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Does the location of coastal brackish waters determine diversity and abundance of zooplankton assemblages?

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Abstract: Habitat conditions may shape the abundance and community structure of planktonic fauna. In this study, we investigated whether reservoirs with different locations and drainage basins also differed in the structure and abundance of zooplankton. The studies were conducted in 2010–2011 between June and October in the Vistula Lagoon and Lake Łebsko. The zooplankton was dominated mainly by small eurytopic organisms belonging to Rotifera. Plankton crustaceans showed a limited diversity of species. Copepods were predominant, while Cladocera were observed sporadically in more freshwater habitats. In the first experimental season (2010), the Vistula Lagoon and Lake Łebsko showed a comparable taxonomic structure and an abundance of investigated zooplankton; a substantially higher density was recorded in Lake Łebsko in 2011, although the taxonomic diversity was higher in the Vistula Lagoon. Zooplankton biomass in a given season differed between these 2 water bodies, but not statistically significantly. The differences in location in the investigated water bodies impacted zooplankton assemblage structure and abundance. The drainage basin type (urbanized areas, forested areas, waterlogged areas) appeared to influence zooplankton species richness significantly.

Key words: Zooplankton, brackish waters, Vistula Lagoon, Lake Łebsko

1. Introduction

Brackish reservoirs are dynamic ecosystems characterized by extensive instability of parameters due to location, morphometrics, and hydrology (Micky et al., 2004; Telesh, 2004). Fluctuations in factors such as salinity, temperature, pH, oxygen content in water, or concentration of biogenes increase ecological stress for many living organisms. Brackish waters are thus thought to be unfavorable habitats for animals, and the inhabiting species must show a wide range of tolerance to environmental factors (Paturej, 2005a, 2006a; Wołowicz et al., 2007). Salinity is the most important factor that determines life in near-sea habitats (Jeppesen et al., 2007); it is much lower in comparison with oceans and most seas. In addition, it undergoes great variation caused by inflows of freshwaters which originate mainly from rivers, an advantage of precipitation over evaporation, and hindered outflow of seawater (Schallenberg et al., 2003; Urbański and Węsławski, 2008). Temperature also exerts a substantial impact on aquatic organisms. Among other factors, it determines the amount of dissolved oxygen in water and the intensity of photosynthesis and biogeochemical processes (growth rate, intensity of respiration, activity of organisms, and susceptibility of organisms to pollution and diseases) (Sousa et al., 2011). Studies on organisms living in the specific conditions of brackish waters provide a basis for understanding biological structures and the functioning dynamics of these biocoenoses. Zooplankton are an important link between primary producers and higher trophic levels, and play an important role in remineralization (Paturej, 2005a). In addition, as a key link in the food chain, zooplankton are responsible for maintaining good water quality by controlling the growth of phytoplankton (Paturej and Kruk, 2011). Zooplankton research on Vistula Lagoon began in the late 1800s (Schoedler, 1866). A significant response of the zooplankton assemblage to anthropogenic factors noted in Vistula Lagoon after 1915, when the Nogat River was cut off by floodgates. This caused a 3-fold decrease in freshwater discharge into the lagoon. Until this time, the lagoon had been inhabited mainly by freshwater species (Wiktor and Wiktor, 1959). Previous studies have reported species composition and distribution patterns of zooplankton assemblages (Wiktor and Wiktor, 1959; Różańska, 1963), spatial distribution of zooplankton communities in response to environmental factors (Adamkiewicz-Chojnacka and Radwan, 1989;

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Paturej and Kruk, 2011, Paturej et al., 2017), and the effects of eutrophication and pollution on zooplankton taxa (Heerkloss et al., 1988). However, compared to Vistula Lagoon, the zooplankton of Lake Łebsko have only been studied sporadically. The structure of the zooplankton assemblage was comprehensively investigated for the first time by Paturej (2005a).

The structure and abundance of zooplankton may also be an indicator of changes in the environmental conditions in a water body (Karabin, 1985a, 1985b). Water bodies' ecosystems are heavily subsidized by nutrients and detritus from surrounding watersheds (Vanni et al., 2005), and catchment basin land use has a significant and adverse effect on zooplankton species richness in freshwater lakes (Dodson et al., 2007). The overall water quality of Vistula Lagoon has deteriorated, and zooplankton diversity was significantly lower in 2007 and 2009 than in 1977 and 1978 (Adamkiewicz-Chojnacka, 1983; Paturej et al., 2012).

