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Article

Bioindicative potential of diatoms and ostracods in the Odra mouth environment quality assessment

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With 6 figures and 2 tables

Abstract: This study aimed to determine the potential of diatoms and ostracods as bioindicators for environmental quality assessments of the Odra river mouth. Over the course of the study period (2005–2006), 27 ostracod taxa and 255 diatom taxa were identified. The most frequent and most abundant diatoms were *Navicula gregaria, Rhoicosphenia abbreviata* and *Tabularia fasciculata*. Additionally, *Amphora pediculus, Cocconeis pediculus, C. placentula, Planothidium engelbrechtii* and *P. delicatulum* were important species in this sampling area. *Cypria ophtalmica, Cytheromorpha fuscata* and *Cyprideis torosa* were dominant amongst the ostracod fauna. Diatoms and ostracods proved to be useful and complementary indicators of ecological conditions in the Odra mouth. The taxonomic composition of both groups indicated that the Odra mouth waters were strongly eutrophic, with temporal and spatial variations in salinity (ranging from oligohaline to β-mesohaline), and with a slightly alkaline pH. The southern part of the study area was influenced by fresh, nutrient rich waters of the Odra river, while the northern part was more impacted by the brackish waters of the Baltic Sea.

Key words: diatoms, ostracods, Szczecin Lagoon, Odra River, bioindication

Introduction

The Odra mouth is a unique environment for aquatic organisms. The temporal and spatial variability of its physical and chemical parameters is reflected in its high floral and faunal diversity. Some groups of organisms, e.g., diatoms or ostracods, are particularly sensitive to environmental changes and react rapidly through variations in taxonomic composition and abundance. Both groups have a high potential for bioindication due to their relatively well-known autecology, narrow ecological tolerance and daily (such as diatoms) to annual life cycles (such as some ostracod taxa). As a result of these features, bioindicators can respond rapidly to periodic changes in environmental conditions, and since both ostracod shells and diatom valves are well preserved in sediments, they are commonly used as proxies in paleoecological and paleoclimatic reconstructions.

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Diatom bioindication potential has been used in a range of applications (e.g., Smol & Stoermer 2010), including (paleo) environment quality assessments of brackish-water ecosystems, riverine mouths and estuaries (e.g., Snoeijs & Weckström 2010, Trobajo & Sullivan 2010, Cooper et al. 2010). The applications of ostracods in bioindication and environmental research (e.g., Milhau et al. 1997, Mezquita et al. 1999), and paleoenvironmental and paleoclimatic reconstructions are reviewed by Frenzel 1991, Boomer & Eisenhouer 2002, Frenzel & Viehberg 2004, Frenzel & Boomer 2005.

It is common for only a single fossil bioindicator group to be used in reconstructions: e.g., Witkowski 1994, Kwandrans et al. 1998, Westman & Sohlenius 1999 (diatoms), or Frenzel (1991), Frenzel & Viehberg (2004) (ostracods), although several studies on fossil material have used multiple proxies and assessed the coherence of the results, e.g., Reed 1996, Schwalb et al. 1998, Edwards et al. 2006, Franz et al. 2006, Hayward et al. 2006, Bunbury & Gajewski 2008). However, there are few examples in which both diatoms and ostracods have been used for the assessment of the contemporary environment.

Little data on ostracod faunas from the lowest reaches of the Odra river are available. Previous studies investigated the quantitative relationships between general abundance, biomass and other meiobenthos components (Radziejewska & Drzycimski, 1988 and 1990; Wolnomiejski & Grygiel 1989; 1994), but beside Frenzel (1991) and Frenzel & Viehberg (2004), and unpublished data by Scharf and Frenzel, all originating from the German part of the Odra river mouth (Kleines Haff), no data on the taxonomic composition of ostracods in the study area were available.

More data on ostracods are available from the other parts of the Baltic Sea basin. The reviews by Frenzel & Boomer (2005) and Frenzel et al. (2005) provide up to date information on the ostracod studies of shallow brackish-water lagoons on the German coast, which is the region adjacent to the Szczecin Lagoon. Their studies concerned the modern ostracod assemblages inhabiting macrophyte-rich regions, and explored the potential use of ostracods in paleoenvironmental reconstructions, while the latest work by Frenzel et al. (2010) provides a paleo- and ecological primer for postglacial to recent ostracods of the Baltic Sea. Frenzel et al. (2010) show that ostracod taxa are useful proxies for salinity, temperature, oxygen, water depth and energy, habitat and substrate type.

The earliest studies documenting the Odra mouth diatom assemblages were performed by German scientists. These were either plankton studies (Hensen 1887–1891), or general biological studies (Neuhaus 1933), but they also included notes on diatoms.

Post-second world war studies focused on the diatom flora as a component of the phytoplankton, and the impact of the Baltic waters on the distribution and abundance of diatoms in the Szczecin Lagoon (Zembrzuska 1962, 1967; Pliński 1979). Further studies focused on the changes in the phytoplankton composition, that were associated with the rapid increase in eutrophication of the basin (Pliński 1973, 1979), while more recent work, based on analyses of fossil and subfossil diatom assemblages (Borówka et al. 1999, Andrén 1999, Witkowski et al. 2003, 2004), have attempted to reconstruct the changing environmental conditions that prevailed during the formation of the Szczecin Lagoon sediments. Bąk et al. (2001, 2004, 2006) studied the structure and variability of the Szczecin Lagoon diatom assemblages, and the impact of the Odra waters on the diatom flora.

The aim of this study is to determine the taxonomic composition of the ostracod fauna dwelling in the Odra mouth, and, 5 years on, to re-examine the taxonomic composition of its diatom assemblages in order to evaluate the possible changes that this environment has undergone. We believe that an ostracod and diatom-based assessment of the environmental quality of the Odra mouth, and a comparison of results from both proxies will contribute to the future paleoecological and paleoclimatic reconstructions for this area. It may also aid the development of an understanding of the differences that arise during the interpretation of studies on diatom and ostracod taphocenoses.

Study area

The Szczecin Lagoon, along with Międzyodrze, Dąbie Lake, Roztoka Odrzańska and the straits of Świna, Dziwna and Piana form the Odra mouth system. The Lagoon alone is a vast flow-through coastal reservoir. It is separated from the open sea by the islands of Uznam (Usedom) and Wolin, and the main link for water exchange between the Lagoon and the Baltic Sea, known as the Świna Gate, crosses both islands (Majewski 1980, Fig. 1). Approximately 75 % of the water exchange takes place through the Świna strait and Kanał Piastowski; the Piana (Peenestrom) and Dziwna straits exchange ca. 13 % and 12 % of the waters, respectively (Buckmann et al. 1998).

The total area of the Szczecin Lagoon equals 687 km^2. The bottom of the Lagoon has a monotonous morphology; its depth averages 3.8 m (Majewski 1980, Osadczuk 1997). The Świna strait is 16 km long, 200–300 m wide, up to 15 m deep, and occupies an area of 27 km^2. The Dziwna strait is 31.5 km long, up to 3 m deep, and occupies an area of 53 km^2; its width varies from 100 m to a few km (in pools).

Mean perennial water salinity in the Lagoon amounts to 1.2 ‰ (WIOŚ 2002), but salinity shows both temporal and spatial variation. The temporal salinity changes are closely linked to the annual cycle of riverine water discharge to the Lagoon. The highest salinities occur in the immediate proximity of the straits and within the artificial navigation channel, but during the larger marine influxes, salinities of up to 6–7 ‰ are recorded in the bottom waters of the Lagoon (Wypych 1970). In the straits, the salinity is usually higher than further South in the Lagoon, and can reach up to 8 ‰.

