with 2 drops (~ 45 μl) of 10% HCl added for chlorophyll degradation, was measured at a wavelength of 750 nm, while turbidity was measured at 665 nm. The results were calculated with the standard Lorenz equation (1967), then recalculated to mg g^{-2} units.

3.5. Statistics

The data distribution was non-normal, so non-parametric statistical analyses were performed. Kruskal-Wallis ANOVA was used to analyse spatial changes in sediment parameters, and Spearman's rank correlation was used to analyse relationships among the investigated parameters. The standard non-parametric Mann-Whitney U test was used to compare variability among the four areas. The results obtained were considered statistically significant at $p < 0.05$.

4. Results

Grain size distribution

Sediment grain sizes ranged from 0.04 mm (station ZG/23) to 0.99 mm (station ZG/22) (average 0.45 mm; $SD = 0.26$), which indicates that sediment types were diverse and ranged from fine-grained silts to coarse sands. The dominant sediment type was medium-grained sand, which covered 48.8% of the investigated area (Figure 3b). This parameter was scattered and exhibited no pattern of diversification.

Water volume

Sediment water volume ranged from 26.9% (station ZG/1) near the entrance to the Port of Gdańsk to 99.8% (station ZG/34) (average 55.7%; SD = 23.1). Sediments with high water volumes were deposited in the inner parts of the Gulf, while those with relatively lower volumes occurred in the shallow coastal zones of the study area (Figure 3c).

Permeability

Sediment permeability was analysed at 30 sampling stations. The sediments were too cohesive for measurement at 18 stations. Permeability ranged from 1.2×10^{-15} m^2 (station ZG/7) to 6.0×10^{-14} m^2 (station ZP/0) (average 7.0×10^{-15} m^2; SD = 1×10^{-14}). A considerable part of the study area had impermeable or slightly permeable sediments. Higher permeability was common in the coastal zone (Figure 3d).

Organic matter

The content of organic matter in the sediments was variable (Figure 3g) ranging from 0.2% (ZG/15) to 16.6% (ZG/21) (average 3.6%; SD = 4.6). The highest values were noted in the central part of the Gulf along the line between the sandbank and the eastern edge of the study area. The rest of the sediments were similarly poor in organic matter.

Chlorophyll *a*

Chloropigment concentrations in the sediments varied from 0.8 mg m^{-2} (ZG/0) to 61.8 mg m^{-2} (ZG/31) (average 18.8 mg m^{-2}; SD = 15.8) for chlorophyll *a*, and from 1.3 mg m^{-2} (ZG/0) to 253.0 mg m^{-2} (ZG/3) (average 86.5 mg m^{-2}; SD = 56.2) for phaeophytin *a*. Concentrations of both chlorophyll *a* (Figure 3e) and phaeophytin *a* (Figure 3f) were relatively low throughout the study area. Higher values were noted on the shallow

Table 2. Kruskal-Wallis test values (H) and significance levels (p) for statistically significant spatial differentiations of the sediment parameters

Analyzed parameters	Kruskal-Wallis test (H)	Significance level (p)
permeability	8.08	0.04
chlorophyll *a*	18.80	0.0003
pheophytin *a*	7.81	0.05
organic matter	9.51	0.02
colloidal carbohydrates	8.63	0.035
bound carbohydrates	11.90	0.008

Table 3. Spearman's rank correlation coefficient R for all statistically significant correlations between measured sediment parameters; significance level $p < 0.05$

	water depth	grain size	permeability	water volume	chlorophyll *a*	pheophytin *a*	organic matter	colloidal carbohydrates	bound carbohydrates
water depth	x	–	0.59	−0.38	0.38	0.34	−0.38	−0.53	−0.62
grain size	–	x	–	–	–	–	–	–	–
permeability	0.59	–	x	−0.76	–	–	−0.69	−0.78	−0.82
water volume	−0.38	–	−0.76	x	–	–	0.81	0.60	0.64
chlorophyll *a*	0.38	–	–	–	x	0.78	–	–	–
pheophytin *a*	0.34	–	–	–	0.78	x	–	–	–
organic matter	−0.38	–	−0.69	0.81	–	–	x	0.62	0.69
colloidal carbohydrates	−0.53	–	−0.78	0.60	–	–	0.62	x	0.90
bound carbohydrates	−0.62	–	−0.82	0.64	–	–	0.69	0.90	x

parts of the bottom in the inner Puck Bay and near the Vistula River mouth.