The objective of this study was to investigate whether the structure and abundance of zooplankton is similar or comparable in 2 brackish reservoirs (i.e. the Vistula Lagoon and Lake Łebsko) with different locations and drainage basins.

2. Materials and methods

The studies were conducted on 2 brackish reservoirs, the Vistula Lagoon and Lake Łebsko, located on the southern coast of the Baltic Sea. These reservoirs differ in their location. The first water body is situated in a shadowed part of the Baltic Sea (in the Gulf of Gdańsk), whereas the second reservoir is located further to the west and contacts the open sea. There are also significant differences between these reservoirs in their morphometrics. While both water bodies have a large surface and small depth, the area of the Vistula Lagoon is nearly 80% larger than that of Lake Łebsko (Table 1). Moreover, these reservoirs differ in their drainage basins. The drainage basin of the Vistula Lagoon encompasses forests, waterlogged areas, agricultural lands, and urbanized areas, whereas that of Lake Łebsko includes mainly forests and waterlogged areas (Table 2). In addition, the Vistula Lagoon—despite the protection of the entire Polish area as a part of the Natura 2000 reserve network—is a spot for intensive tourist flow (sailing), and its waters are used as fishery resources (Psuty, 2011; Kruk et al., 2012). The impact of humans on Lake Łebsko is limited as this reservoir is situated in Słowiński National Park (Morozińska-Gogol, 2005). In both reservoirs, salinity is low, with a characteristic spatial variation: the highest salinity is found at the near-sea zone, and the concentration of solute salts decreases with increasing distance from the junction with the sea (Antonowicz and Trojanowski, 2010; Kruk et al., 2012).

The studies of zooplankton were carried out in 2010–2011 between June and October, with samples being taken once per month. Six research stations were set on the Vistula Lagoon and 3 on Lake Łebsko (Figure 1).

Table 1. Basic morphometric parameters of the Polish part of the Vistula Lagoon. (Chubarenko and Margoński, 2008) and Lake Łebsko (Baranowski and Chlost, 2009).

	Vistula Lagoon	Lake Łebsko
Surface	328 km^2	71 km^2
Water volume	2300 mln m^3	117,521 m^3
Average depth	2.6 m	1.6 m
Maximum depth	5.2 m	6.3 m
Length of coastline	111 km	55.4 km
Surface of drainage basin	14,509 km^2	1801 km^2

Table 2. Land use types in the study area watershed of Vistula Lagoon and Łebsko Lake.

Land use type	Vistula Lagoon	Łebsko Lake
Urban	2, 3, 4, 5	
Agriculture	1, 2, 3, 6	
Forest and seminatural ecosystems	5, 6	7, 8, 9
Wetlands	3	7, 8