The Szczecin Lagoon is an environment of contrasting fresh- and marine-water influences. The average salinity of the Lagoon is not a limiting factor for the majority of freshwater organisms, but it is considerably below the tolerance limits for most of the Baltic Sea taxa, which usually occur in the straits. Waters within the Lagoon are inhabited largely by freshwater organisms.

The shallow, nutrient rich, strongly sun-warmed waters of the Lagoon provide favorable conditions for the growth of phytoplankton, which blooms from May to October. It is dominated by diatoms, with abundance maxima in May–June, and in early autumn. Cyanobacteria occur in summer, and peak in abundance during late summer or autumn (Wiktor 1980).

Coastal areas and bottom waters are vegetated and are the richest faunal habitats. The benthic fauna of sandy shoals, rich in molluscs, crustaceans and polychaetes, has the highest diversity. Muddy parts of the Lagoon bottom are generally impoverished (Wiktor 1980).

Materials and methods

In the paper presented are results of analyses of a total of 77 diatom samples and 68 ostracod samples collected from 6 sites. The sites were located in Roztoka Odrzańska (SWT), in the eastern part of the Szczecin Lagoon (Zatoka Skoszewska – Skoszewska Bay – SKO), and in the middle and lower reaches of the Świna (KAR and SWN) and Dziwna (GOG and DZI) straits (Fig. 1). The sampling was performed during 2005 and 2006. Samples were collected during three seasons (spring, summer, autumn) and no samples were collected in winter when the basin is covered in ice.

Diatom samples were collected in the coastal zone. Sediment was sampled using a corer with 25 mm internal diameter and cut to the depth of 1 cm of sediment thickness. Samples were also collected from surfaces of submerged objects (pebbles, hydrotechnical constructions), macrophytes (reed, vascular aquatic plants, macroalgae). Permanent slides for light microscopy were prepared following standard protocols (Battarbee et al. 2001) and mounted using Naphrax©. Between 300 and 600 valves were identified to the species or variety level and counted (Battarbee 1986, Bodén 1991). Identifications were based on the following references: Krammer & Lange–

Fig. 1. Map of the Odra mouth, with sampling sites (modified from Osadczuk 1999).

Bertalot (1986, 1988, 1991 a, 1991 b), Witkowski (1994), Lange-Bertalot & Metzeltin (1996), Lange-Bertalot et al. (1996), Metzeltin & Witkowski (1996), Lange-Bertalot & Genkal (1999), Witkowski et al. (2000), Rumrich et al. (2000), Krammer (2000, 2002, 2003), Lange–Bertalot (2001), Snoeijs (1993), Snoeijs & Vilbaste (1994), Snoeijs & Potapova (1995), Snoeijs & Kasperoviciene (1996), Snoeijs & Balashova (1998), Levkov (2009), etc.

Samples for ostracods were taken from surfaces of about 0.5 m^2 of the upper layer of the sediment, using a hand dredge with 50 µm mesh net. After preliminary cleaning the samples were preserved in 96 % ethanol. In the laboratory, the sediments were sieved on a 4 mm-mesh sieve, in order to separate coarse grains, and subsequently decanted in order to separate sand fraction. Bubbling technique of Higgins (1964) was employed to place the ostracods on the surface film. Ostracods were extracted from the resultant film by means of an exhauster and eventually separated from the remaining sediment and identified in a Petri dish under a Zeiss Discovery V12 stereomicroscope. For permanent slides, the soft parts of the ostracod bodies were embedded in Hydro-Matrix©. Identifications were based on the determination keys of Meisch (2000) and Sywula (1974). The ostracods from this study are stored in the collection of the author (ASŁ).

At the sampling sites, water samples for nutrient content analysis were collected simultaneously with diatom and ostracod samples. Mineral (ammonium ions, nitrites and nitrates) and organic nitrogen, mineral (orthophosphates) and organic phosphorus and biogenic silica contents were measured. Nutrient content analyses were performed in the field, using a SLANDI LF 205 photometer. A total of 18 water samples were collected. A number of physical and chemical water parameters, including temperature, depth, pH, salinity, oxygenation, conductivity and redox potential, were measured at every sampling site using an integrated CTD profiler.

A number of ecological metrics were used to analyze diatom and ostracod samples: percentages of individual taxa (Tümpling et al. 1999), dominance coefficient (Engelmann 1978), frequency coefficient (Trojan 1975) and biodiversity indices (i.e., species richness, Shannon index and Evenness index) were calculated. OMNIDIA v5 software was used for calculating the percentages of diatoms in particular ecological groups.

The structures of the diatom and ostracod assemblages and the mutual relationships between them at particular sites were analyzed using statistical multivariate methods, provided by the PRIMER software (Plymouth Routines in Multivariate Ecological Research; Clarke & Warwick 1995). Principal Component Analysis (PCA) was performed in order to analyze the similarity of sites with respect to the physical and chemical water parameters, and the discrimination between groups of sites with similar diatom and ostracod assemblages was aided by cluster analysis. Ranked similarity matrices were constructed using the Bray-Curtis similarity measure and group-average sorting, i.e., average similarity indices for successively created group of sites (Lance & Williams 1967).

Results

Physical and chemical water parameters

During the sampling season (from spring to autumn), water temperatures ranged from 10.1 to 22.9 °C (average temperature for the whole study period = 16.1 °C) and salinity ranged between 0.3 and 7.28 ‰ (mean 2 ‰). The highest salinities were observed in autumn 2005 in Dziwna and Świna straits (Dziwnów 7.28 ‰; Karsibór 6.76 ‰; Świnoujście 6.72 ‰), and the lowest salinities were recorded in Święta, Gogolice and Skoszewo in May 2005 and 2006. Water oxygenation ranged from 39.8 to 144.9 % (4.16–14.11 mg/dm^3; average 103 % and 9.8 mg/dm^3), and showed high seasonal variability. The lowest water oxygenation with 40 % was recorded in Dziwnów (autumn 2005), and significant water over-oxygenation with maximum 145 % was recorded dur-

Table 1. Physical and chemical water parameters in Odra mouth during the sampling period.