Carbohydrates

Two fractions of carbohydrates, colloidal and bound, were analysed, and relatively wide ranges of values were noted for both. Concentrations of the colloidal fraction (Figure 3h) varied from 102.7 μg g^{-1} (ZG/17) to 7634.8 μg g^{-1} (ZG/9) (average 2184.5 μg g^{-1}; SD = 1952.7). Concentrations of the bound fraction (Figure 3i) were lower, ranging from 75.0 μg g^{-1} (ZG/16 and ZG/17) to 4286.6 μg g^{-1} (ZG/9) (average 921.4 μg g^{-1}; SD = 1114.0). Concentrations of both fractions were higher in the bottom sediments in deeper waters.

Statistics

The four separate areas of the study area were analysed statisticaly: (1) inner Puck Bay (Puck Basin); (2) outer Puck Bay; (3) outer Gulf of Gdańsk; (4) open sea area. This division (Figure 1) was made according to the morphometric and environmental differences among the areas described in the study site section of this paper. The spatial differentiation of sediment parameters (non-parametric K-W ANOVA) was statistically significant for nearly all of them (Table 2). A lack of distinct diversification was noted only for grain size distribution and water volume. Significance among the parameters investigated was analysed using the non-parametric Spearman rank test at a significance coefficient of $p < 0.05$. The values of coefficient (R) are presented in Table 3. With the exception of grain size distribution, nearly all of the parameters were correlated with water depth, but strong correlations with depth were noted only for permeability and carbohydrate concentration. Distinct, strong correlations were recorded for parameters such as permeability, water volume, organic matter content and carbohydrate concentrations. They appeared to be highly interrelated. Other parameters, such as grain size distribution or chlorophyll concentration were weak or moderately correlated.

5. Discussion

5.1. Sediment parameters in the western Gulf of Gdańsk

That there is diversification in some sediment parameters in the Gulf of Gdańsk, such as grain size distribution or organic matter, is a relatively well known fact. Little is known, however, about chlorophyll *a* concentrations. No thorough investigations of the spatial distribution of parameters such as porosity or permeability have yet been performed, and neither have any studies of EPS and its role in the sediments been conducted in this region. However, grain size distribution and organic matter in sediments have been investigated by, for example, Pieczka (1980), Kępińska & Wypych (1990) and Uścinowicz & Zachowicz (1992). All these results are generally in agreement; they are also consistent with those of the present study. There are only slight differences, firstly in the contribution and distribution of fine and coarse sediments, and secondly in organic matter richness in the vicinity of the River Vistula. Differences may be due to changes in the sea bottom that occur over time, but also from the use of different sampling and analytical methods. Anthropogenic factors, which were stronger than two decades ago, might also be of significance. Chlorophyll *a* was investigated previously by Szymczak-Żyła (2006) and Szymczak-Żyła & Kowalewska (2007). Their results were alike and were generally confirmed by those of the present study. Only the concentrations at the Vistula mouth were distinct, but this could have been due to the different season in which the sampling campaign was conducted and to the highly diversified environmental parameters in this area. The sediment permeability map of the Gulf of Gdańsk indicates that the sediments in the shallow parts of the Gulf, i.e. the coastal zones and the inner Puck Bay, were more permeable. Sediments deposited in the central basin of the Gulf are impacted by the submerged rubbish dump located in this area. The permeability distribution is the result of the combined interactions of various factors, including some of the other parameters studied. Analysis of their patterns demonstrates clearly that permeability is strongly compatible with most of them. This suggests that environmental conditions in benthic systems are important as regards the vertical water flux through sediments, which takes place in the shallow parts of the Gulf. The spatial distributions of both fractions of EPS, expressed as carbohydrate concentrations, are significantly affected by the distribution of other parameters. Aerobic conditions in the upper sediment layer and benthic organism activity are also important to this. Maps of the EPS spatial distribution could be helpful in the estimation of the areas of the bottom, which are more or less stable and can undergo with the erosion and transportation processes in different rates (Le Hir et al. 2007, Borsje et al. 2008).

5.2. Environment dynamics and sediment transportation

The main factor shaping the condition and functioning of the sea bottom is the dynamics of the environment. Sediments are continuously affected by numerous processes that build and destroy the sea bottom. The macro-scale investigation of other sediment parameters and their spatial distribution throughout the Gulf described in this paper is the first such study to be conducted in the Gulf of Gdańsk. Knowledge regarding the spatial distribution of the sediment parameters under investigation may provide a basis for predicting which parts of the sea bottom will be subject to more or less intense erosion/accumulation. This, in turn, could make a significant contribution to understanding the intensity and directions of sediment transport in the study area and of the condition of the semi-enclosed Gulf of Gdańsk ecosystem. If the various parameters were analysed separately, some important facts could quite easily be overlooked and parameter patchiness might be misinterpreted. To prevent this, we need some additional information. Water depth is a highly relevant factor; wave motion can affect the bottom only at depths equal to or less than half of the wave length ($h \leq 1/2$ L). The most frequent wave lengths in the Gulf of Gdańsk are 30–40 m (Paszkiewicz 1990), which means that the areas where waves can affect the bottom and cause erosion are restricted to the coastal zones and the inner Puck Bay, where the water depth is no greater than 15–20 m. Deeper areas can be affected and rebuilt by waves only during storms or by bottom currents. Urbański et al. (2007) argued that the most important factor for sediment erosion is the orbital velocity above the sea bottom. Maps of this parameter indicate that only the coastal zones and the inner Puck Bay can really be affected by wave-generated currents. This suggests that the parts of the bottom exposed to erosion and re-suspension are, in fact, only the shallow ones, as mentioned above. The bottom currents in the Gulf of Gdańsk act more as local phenomena and can affect sediments in restricted areas only. This knowledge can significantly improve the interpretation of the maps produced by this project and in more accurate analyses of processes and interactions occurring among bottom parameters.