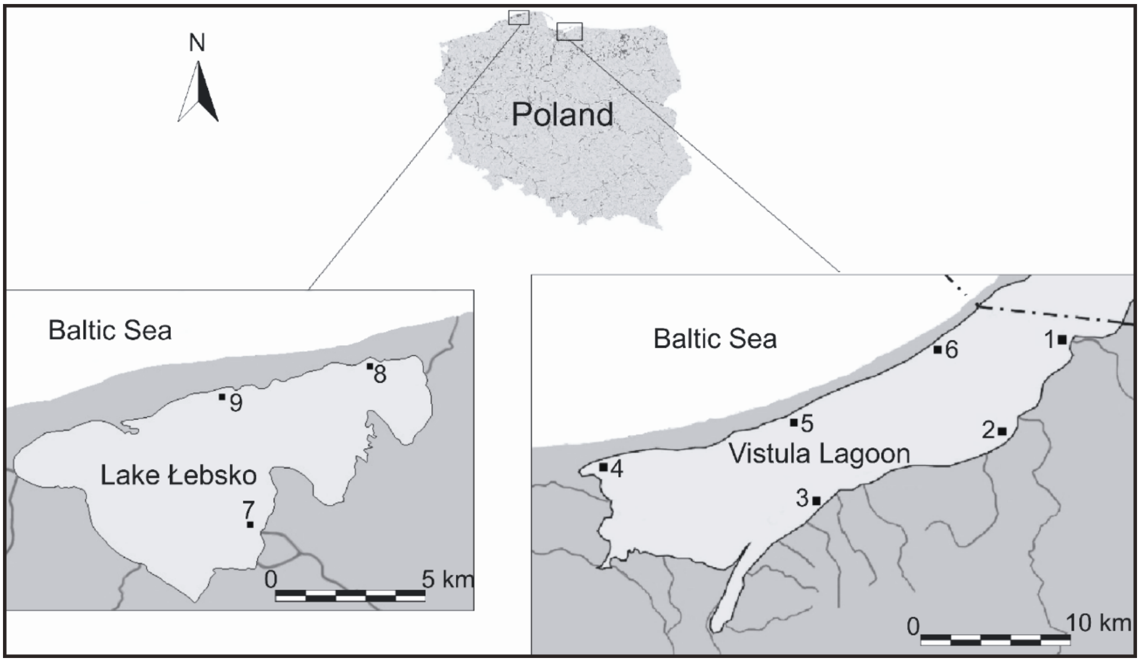

Figure 1. Location of the research stations on the Vistula Lagoon and Lake Łebsko.

The samples were collected from the coastal zone of open water and from the surface layer (0–1 m) with a 10-dm^3 bucket or a 5-dm^3 Ruttner sampler. From each station, 25 dm^3 of water was collected; it was then concentrated on an Apstein-type plankton mesh with 30-µm holes, fixed with Lugol's solution, and preserved in 4% formalin. Next, the biological material was analyzed qualitatively and quantitatively based on a microscopic examination. The zooplankton was examined under a Carl Zeiss Axio Imager A1 microscope fitted with a camera AxioCam MRc 5. The qualitative analyses of zooplankton included the qualification of zooplankton to a specific species within 3 taxonomic groups: Rotifera, Cladocera, and Copepoda. Zooplankton identifications were made to the lowest possible taxonomic level according to Voigt (1956/1957), Kutikova (1970), Koste (1978), Radwan et al. (2004) (Rotifera); Flössner (1972), Rybak (1994), Einsle (1996), Dussart and Defaye (2001) (Copepoda); Rybak (1993), Rybak and Błędzki (2010) (Cladocera). The abundance of zooplankton was determined by calculating the number and mass (biomass) of individuals in a water volume unit (1 dm^3), (Starmach, 1955; Hillbricht-Ilkowska and Patalas, 1967; Bottrell et al., 1976; Ejsmont-Karabin, 1998). To determine the biomass of zooplankton, a maximum of 20 specimens of all species were measured with a Carl Zeiss ocular micrometer, and formulas that relate the total length with the dry weight of the specimens were used (Patalas, 1954; Hilbricht Ilkowska and Patalas, 1961; Dumont et al., 1975; Bottrell et al., 1976; Ruttner-Kolisko, 1977; Ejsmont-Karabin, 1998). The following biocoenotic indices were used to determine the structure and diversity of zooplankton assemblages: constancy (C), i.e. the frequency of occurrence of a particular species in samples, and the dominance (D) of a given species in the biocoenosis (Kasprzak and Niedbała, 1981).

The results were statistically processed with STATISTICA PL 10.0 (StatSoft, 2011). One-way analysis of variance was performed to investigate the differences in the number of species, density, and biomass of zooplankton between the Vistula Lagoon and Lake Łebsko, i.e. 2 reservoirs with different anthropogenic pressures. The main factors influencing the state of the Vistula Lagoon were domestic and industrial effluents, agricultural runoff, tourism, fisheries, and transport. Seasonal tourism also has an impact on Lake Łebsko's environment. One-way analysis of variance performed to investigate differences in species numbers among stations indicated differences in water body features; the research stations were divided into 2 groups according to these features (Table 2).

In addition to samples collected for zooplankton quality and quantity determination, water samples for physical and chemical analysis were also taken, but the results were not directly included in the present study. They were used in the correlation analysis (sampling sites relations with habitats and the type of basin).

The stations located in the drainage basin that was directly impacted by anthropogenic factors were compared with the group of stations located in the drainage basin that was not affected by these factors. The same was done for other types of drainage basins (forested, agricultural, waterlogged).

The taxonomic structures of the zooplankton assemblages at the research stations were compared with the MVSP program (Kovach, 1999) using the Bray–Curtis coefficient.