Station	Season	Temp [°C]	Cond. [mS/cm]	Salinity [psu]	DO [%]	DO [mg/dm^3]	pH	ORP [mV]	NH_4-N[mg/dm^3]	NO_2-N [mg/dm^3]	NO_3-N [mg/dm^3]	PO_4-P [mg/dm^3]	SiO_2 [mg/dm^3]
SWT	2005 May	14.67	0.62	0.3	123.1	12.48	8.68	203	0.05	0.03	4.5	3.2	1.7
	2005 July	22.88	0.73	0.35	116.45	10.81	7.4	389	0.3	0.04	2.1	0.9	8
	2005 Oct.	13.45	0.85	0.42	41.1	4.27	7.67	340	0.3	0.03	4	0.4	4.7
	2006 May	17.61	0.64	0.31	95.7	9.11	8.16	67	0.1	0.03	7.3	0.2	1.3
	2006 July	21.26	0.95	0.47	108.88	9.77	7.95	122	0.9	0.04	2.4	0.9	2.8
	2006 Oct.	10.97	1.08	0.53	93.8	8.71	8.22	193	0.2	0.02	7.5	0.4	4.6
SKO	2005 May	15.24	1.23	0.61	105.6	10.55	8.68	203	0.05	0.04	4.2	0.05	0.7
	2005 July	21.1	1.64	0.83	123.1	10.9	8.25	348	0.2	0.005	0.2	0.05	2.6
	2005 Oct.	11.55	2.22	1.14	59.4	6.42	8.93	329	0.05	0.02	0.9	0.4	0.7
	2006 May	20.4	0.66	0.32	143.8	12.94	8.87	79	0.1	0.03	5.3	0.05	0.15
	2006 July	20.86	2.39	1.23	104.08	9.36	8.09	124	0.1	0.005	0.2	0.9	5
	2006 Oct.	10.28	1.96	1	101.1	9.6	8.37	191	0.3	0.03	3.8	0.5	3
GOG	2005 May	13.92	1.25	0.63	141.8	14.58	9.18	201	0.05	0.03	3.6	0.05	0.6
	2005 July	21.01	1.7	0.86	106.4	9.43	8.05	369	0.05	0.005	0.2	0.2	5.6
	2005 Oct.	12.27	2.56	1.33	45.8	4.86	7.92	335	0.2	0.03	1.8	0.6	10
	2006 May	16.55	0.63	0.31	107.7	10.48	8.57	85	0.1	0.03	5.3	0.05	0.6
	2006 July	21.83	2.23	1.14	131.58	11.7	9.02	120	0.1	0.005	0.2	0.05	7
	2006 Oct.	10.12	2.53	1.31	96.2	9.06	8.3	188	0.1	0.02	4.1	0.5	3.4
DZI	2005 May	12.51	2.51	1.3	136.1	14.38	9.14	199	0.05	0.03	3.2	0.05	3
	2005 July	21.28	3.48	1.83	110.1	9.65	8.67	323	0.2	0.005	0.2	0.05	9.6
	2005 Oct.	11.32	12.64	7.28	39.8	4.16	7.87	337	0.05	0.005	0.2	0.1	1.7
	2006 May	16.52	0.79	0.39	144.9	14.11	9.23	86	0.05	0.03	4.5	0.05	0.03
	2006 July	21.32	4.32	2.3	136.18	12.12	9.43	115	0.1	0.005	0.2	0.05	6.7
	2006 Oct.	10.73	6.02	3.28	93.3	8.58	8.25	186	0.2	0.02	2.4	0.4	2
KAR	2005 May	13.22	1.76	0.89	132.8	13.84	9.2	200	0.05	0.02	5	0.05	1
	2005 July	20.68	8.74	4.89	90.9	7.92	7.97	355	0.2	0.005	0.2	0.2	3.4
	2005 Oct.	13.27	11.79	6.76	45.2	4.53	8.14	353	0.05	0.02	0.2	0.05	6
	2006 May	15.99	1.45	0.73	122.7	12.06	9.17	91	0.1	0.03	4.4	0.05	0.09
	2006 July	21.31	4.81	2.58	123.98	11.04	8.96	119	0.05	0.005	0.2	1.2	3.2
	2006 Oct.	10.96	5.99	3.27	100.6	9.34	8.08	156	0.3	0.02	2.1	0.3	2.6
SWN	2005 May	12.62	6.05	3.3	112.6	11.72	8.73	200	0.05	0.02	2.3	0.05	0.75
	2005 July	21.83	8.48	4.72	111.2	9.49	8.25	316	0.05	0.005	0.2	0.05	2.6
	2005 Oct.	13.08	11.73	6.72	45.8	4.61	8.14	353	0.05	0.005	0.2	0.05	2
	2006 May	14.57	5.35	2.9	116	11.59	8.72	100	0.05	0.02	3.3	0.05	0.03
	2006 July	21.15	5.26	2.84	110.18	9.85	8.77	120	0.05	0.005	0.2	0.9	2.6
	2006 Oct.	11.49	5.98	3.27	89.6	8.08	8.16	88	0.4	0.02	1.6	0.5	2.8

ing spring phytoplankton bloom. Water pH values ranged from 7.4 to 9.43 (mean 8.5), with the lowest values recorded in Święta, and the highest observed in Świna and Dziwna. Seasonal pH changes followed the same pattern as oxygenation, and were linked to phytoplankton blooms in spring and late summer or early autumn. Redox potential ranged from 67 to 389 mV (average 210.6 mV). Conductivity ranged from 0.62 to 12.64 mS/cm (mean 3.7 mS/cm), with the lowest values recorded in Dziwna and Świna straits in autumn 2005, and the highest values in Święta in May 2005 and 2006.

Dissolved orthophosphate concentrations ranged from 0.05 to 3.2 mg PO_4/dm^3 (mean 0.4 mg PO_4/dm^3). The highest PO_4 concentration was recorded in Święta in spring 2005. Considering seasonal variability, the highest phosphate concentrations were recorded in spring and autumn, and the lowest ones in summer. The concentrations of nitrates ranged from 0.2 to 7.5 mg $N–NO_3/dm^3$, nitrites from 0.005 to 0.04 mg $N–NO_2/dm^3$, and ammonium nitrogen from 0.05 to 0.9 mg/dm^3. The highest concentration of nitrogen compounds was recorded in Zatoka Skoszewska and Święta, while the biogenic silica concentration ranged from 0.03 to 10 mg/dm^3, with the highest values attained in Dziwna in June 2005, and the lowest in Świna and Dziwna in May 2006 (Tab. 1).

Similarities between sites with respect to physical and chemical water parameters

Principal Component Analysis was used to determine similarities between sampling sites with respect to physical and chemical water parameters. The following parameters were considered: water temperature, oxygenation [%], pH, redox potential, and nitrogen, phosphorus and silica concentrations. Data coverage included all sites throughout the sampling period. Average two-year values of individual parameters were calculated for each season (May, July, October, Fig. 2).

Three groups of sites are clearly distinguished in the PCA diagram, the main factor responsible for their similarity being the sampling season. Similarity analysis yielded the same pattern as the PCA diagram. In addition, the sites located in the southern part of the basin (SWT, SKO) differ considerably from the sites located in the northern part (GOG, KAR, DZI, SWN). The former are more impacted by the riverine waters, while the latter are under a stronger influence of the Baltic Sea waters.

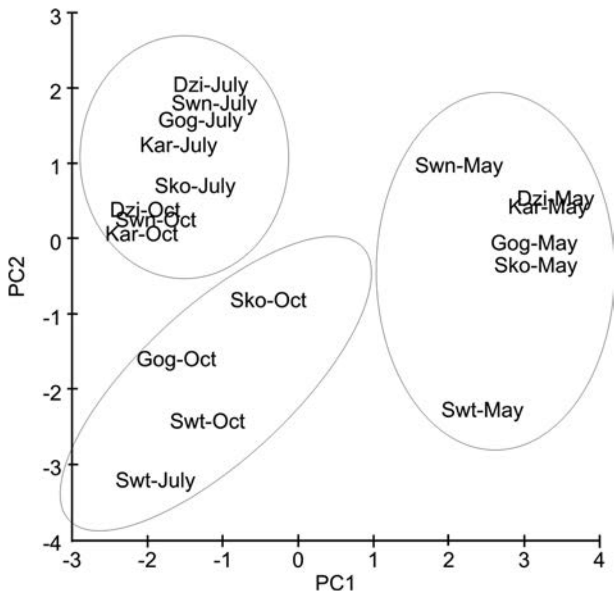

Fig. **2.** PCA analysis diagram grouping the sites with respect to physical and chemical parameter values. (PC1: 43.6 % variation; redox + DO + pH; PC2 21.5 % variation; NH_4-N + NO_2-N, Cumulative % variation –65.2).