5.3. Microbiological activity and sediment condition

It is important to emphasize that none of the parameters should be interpreted singly. Of course, erosion will be more pronounced when porosity, or water volume, is higher or when sediment grain size is finer. However, the only way to predict which areas are more resistant to the influence of water, and thus more stable, is to consider all of the parameters together with information on water depth. To date, sediment condition has been assessed primarily on the basis of physical parameters. Biological parameters, such as chlorophyll and EPS concentrations, are probably as relevant, because they are both indicators of biological activity and benthos biodiversity. The occurrence of EPS is an important factor for sandy sediment stability (Madsen et al. 1993, Meadows et al. 1994, Perkins et al. 2004). The map of the spatial distribution of these substances may indicate that concentrations are relatively high and can effectively stabilize sediments only in deeper parts of the sea bottom, where finer sediments are deposited. Huzarska (2011) argues, however, that in the sandy sediments of the Gulf of Gdańsk, the stabilizing effect is relevant even at low concentrations of approximately 150 μg g^{-1} for the colloidal fraction and 50 μg g^{-1} for the bound fraction. This leads to the conclusion that sediment stabilization could occur throughout the Gulf. This includes the highly dynamic shallow zones, where intense sediment transport can be expected. EPS can also affect sediment permeability by clogging interstitial spaces in sandy sediments, which make up the majority of sediments in the Gulf of Gdańsk (Baveye et al. 1998). Huzarska (2011) demonstrates that EPS concentrations > 100 μg g^{-1} can significantly reduce permeability in the sandy sediments of the Gulf of Gdańsk. Consequently, it can be assumed that permeability is generally affected by microbial activity throughout the region. The permeability parameter provides information about sediment filtration capabilities. This, in turn, helps to understand the water purification capabilities of the shallow coastal zone (Węsławski et al. 2005). This process is one of the most important aspects of ecosystem functioning, especially in regions like the Gulf of Gdańsk, which is a semi-enclosed basin, receiving large inputs of eutrophic, riverine waters but low inputs of seawater. Developing a better understanding of how this system works is necessary, since this part of the coastal zone, one of the most popular tourist areas in northern Poland, is under tremendous anthropogenic pressure. Information about filtration productivity can contribute to a better and more balanced utilization of the Gulf's beaches and seawater. Filtration productivity is also an indicator of the distribution of organic matter and oxygen from the water column to sediments. Oxygen penetration influences the decomposition ratio of organic matter (Kristensen et al. 1995, Hulthe et al. 1998, Dauwe et al. 2001) and the metabolic activity of benthic organisms (Aller & Aller 1998). This influences nitrification/denitrification processes and can be helpful in predicting occurrences of anaerobic death zones in the Gulf.

5.4. Summary and conclusions

The bottom of the Gulf of Gdańsk is highly diversified. Sediment transport and water filtration are linked primarily to shallow waters, where wave motion can disrupt the balance of the sediment/water column interface. The interdependence of these processes and sediment properties is apparent. Wave motion appears to be the most important factor affecting sediment conditions and the diversification patterns of this parameter. Consequently, the most dynamic bottom areas are those in the shallow waters of the coastal zone. These are also crucial for the proper functioning of the Gulf of Gdańsk ecosystem. An interesting, novel discovery made during the current study is that biological factors such as microbial activity expressed by EPS and chlorophyll concentrations play significant roles in these processes.

The data obtained during this study paint only a transient picture of the state and condition of the sediments in the warm, late spring. More detailed investigations that focus on temporal, not just spatial, variability should be undertaken. The knowledge gained from such studies would be useful for developing a better understanding of all the processes occurring at both macro- and micro-scales in the upper sediment layer of the sea bottom. This is particularly pertinent in the semi-enclosed ecosystem of the Gulf of Gdańsk, where ecosystem balance is intimately linked with human impact and where, in turn, human activity is totally reliant on the condition of this ecosystem.

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