3. Results

The zooplankton in the Vistula Lagoon and Lake Łebsko was represented by organisms classified as plankton rotifers and crustaceans. In 2010, 50 species were identified in the Vistula Lagoon and 32 in Lake Łebsko; in 2011, 47 taxa were recorded in the Vistula Lagoon and 39 in Lake Łebsko. In both experimental years, rotifers were most numerous (68.1% in Vistula Lagoon and 72.7% in Lake Łebsko of the total zooplankton number), with copepods being the second (17.4% and 19.4%, respectively), and Cladocera species being the least common (14.4% and 8.0%, respectively) (Figure 2).

At individual stations, the richness of species ranged from 5 to 24 taxa in 2010 and from 7 to 24 in 2011 in the Vistula Lagoon, and between 8 and 14 species in 2010 and between 7 and 15 species in 2011 in Lake Łebsko. In 2010, 21 species that were recorded in the Vistula Lagoon were missing in Lake Łebsko. Of rotifers, these included

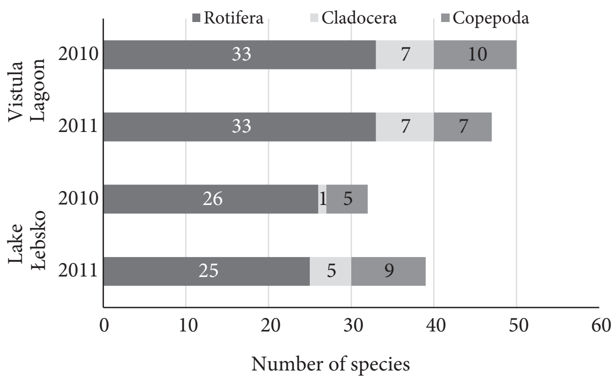

Figure 2. Number of zooplankton species identified in the Vistula Lagoon and Lake Łebsko during the experimental seasons in 2010–2011.

Brachionus quadridentatus Hermann, *Colurella uncinata* (Müller), *Filinia brachiata* (Rousselet), *Monommata longiseta* (Müller), *Notholca acuminata* (Ehrenberg), *Rotaria neptunia* (Ehrenberg), *Rotaria rotatoria* Pallas, *Synchaeta pectinata* Ehrenberg, *Synchaeta tremula* (Müller), and *Testudinella patina* (Hermann) (Table 3). The following Cladocera species were recorded only

Table 3. Composition of zooplankton assemblages in the Vistula Lagoon and Łebsko Lake over the experimental period.

Taxa	Vistula Lagoon 2010	Łebsko Lake 2010	Vistula Lagoon 2011	Łebsko Lake 2011
ROTIFERA				
Anuraeopsis fissa (Gosse, 1851)	+	+	+	+
Ascomorpha saltans Bartsch, 1870			+	+
Asplanchna priodonta Gosse, 1850	+	+	+	
Brachionus angularis Gosse, 1851	+	+	+	+
Brachionus calyciflorus Pallas, 1766	+	+	+	
Brachionus diversicornis Daday, 1883			+	
Brachionus quadridentatus Hermann, 1783	+		+	
Brachionus urceolaris Müller, 1773	+	+	+	+
Cephalodella catellina Müller, 1786	+	+	+	+
Cephalodella gibba Ehrenberg, 1832	+	+	+	+
Colurella colurus Ehrenberg, 1830	+	+	+	+
Colurella uncinata Müller, 1773	+		+	
Euchlanis dilatata Ehrenberg, 1832	+	+	+	+
Filinia brachiata Rousselet, 1901	+			
Filinia longiseta Ehrenberg, 1834	+	+	+	+
Keratella cochlearis (Gosse,1851)	+	+	+	+
Keratella cochlearis tecta (Gosse, 1886)	+	+	+	+
Keratella quadrata (Müller, 1786)	+	+	+	+
Lecane closterocerca (Schmarda, 1859)	+	+	+	+
Lecane flexilis (Gosse, 1886)	+	+	+	+
Lecane luna (Müller, 1776)	+	+	+	+
Lepadella ovalis (Müller, 1786)	+	+	+	+
Monommata longiseta (Müller, 1786)	+			+

Table 3. (Continued).