Diatoms

Diatom taxa identified in the Odra mouth were represented by 56 genera. The centric forms were represented by 8 genera with 32 species and varieties, while the 48 pennate genera comprised 223 species and varieties. Only three of the identified taxa were euconstants (taxa occurring in between 75 and 100 % of samples). In order of decreasing frequency degree these were: *Navicula gregaria* Donkin, *Rhoicosphenia abbreviata* (Agardh) Lange-Bertalot and *Tabularia fasciculata* (Agardh) D. M. Williams & Round. Constants (occurring in 50–75 % of samples) included 18 taxa: *Amphora copulata* (Kützing) Schoeman & R. E. M. Archibald, *Amphora pediculus* (Kützing) Grunow, *Planothidium delicatulum* (Kützing) Round & Bukhtiyarova, *Cocconeis placentula* var. *placentula* Ehrenberg, *Fragilaria brevistriata* Grunow, *Planothidium engelbrechtii* (Cholnoky) Round & Bukhtiyarova, *Cyclotella meneghiniana* Kützing, *Fragilaria capucina* var. *vaucheriae* (Kützing) Lange-Bertalot, *Fragilaria sopotensis* Witkowski & Lange-Bertalot, *Opephora mutabilis* (Grunow) Sabbe & Vyverman, *Navicula cryptotenella* Lange-Bertalot, *Nitzschia frustulum* (Kützing) Grunow, *Cocconeis pediculus* Ehrenberg, *Diatoma tenuis* Agardh, *Fragilaria pulchella* (Ralfs) Lange-Bertalot, *Hippodonta hungarica* (Grunow) Lange-Bertalot, Metzeltin & Witkowski, *Nitzschia palea* (Kützing) W. Smith, and *Stephanodiscus hantzschii* Grunow. Accessory diatoms (occurrences in 25–50 % of samples) comprised 32 taxa; the largest number of taxa (202) occurred in between 0 and 25 % of samples and were classified as incidental.

In terms of salinity preferences, the flora was dominated by taxa typical for fresh-brackish waters (salinity < 0.9 ‰), which accounted for 45,2 % of the assemblages. Brackish-freshwater (salinity between 0.9–1.8 ‰) and brackish-water (salinity between 1.8 and 9 ‰) taxa accounted for 35.2 and 14.1 %, respectively. Alkaliphilous and alkalibiontic taxa were prevalent in terms of pH preferences, accounting for 54 % and 18.3 % of the flora, respectively. Taxa with neutral water pH preference were considerably less abundant (6.3 %). Among all taxa with known trophic preferences, eutraphentic taxa were the most abundant group (52.6 %). Hypereutraphentic taxa and those tolerant of oligotrophic to hypertrophic conditions accounted for 4 % and 3.5 %, respectively. With respect to saproby, β-mesosaprobous and α-mesosaprobous taxa reached the highest percentages (39.5 % and 17.1 %, respectively). Oligosaprobous and α-mesopolysaprobous taxa had lower percentages, 5.6 % and 2.9 %, respectively (Figs 3 and 4).

Similarities between sites with respect to diatom assemblages

The analysis of similarities between sampling sites with respect to diatom assemblages and abundance of taxa was aided by Bray-Curtis similarity measure. Taxonomic data from all seasons for each site, regardless of abundances of particular taxa, were analyzed. For the sake of clarity, average percentages were calculated for each season for each site. The resulting dendrogram shows two sites and three groups of sites, with approximately 30 % similarity (Fig. 5).

The sites cluster predominantly accordingly to locality and sampling season. The first group comprises sites that were sampled mainly in spring, located in the southern part of the basin (SWT), and sites located in Świna and Dziwna straits. Diatom assemblages from these sites were composed predominantly of taxa with fresh-brackish water preference. This confirms the maximum impact of Odra river on its mouth in spring.

The second distinct group comprises sites located in straits connecting the Lagoon to the Baltic Sea sampled in summer and autumn. This group mainly comprised fresh-brackish, brackish-fresh and brackish-water taxa, and the optimum salinity for these assemblages is of the order of a few psu.

The third group comprises sites located on the southern and eastern sides of the Lagoon (SWT, SKO, GOG), sampled in summer and autumn. In this group, the prevalent diatoms had

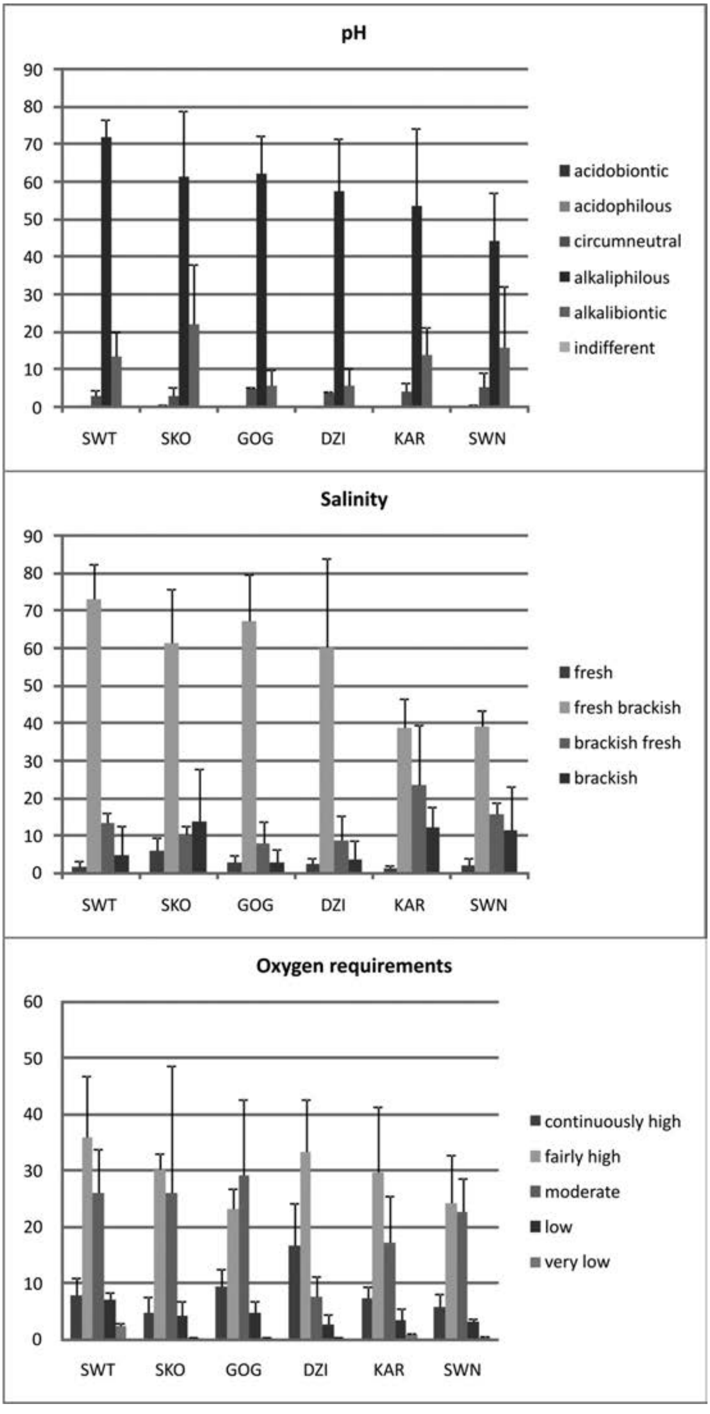

Fig. 3. Mean percentages of diatom taxa in the Odra mouth flora, by ecological groups (with respect to pH, salinity and oxygen requirements).

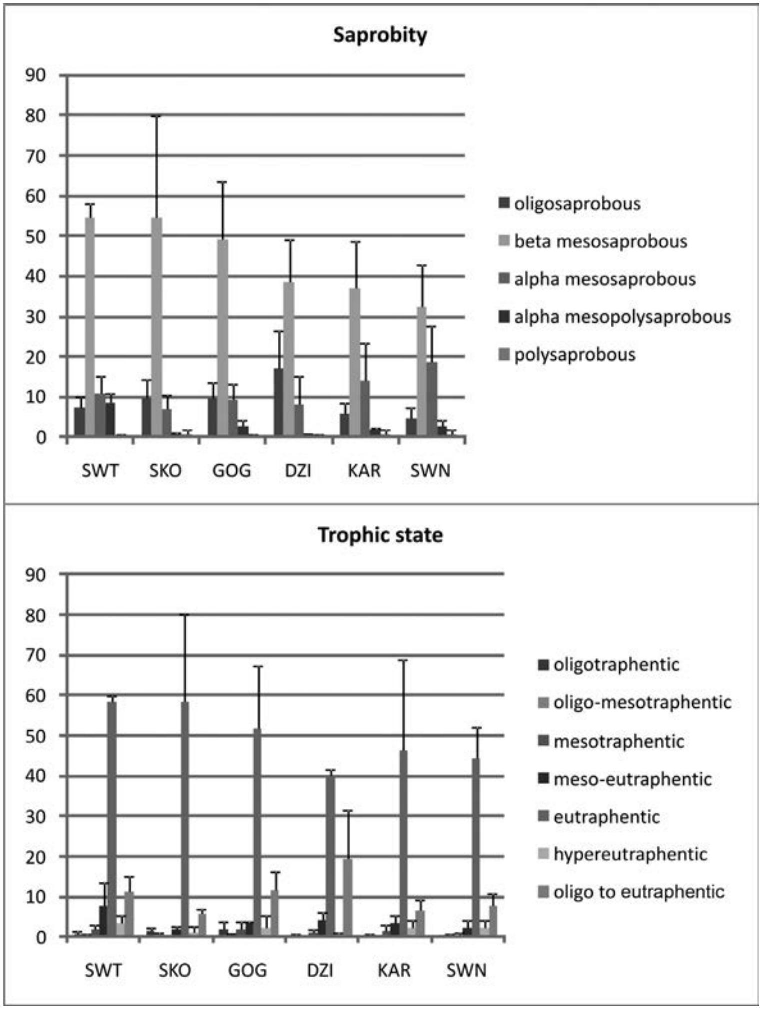

Fig. 4. Mean percentages of diatom taxa in the Odra mouth flora, by ecological groups (according to saprobity and trophic state).

mostly fresh-brackish water preferences, but the vast majority were β-mesosaprobous taxa, with a considerable proportion of oligosaprobous taxa. On the contrary, in the remaining groups α-mesosaprobous taxa were present in addition to the dominant β-mesosaprobous taxa.

Two single sites that plotted separately are located in SWN, in the Świna mouth. Spring samples were dominated by *Tabularia fasciculata* and *Fragilaria pulchella*, and *Nitzschia frustulum*, *Rhopalodia brebissonii* and *Melosira nummuloides* dominated in autumn samples.

Biodiversity of the diatom flora in the Odra mouth

The study sites are characterized by a high diversity of diatom assemblages. The number of taxa at particular sites in all seasons varied from 19 to 63, with an average of 43 taxa per sample. The

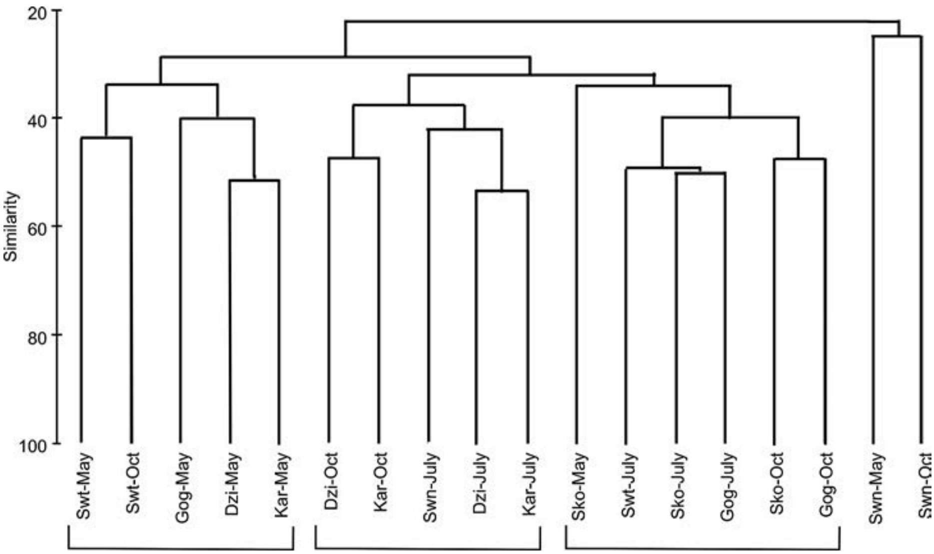

Fig. 5. Dendrogram showing similarity between sites with respect to diatom flora.

lowest number of taxa was recorded periodically in Dziwna mouth, and the highest number of taxa was also recorded periodically in Święta. The Shannon index (for logs to the base 2) exceeded 4 on 72 % of sampling sites, and the values of this index varied from 2.86 to 5.09 (mean 4.28). The evenness index ranged from 0.36 to 0.64 (mean 0.54). The lowest values of both indices were recorded in autumn in Skoszewo, and the highest ones in Dziwna (GOG). Diversity of the diatom flora was also examined in relation to seasonal variability. The number of taxa in Odra mouth in spring varied from 29 to 63 (mean 48 taxa) and the Shannon index ranged from 3.5 to 5.09. In summer, the number of taxa at particular sites ranged from 19 to 55 (37 on average), with the Shannon index values ranging from 4.05 to 4.85. In autumn, the number of taxa varied from 36 to 59, with an average of 50 taxa. The Shannon index varied from 2.85 to 4.97.

Ostracods

A total of 8290 ostracod specimens were examined: 2158 collected in spring, 1960 collected in summer, and 4182 collected in autumn. The samples yielded 27 taxa, including 22 species belonging to 15 genera.

Cypria ophtalmica (Jurine, 1820) was eudominant (32–100 %), with a mean dominance coefficient of 43 %. Juvenile *Pseudocandona compressa* (Koch, 1838), *Cytheromorpha fuscata* (Brady, 1869), *Cypridopsis vidua* (O. F. Müller, 1776), *Limnocythere inopinata* (Baird, 1843), *Darwinula stevensoni* (Brady & Robertson, 1870), and *Cyprideis torosa* (Jones, 1850) were classified as subdominants (3.2–10 %). The dominance structure varied seasonally; in spring, *C. ophtalmica* was eudominant and *L. inopinata* and *D. stevensoni* were dominants (10–32 %), whereas in summer, *C. vidua* became eudominant, while *C. fuscata* and juvenile *Pseudocandona* sp. were dominant. In autumn, *C. ophtalmica* was again eudominant, reaching percentages of up to 65 %, while the juvenile *Pseudocandona* remained dominant.

Due to its occurrence in more than half of the studied sites, *Cypria ophtalmica* had the highest frequency index and was considered a constant (75–51 %). Accessory species (50–26 % were:

Table 2. Taxonomic list of ostracods, with sampling sites and dominance coefficient (5: 32–100 %, 4: 10 – < 32 %, 3: 3.2 – < 10.0 %, 2: 1 – < 3.2 %, 1: 0.32 – < 1 % , + : < 0.32 %).