Taxa	Vistula Lagoon 2010	Łebsko Lake 2010	Vistula Lagoon 2011	Łebsko Lake 2011
Mytilina mucronata (Müller, 1773)			+	
Notholca acuminata (Ehrenberg, 1832)	+			
Notholca squamula (Müller, 1786)		+		
Polyarthra longiremis Carlin, 1943	+	+	+	+
Polyarthra major Burckhardt, 1900		+		+
Polyarthra vulgaris Carlin, 1943	+	+		
Pompholyx sulcata Hudson, 1885	+	+	+	+
Proales sp. Gosse, 1886	+	+	+	
Rotaria neptunia (Ehrenberg, 1832)	+		+	
Rotaria rotatoria (Pallas, 1766)	+			
Synchaeta *kitina* Rousselet, 1902			+	
Synchaeta oblonga Ehrenberg, 1831	+	+	+	+
Synchaeta pectinate Ehrenberg, 1832	+		+	
Synchaeta tremula (Müller, 1786)	+			
Testudinella elliptica (Ehrenberg, 1834)	+	+	+	
Trichocerca insignis (Herrick, 1885)				+
Testudinella patina (Hermann, 1783)	+			
Trichocerca pusilla (Lauterborn, 1898)	+	+	+	+
Trichocerca similis (Wierzejski, 1893)		+	+	+
Trichotría pocillum (Müller, 1776)			+	+
Trichotría tetractis (Ehrenberg, 1830)			+	+
CLADOCERA				
Alona rectangula G.O. Sars, 1862	+		+	+
Alonella nana (Baird, 1843)			+	
Bosmina longirostris (Müller, 1785)	+		+	
Ceriodaphnia quadrangula (Müller, 1785)	+		+	
Chydorus sphaericus (Müller, 1776)	+		+	+
Diaphanosoma brachyurum (Liévin, 1848)	+	+	+	+
Eubosmina coregoni (Baird, 1857)	+		+	
Leptodora kindtii (Focke, 1844)	+			+
Leydigia leydigii (Schoedler, 1863)				+
COPEPODA				
Acanthocyclops vemalis (Fischer, 1853)	+	+		+
Acartia bifilosa (Giesbrecht, 1881)			+	
Acartia longiremis (Dana, 1846)	+		+	
Acartia tonsa (Dana, 1846)	+		+	
Cyclops insignis Claus, 1857				+
Cyclops strenuus Fisher, 1851	+			
Eurytemora affinis (Poppe, 1880)	+	+	+	+
Harpacticoida	+	+	+	+
Megacyclops viridis (Jurine, 1820)	+			+
Mesocyclops leuckarti (Claus, 1857)	+	+	+	+
Metacyclops gracilis (Lilljeborg, 1853)	+	+		+
Paracyclops affinis (G.O. Sars, 1863)			+	+
Thermocyclops oithonoides (G. O. Sars, 1863)	+			+

in the Vistula Lagoon: *Alona rectangula* Sars, *Bosmina longirostris* (Müller), *Ceriodaphnia quadrangula* (Müller), *Chydorus sphaericus* (Müller), *Eubosmina coregoni* Baird, and *Leptodora kindtii* (Focke). Of copepods, this group included *Acartia longiremis* (Lilljeborg), *Acartia tonsa* Dana, *Cyclops strenuus* Fischer, *Megacyclops viridis* (Jurine), and *Thermocyclops oithonoides* (Sars). In Lake Łebsko, only 3 species were found that were not recorded in the Vistula Lagoon: the rotifers *Notholca squamula* (Müller), *Polyarthra major* Burckhardt, and *Trichocerca similis* (Wierzejski) (Table 3). In 2011, 18 taxa that were identified in the Vistula Lagoon were not found in Lake Łebsko. Of Rotifera, these included *Asplanchna priodonta* Gosse, *Brachionus calyciflorus* Pallas, *Brachionus diversicornis* (Daday), *B. quadridentatus*, *Colurella uncinata*, *Mytilina mucronata* (Müller), *Proales sp*., *Rotaria neptunia*, *Synchaeta kitina* Rousselet, *Synchaeta pectinate*, and *Testudinella elliptica* (Ehrenberg). Of Cladocera, these were *Alonella nana* (Baird), *Bosmina longirostris*, *Ceriodaphnia quadrangula*, and *Eubosmina coregoni*; whereas of Copepoda, there were 3 species of the *Acartia* genus: *A. bifilosa* (Giesbrecht), *A. longiremis*, and *A. tonsa*. The following species were recorded only in Lake Łebsko: Rotifera *Monommata longiseta*, *Polyarthra major*, and *Trichocerca insignis* (Herrick); 2 species of Cladocera: *Leptodora kindtii* and *Leydigia leydigi* (Schoedler); and 5 Copedoda taxa: *Acanthocyclops vernalis* (Fischer), *Cyclops insignis* Claus, *Megacyclops viridis*, *Metacyclops gracilis* (Lilljeborg), and *Thermocyclops oithonoides* (Table 3).