Taxon	SWT	SKO	GOG	DZI	KAR	SWN
Bradleystrandesia reticulata	–	–	–	–	+	–
Candona angulata	–	–	–	–	+	–
Candona candida	–	–	+	–	–	–
Candona neglecta	+	–	2	1	3	–
Candona juv. sp.	–	–	–	–	+	–
Candoninae	3	4	2	2	2	–
Cyclocypris leavis	–	–	2	–	+	–
Cyclocypris ovum	–	–	1	–	1	–
Cypria ophtalmica	5	4	1	3	5	5
Cypria subsalsa	2	–	–	–	–	1
Cyprideis torosa	–	4	3	4	1	–
Cypridopsis vidua	3	–	5	+	1	–
Cytheromorpha fuscata	1	3	2	5	4	2
Darwinula stevensoni	3	–	+	4	3	+
Fabaeformiscandona holzkampfi	–	–	2	4	3	–
Fabaeformiscandona levanderi	2	–	+	–	–	–
Fabaeformiscandona protzi	–	–	–	+	+	–
Fabaeformiscandona juv. sp.	–	–	2	+	–	–
Ilyocypris decipiens	2	–	2	–	1	–
Ilyocypris juv. sp.	2	–	–	–	–	–
Isocypris beuchampi	+	–	–	–	–	–
Limnocythere inopinata	4	5	4	+	2	–
Physocypria kraepelini	4	–	–	1	2	–
Potamocypris unicaudata	–	–	2	–	–	–
Potamocypris smaragdina	+	2	1	+	1	–
Pseudocandona compressa	+	–	2	3	3	–
Pseudocandona juv. sp.	+	2	4	3	4	–

C. fuscata, *D. stevensoni*, *L. inopinata*, *C. torosa*, juvenile *Pseudocandona* sp. and juvenile Candoninae.

The majority of the taxa recorded in these samples have a broad salinity tolerance, including freshwater (< 0.5 ‰), oligohaline (0.5–5 ‰) and β-mesohaline (5–10 ‰) species. *Cypria subsalsa* Redeke 1936, *Cyprideis torosa* and *Cytheromorpha fuscata* can be considered as saline water indicators. *Cypria subsalsa* is reported to occur in salinities ranging between 0.5 and 13.4 ‰, in waters classified as β-oligohaline (0.5–3 ‰) through α-mesohaline (10–18 ‰), and in this study it was recorded only in Święta (SWT) in May and July. The salinity range reported for *C. torosa* is 0.4–20 ‰ (although it has been recorded from salinities as high as 60 ‰). The nodded form (f. *torosa*) occurs from 0.5 to 7 ‰, and is dominant between 0.5 and 2 ‰ (Frenzel et al. 2010), while the smooth-valved *C. torosa* usually thrive in salinities from 6 to 10 ‰ (Anadona et al. 1994). Keyser & Aladin (2004) recorded an increase in relative abundance of nodded individuals in salinities below 6,9 ‰; at 2,1 ‰, nodded specimens accounted for 100 % of the population (Keyser & Aladin 2004). In the middle reaches of Dziwna (GOG), the percentage of forma *torosa* reached 67 %, and 82 % in the mouth of Dziwna (DZI), which gives an average of 76 %. This species was the most abundant in Skoszewo (SKO) in May, in the middle reaches of Dziwna

(GOG) in October, in Dziwna mouth (DZI) in July and October, and in Świna mouth (SWN) in July. The salinity range for *C. fuscata* is 0.6–14‰, i.e., from β-oligohaline to β-mesohaline, but records from salinities as high as 29‰ are also available (Frenzel et al. 2010). The highest dominance of this species was recorded during all seasons in Dziwna (DZI), in May and July in the middle reaches of Świna (KAR), and in May and October in Świna mouth.

The majority of taxa recorded in this study show a high tolerance with respect to low oxygenation. Only *Cypridopsis vidua*, *Cytheromorpha fuscata*, *Fabaeformiscandona levanderi* (Hirschmann, 1912) and *F. protzi* (Hartwig, 1898) require conditions with a higher oxygen content.

Candona neglecta Sars 1887, *C. ophtalmica*, *C. torosa*, *Fabaeformiscandona holzkampfi* (Hartwig, 1900), *F. protzi*, and *Pseudocandona compressa* are thought to prefer muddy substrates. Sandy substrates were typically inhabited by: *C. subsalsa*, *C. fuscata*, *Ilyocypris decipiens* Masi, 1905. *Cypridopsis vidua* inhabits waters with lush vegetation; in this study, it reached a maximum in July in sites of Święta, and in the middle reaches of Dziwna (GOG). The taxonomic list of Ostracods from Odra mouth is given in Table 2.

Similarities between sites with respect to ostracod fauna

As in the case of the diatom assemblages, the analysis of similarities between sites with respect to the taxonomic composition of ostracod fauna was aided by Bray-Curtis similarity measure. Data from all seasons for all sites, including all the recorded taxa regardless of their abundances were utilized in the analysis. For the sake of clarity, mean percentages for all seasons for each site were calculated. The analysis yielded a distinct group of samples from various seasons from the sites: Skoszewo – SKO (May), Gogolice – GOG (May, October), Karsibór – KAR (May, July), Dziwnów – DZI (May, July, October), Świnoujście – SWN (July). The common feature of all these samples were high percentages of indicators typical of saline waters – *Cyprideis torosa* (1.5–35.5%) and *Cytheromorpha fuscata* (3–77.8%). In other samples, brackish-water taxa were lower or were not observed. All samples from Święta and Świna (SWN – May and

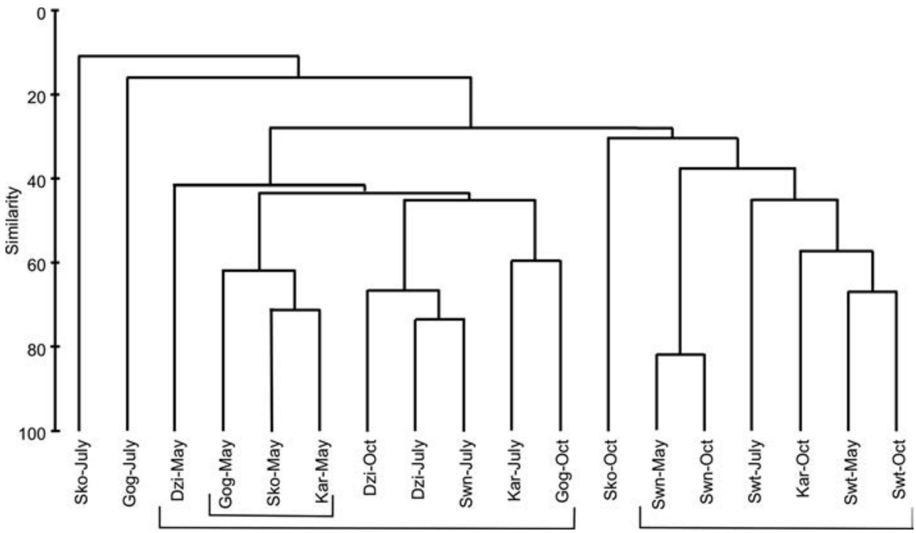

Fig. 6. Dendrogram showing similarity between sites with respect to ostracod fauna.

October, KAR – October) were plotted together in the second group. Their common feature was the high percentage of *Cypria ophtalmica* (50–99.9 %, except for the July sample from Święta, in which it accounted for 15 %). This species is a eurytopic taxon which becomes eudominant in nutrient-rich waters.

A distinct subgroup is formed by spring samples from Gogolice (Dzwina), Skoszewo and Karsibór (Świna), whose common feature was the high percentage of *Limnocythere inopinata* (23.3–61.6 %). The samples from Skoszewo (July – dominance of *L. inopinata* and *Potamocypris smaragdina* (Vavra, 1891) – 50 % each; October –80 % Candoninae larvae), and from Gogolice (July –90.7 % *Cypridopsis vidua*) could not be grouped according to seasonal characteristics (Fig. 6).

Ostracod fauna biodiversity

In the course of this two-year study, considerable differences in species richness between sampling sites were observed. The highest number of taxa occurred in the middle reaches of the Świna (KAR) and Dziwna (GOG) straits, 20 and 19 taxa, respectively. Somewhat less, 16 taxa occurred in Święta and 15 in Dziwna mouth. Impoverished fauna was observed in Skoszewo (7 taxa) and Świnoujście (4 taxa).