The species composition of both reservoirs was comparable in 2010. The statistical analysis did not demonstrate any significant differences in the course of species structure between the Vistula Lagoon and Lake Łebsko ($P = 0.064$). In 2011, a higher number of species was recorded in the Vistula Lagoon ($P = 0.037$) (Table 4). A higher species richness was observed in the Vistula Lagoon in both years (Table 4), even though the difference was not statistically significant in 2010 ($P = 0.064$ in 2010 and 0.037 in 2011).

Analyzing the structure of zooplankton in the Vistula Lagoon in 2010, 2 eudominant and 4 dominant species were identified. In Lake Łebsko, there were 2 eudominant species and 1 dominant species. In 2011, 3 eudominant species were identified in the Vistula Lagoon, whereas, in Lake Łebsko, there were 2 eudominant species and 1 dominant taxon.

Larval stages of copepods (nauplii) were also dominant in the zooplankton in both examined reservoirs (Table 5). In 2010, 7 taxa were constantly present in the Vistula Lagoon, while 10 taxa were present in 2011. In Lake Łebsko, 7 taxa were constantly present in both 2010 and 2011 (Table 6).

Based on the analysis of the collected samples, it was found that the total density of zooplankton in the Vistula Lagoon and Lake Łebsko in 2010 was 1102 ind. dm^{-3} and 1257 ind. dm^{-3}, respectively. In that year, rotifers were the most numerous group, constituting 84.3% and 92.3% of the total zooplankton abundances in the Vistula Lagoon and Lake Łebsko, respectively (Figure 3). The high proportion of rotifers in the total zooplankton in the Vistula Lagoon was composed of such species as *Keratella cochlearis* (Gosse), with *K. cochlearis cochlearis* (59.3%) as the dominant form, and *Polyarthra longiremis*, *Filinia longiseta* (Ehrenberg), and *Brachionus angularis* (Gosse), in which the *B. angularis bidens* form was predominant (79.4%). In Lake Łebsko, the most numerous rotifers included *K. cochlearis*, of which the *K. cochlearis tecta* form constituted 95.0%. In addition, *P. longiremis* and *Anuraeopsis fissa* (Gosse) were numerous. Copepods were the second most numerous group (Figure 3). In the Vistula Lagoon, the most numerous species were *Eurytemora affinis* (Poppe) and *Mesocyclops leuckarti* (Claus), while, in Lake Łebsko, the most numerous were *M. leuckarti* and *M. gracilis*. However, the total number of zooplankton in both reservoirs was mostly impacted by 2 developmental stages of copepods, nauplius and copepodit, which were seen throughout the experimental period. In the Vistula Lagoon, the density of copepodit stages was 9 ind. dm^{-3}; of nauplii, 70 ind. dm^{-3}. In Lake Łebsko, the number of juvenile forms (copepodits) was 17 ind. dm^{-3} and of larval forms (nauplii) 68 ind. dm^{-3}. Cladocera were the least numerous group of zooplankton identified in both reservoirs (Figure 3). In the Vistula Lagoon, these organisms were detected mainly in the warmest months (July, August) and formed numerous populations, while in Lake Łebsko their occurrence was sporadic and in low numbers.

Table 4. Zooplankton species richness, abundance, and biomass in the Vistula Lagoon and Lake Łebsko in 2010–2011 (mean ± SD).

Reservoirs	Species richness		Abundance [ind. dm^{-3}]		Biomass [mg dm^{-3}]	
	2010	2011	2010	2011	2010	2011
Vistula Lagoon	12 ± 4.8	14 ± 4.2	1102 ± 1486	1029 ± 1346	1.84 ± 4.12	0.91 ± 1.15
Lake Łebsko	10 ± 1.7	11 ± 2.5	1257 ± 875	2609 ± 2135	0.38 ± 0.26	2.38 ± 7.07

Table 5. Eudominant and dominant zooplankton species* in the Vistula Lagoon and Lake Łebsko over the experimental period.