A total of 21 taxa were recorded in spring and autumn, with Shannon index values (for logs to the base 2) of 2.02 and 1.6, respectively, and Evenness values of 0.42 and 0.34 respectively. In summer there were 19 taxa, with a Shannon index of 1.4, and an Evenness value of 0.3. In certain sites, the number of taxa varied considerably from season to season, ranging from 2 to 17 taxa. The maximum number of taxa was recorded in autumn in the middle reaches of Dziwna (GOG –14 taxa) and in Święta (13 taxa), and the minimum number of taxa was recorded in Świna mouth (SWN –2 taxa). In spring, the Shannon diversity index ranged from 0.5 to 2.68. In summer, the highest number of taxa was recorded in the middle reaches of Świna (KAR –14 taxa), and the lowest number of taxa occurred in Skoszewo (2 taxa) and in Świna mouth (SWN –4 taxa). The Shannon diversity index for summer samples ranged from 0.6 to 2.41. In autumn, the maximum number of taxa was recorded in the middle reaches of Świna (KAR –17 taxa), and the minimum value in the middle reaches of Dziwna (GOG) and in Świna mouth (SWN), with 2 taxa in each site. For autumn, the Shannon diversity index ranged from 0.01 to 2.3.

The mean biodiversity index for the ostracod fauna of the Odra mouth equaled 1.7, and the mean value of the Evenness index equalled 0.35.

Discussion

Diatoms

In the previous study, performed in 2005 and 2006, 255 taxa (species and varieties) were identified, whereas the number of taxa identified during a preliminary study between autumn 1998 and autumn 1999 was 271 (Bąk et al. 2001). The total number of taxa recorded during the whole period of previous studies (1998–2001) was 521 (Bąk et al. 2006), but the differences in species richness in these study periods do not result from changes in the diatom flora; instead, they are clearly correlated to the number of samples per study (77 in this study, 945 between 1998 and 2001, including 368 from 1998 to 1999 during the preliminary study), with an obvious trend towards increased species richness with an increase in the number of samples.

The number of valves counted in each slide also impacts the number of identified species. Standard procedures (e.g., Battarbee 1986) recommend counting between 300 and 600 valves. Distribution of the number of taxa in the studied slides, however, shows that the number of taxa per sample is generally higher when the number of counts approaches the upper limit of the recommended range. Our study revealed that the number of taxa identified with 600 counts can be as much as 30–50 % higher than the number of taxa identified based on a count of 300 valves. The high biodiversity of the Odra mouth diatom flora results from a number of factors, including the occurrence of incidental species that are present in a low number of samples (not more than 25 %) in low abundances (up to a few valves per slide). This study yielded 202 incidental taxa, and in previous studies (1998–2001) as many as 369 incidental taxa were recorded. A similar rule, to a lesser extent, holds for accessory species (i.e., occurring in 26–50 % of samples). Thus, the more slides are examined and the more valves are counted in each slide, the higher the species richness.

Although the number of samples and the number of counts have a direct impact on the number of recorded taxa, these results do not influence the diatom-based assessment of the environment quality in the Odra mouth. We based our analysis on the occurrences of the dominant (most frequent and most abundant) species, and their dominance proportions remain similar, regardless of the number of studies slides and valve counts. Thus, for the sake of environment quality monitoring in the Odra mouth, a considerably lower number of samples, and counts of 300 valves per slide are sufficient. However, for the purpose of floristic studies, the maximum possible numbers of sites and microhabitats, as well as counts overrating estimated number of 300 valves per slide to as high extent as possible, are essential.

The diatom assemblages indentified in this study show considerable similarity, as shown for instance in the similarity dendrogram, where the populations from particular sites diversify at ca. 30 % level (Fig. 5). The differences in the assemblage structure between, e.g., northern and southern parts of the Odra mouth are subtle, which suggests an influence of waters originating from both Odra and the Baltic Sea on the whole Odra mouth area. The inflow of fresh and fertile riverine waters was more pronounced in the southern part of the basin, and that of the saline Baltic waters was more distinct in the northern part.

The most abundant diatom taxa of the Odra mouth were eutraphentic, alkaliphilous and alkalibiontic, preferring weakly saline (fresh-brackish and brackish-fresh), and tolerant of moderately polluted waters (β-mesosaprobus). However, the diatom flora of the Odra mouth, shows a high proportion of freshwater, oligo- or mesotraphentic and oligosaprobous taxa. These taxa did not reach significant abundances. The less numerous, but more abundant eutraphentic, halofilous and mesosaprobous taxa were dominant. The persistence of taxa that thrive in distinctly different conditions than those found in the Odra mouth suggests a high adaptive potential of these diatom assemblages, which enables a rapid response of the assemblage to the changes experienced in this dynamic environment.

As indicated by previous studies (Bąk et al. 2001, 2006), except for a lower proportion of α-mesosaprobous taxa in this study, no considerable differences in proportions of ecological groups were recorded. This difference may have been affected by the lower number of samples, and by the shorter duration of this study (two years instead of four). Alternatively, a number of sewage treatment plants were founded in the Odra drainage area after 2001, which must have considerably reduced the influx of organic pollutants. However, a significant improvement of the Odra mouth environment cannot be announced until further study cycles are completed.

Ostracods

This study yielded as many as 22 ostracod species identified with certainty in the Odra mouth, with the five remaining taxa identified to the genus or family level (Table 2). Such species richness is remarkably high in comparison to the middle and upper reaches of Odra, where only 13 species were identified (Szlauer-Łukaszewska 2008), and in the basins adjacent to the Odra mouth (mainly in Germany), where between one and eight ostracod taxa were identified to the species or forma level (Frenzel unpublished data). Scharf (unpublished data from Odra mouth), however, recorded 16 taxa, including 15 living and 1 subfossil species. In comparison to studies by Frenzel and Scharf, no significant differences in taxonomic composition of ostracod fauna were observed in study, except for the occurrences of *Cytherissa lacustris* and *Ilyocypris gibba* recorded by Scharf. *Cytherissa lacustris* is commonly found in sublittoral and profundal zones of cold deep lakes. The individuals of this taxon may have been carried into the Lagoon from mesotrophic bayous. 14 ostracod taxa are reported for the Polish part of the Vistula Lagoon (Sywula et al. 2004).

The species richness of ostracods in the Odra mouth is higher on the Polish side of this basin. A total of 14 taxa (species and formae), with one taxon identified to the genus level (Frenzel & Viehberg 2004 and Frenzel 2010 – unpublished data), are reported from the German side of the basin. All of the taxa occurring on the German side are also recorded in the Polish part of Odra mouth, but the remaining eight species which occurred in the Polish part have not been reported from Germany.

A total of 702 freshwater ostracod species, including groundwater-dwelling taxa, occur in the palearctic (Martens et al. 2008). Of these, 602 are endemic species, and only 82 are cosmopolitan. Namiotko (2008) reported 140 ostracod species to occur in fresh (including groundwaters) and brackish waters of Poland and the taxa reported in this study account for approximately 20 % of the benthic ostracofauna of Western Pomerania. Since Creuzé des Chatelliers & Marmonier (1993) reported 24 taxa from Rhone River in Lyon, and Nagorskaya & Keyser (2005) reported 21 taxa from Belarusian rivers, the species diversity recorded in the Odra mouth is comparable to other riverine habitats.

Euryhaline species, ranging in preferences from freshwater to brackish-water, and those characteristic of eutrophicated and organic matter-rich waters, had the highest percentages in the ostracod assemblages of the Odra mouth. *Cypria ophtalmica* is a freshwater species that is known to occur in various types of waters, including those with high organic pollution content. It produces abundant populations in ponds filled with leaf-litter (Meisch 2000). Both *C. ophtalmica* and *Physocypria kraepelini* are dominant taxa in sapropels of the main Odra bed adjacent to Szczecin (ASŁ unpublished observations). It occurred at all sites in this study, but reached the highest abundance in Roztoka Odrzańska (SWT), indicating the eutrophication of the southern part of the Odra mouth, and the highest impact of the nutrient-rich riverine waters in this part of the study area. Conversely, *Cytheromorpha fuscata* and *Cyprideis torosa* are indicative of brackish-waters. Their occurrences and abundances at particular sites allow us to investigate the impact of the Baltic Sea waters on the study area, which was most pronounced in the northern part of the Odra mouth (Świna and Dziwna straits), but was also detectable to a lesser extent in the eastern and southern parts. Based on the percentages of freshwater and brackish-water taxa, the site in Święta (SWT) appears to be least saline, although the solitary specimens of *C. fuscata* and *C. subsalsa* in Święta suggest periodic salinity increases. *Cypria ophtalmica*, a freshwater species, was dominant in the mouth of Świna (SWN) only once in autumn 2006. This is a noteworthy finding, because in other seasons, the brackish-water taxa *C. fuscata* and *C. torosa* were dominant in this area. The Świna mouth is unusual because it is sheltered on both sides by a breakwater, supported with concrete blocks and boulders on the interior. The depressions between these boulders are washed with Świna waters, and are inhabited by ostracods that cannot dwell in open waters due to the strong currents and sandy substrate. Freshwater species may be dominant at these sites due to the periodic submersion of these habitats by rainwater. The lack of strong waves, combined with the lower density of freshwater, probably allowed the persistence of freshwater conditions over an extended period. The high concentrations of *Cypridopsis vidua* in the middle reaches of Dziwna (GOG) are also remarkable, and probably point to the occurrences of submerged vegetation.

Bioindicative potential of diatoms and ostracods in the Odra mouth

Numerous ostracod species are stenobionts, inhabiting sites with narrowly defined physical and chemical parameters. There are species whose occurrences are limited to a particular basin zone (e.g., littoral or profundal of a lake), or associated with certain types of basins (e.g., springs and streams originating from them, ground waters, ponds, brine seeps), whereas some taxa prefer particular types of aquatic vegetation (e.g., reed, submerged plants), or bottom sediments (e.g. Meisch 2000, Frenzel et al. 2010, 2005, Mezquita et al. 2005, Külköylüoğlu 2004, Yilmaz & Külköylüoğlu 2006). Similarly, some diatoms have narrow tolerance limits with reference to the gradient of environmental conditions (i.e. Round et al. 1990, Round 1991, van Dam et al. 1994, van Dam & Mertens 1995, Hall & Smol 2010). An advantage of both groups is their widespread occurrences; diatoms are the most abundant algae in the Odra mouth (Wiktor 1980), as indicated by the chlorophyll *a* content, which reached up to 140 mg/m^3 during our study period (WIOŚ 2008). Similarly, in brackish waters, ostracods are either the most abundant, or the second most abundant animal group (after nematodes) (Köhler & Arlt 1984, Radziejewska & Drzycimski 1988, Frenzel & Boomer 2005), and the ostracod wet biomass in Szczecin Lagoon can reach up to 9 g/m^2 (Wolnomiejski & Grygiel 1989).

Both ostracods and diatoms are good indicators of habitat or substrate type, water depth and energy, primary production level, water temperature, salinity, oxygen concentration and eutrophication. As a result of their bioindicative potential, they are commonly used as proxies in climate change reconstructions, sea/lake level variation inferences, and reconstructions of sedimentary processes or anthropogenic impact. Numerous studies have explored both ostracods and diatoms in environmental quality assessment and paleoreconstructions. In case both of these organismic groups are applied, the results are generally consistent between them (e.g., Schwalb et al. 1998, Edwards et al. 2006). However, in some cases, the diatom- and ostracod-based assessments can be divergent, e.g., the studies on Lake Wigry (in NE Poland), in which ostracod faunas indicated oligotrophic conditions, while diatom assemblages pointed to eutrophicated waters (Staniszewska & Namiotko 2009 and Witkowski et al. 2009). It is possible that these discrepancies can be accounted for by the much smaller diameters of diatoms, because smaller size promotes the transport of both living and dead cells across long distances. Additionally, it is more challenging to proof whether a diatom assemblage is autochthonous or allochthonous in comparison to ostracod fauna. The co-occurrence of diatom species with contrasting preferences, e.g., ranging from oligosaline to hypersaline (e.g., Edwards et al. 2006) in the same fossil or subfossil zone is quite common, suggesting the reworking of allochthonous species from other areas or geological levels. Furthermore, the higher number of species, and the higher abundances of diatoms than ostracods within a basin, make the interpretation of diatom data more difficult. It is also impossible to collect diatom samples (both benthic and periphytic) without contaminating them with valves from the sediment surface, or those comprised in the detritus in a periphytic formation. On the one hand, all of this hinders the assessment of current conditions of the site during sample collection, but on the other hand, it prevents the environment quality assessment from being biased by a short-term change in environmental parameters. As a result, the effect of this contamination averages the gradients of environmental parameters impacting the diatom assemblages of the Odra mouth.

Diatom and ostracod valves become easily incorporated into the sediments. Whilst the calcareous shells of ostracods are fossilized in alkali-rich sediments (in which diatom valves are quickly dissolved), diatoms are better preserved in organic-rich, brackish-water sediments, where calcareous shells of ostracods are often subject to varying degree of dissolution (Frenzel & Boomer 2005).

This study shows that slightly different combinations of physical and chemical, and habitat factors impact the geographic distribution and assemblage structures of diatoms and ostracods, and strongly impact the similarities between sites. In the case of ostracods, salinity and trophic status were the key factors, and the interpretation of the results is rather unambiguous. However, in the case of diatoms, the similarities between assemblages were controlled by a combination of factors, and interpretation of their bioindicative potential was more complicated. As in the case of ostracods, salinity was the key factor, with trophic status (largely the nitrate concentration) and silica availability as secondary factors.

Although the general interpretation of diatom and ostracod results yielded a coherent assessment of the environment quality in the Odra mouth, some discrepancies were also observed. These concerned, for instance, the percentage of freshwater taxa periodically occurring in the Świna mouth. The differences between diatom and ostracod results may also originate from the different biological properties of these organisms; most importantly reproduction rates. In favorable conditions, some species of diatoms can divide once per day (Rivkin 1986), while ostracods generate from one to a few generations per year, the reproduction rate being species-specific. Owing to their high reproduction rate, diatoms can react to changes in physical and chemical water parameters nearly instantaneously, while ostracods reflect the longer-term (seasonal) trends in the basin.

Conclusions

(1) Diatoms and ostracods proved to be useful as complementary indicators of ecological conditions in the Odra mouth. (2) The taxonomic composition and structure of diatom and ostracod assemblages indicated high levels of eutrophication in the whole study area, particularly in its southern part (Roztoka Odrzańska). (3) Salinity ranged from oligohaline to β-mesohaline through both time and space, and was dependent on the season and the distance from the sea. We found that the southern part of the Odra mouth was a freshwater environment, while the Świna and Dziwna straits in the north were predominantly brackish environments. (4) High biodiversity of both diatoms and ostracods is linked to the elevated trophic status and the variability of environmental parameters (predominantly salinity). (5) The comparison of the diatom results obtained in this study with previous work shows a similar taxonomic composition and assemblage structure, suggesting no significant changes in the Odra mouth environment.

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