	Vistula Lagoon		Lake Łebsko	
	2010	2011	2010	2011
Anuraeopsis fissa (Gosse, 1851)			8.2	22.7
Brachionus angularis Gosse, 1851	9.9	12.7		
Filinia longiseta Ehrenberg, 1834	9.8	18.5		
Keratella cochlearis (Gosse, 1851)	29.7	36.4	59.5	49.5
Polyarthra longiremis Carlin, 1943	16.2		20.0	
Pompholyx sulcata Hudson, 1885	7.5			
Trichocerca pusilla (Lauterborn, 1898)				10.0
Bosmina longirostris (O.F. Müller, 1785)	6.3			
Nauplii	6.3	7.3	8.6	8.6

* Species dominance classes according to Kasprzak and Niedbała (1981): >10.0% eudominant species, 5.1%–10.0% dominant species.

Table 6. Absolutely constant and constant species* in the Vistula Lagoon and Lake Łebsko over the experimental period.

	Vistula Lagoon		Lake Łebsko	
	2010	2011	2010	2011
Anuraeopsis fissa (Gosse, 1851)			71.4	80.0
Asplanchna priodonta Gosse, 1850		53.3		
Brachionus angularis Gosse, 1851	70.0	80.0	57.1	80.0
Brachionus calyciflorus Pallas, 1766		66.7		
Colurella colurus Ehrenberg, 1830	55.3			
Euchlanis dilatata Ehrenberg, 1832		56.7		
Filinia longiseta Ehrenberg, 1834		96.7		73.3
Keratella cochlearis (Gosse, 1851)	100.0	100.0	100.0	100.0
Keratella quadrata (Müller, 1786)		60.0		
Lecane closterocerca (Schmarda, 1859)			57.1	
Polyarthra longiremis Carlin, 1943	56.7		85.7	
Pompholyx sulcata Hudson, 1885	90.0	63.3		
Synchaeta oblonga Ehrenberg, 1831	56.7			
Trichocerca pusilla (Lauterborn, 1898)	53.3	90.0	85.7	100.0
Eurytemora affinis (Poppe, 1880)		66.7		
Mesocyclops leuckartii (Claus, 1857)			57.1	60.0
Paracyclops affinis (G.O. Sars, 1863)				53.3

*Frequency criterion according to Tischler (1949) as cited in Trojan (1980): 100%–76% (absolutely constant species), 75%–51% (constant species).

In 2011, the total number of zooplankton was 1029 ind. dm^{-3} in the Vistula Lagoon and 2609 ind. dm^{-3} in Lake Łebsko. As in the preceding year, rotifers were most numerous in both water bodies (Figure 3), constituting 87.6% of the total number of zooplankton in the Vistula Lagoon and 89.4% in Lake Łebsko. In the Vistula Lagoon, the most numerous rotifers were *K. cochlearis*, of which the *cochlearis* form constituted 92.5%, *F. longiseta*, and *B. angularis*, with the dominant *angularis* form (60.3%) and *aestivus* (27.2%) and *bidens* (12.5%) forms constituting a smaller percentage. In Lake Łebsko, a significant density of rotifers was composed of species such as *K. cochlearis*, of which the *tecta*

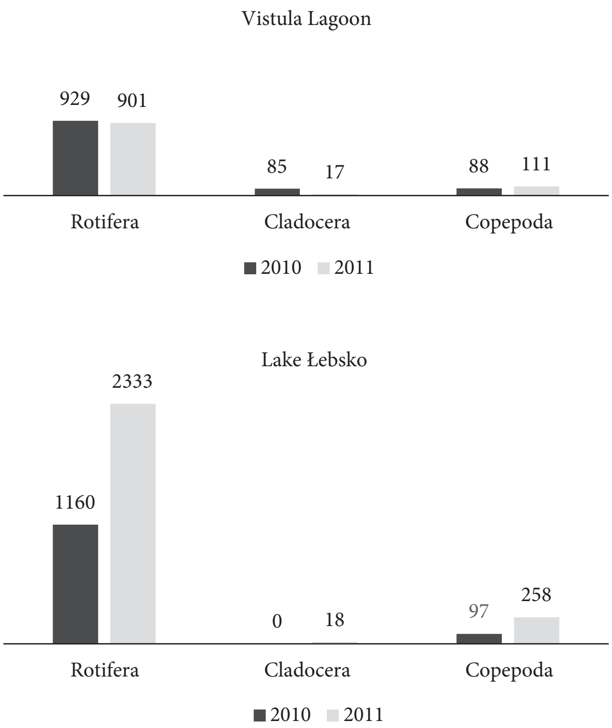

Figure 3. Abundance (ind. dm^{-3}) of zooplankton in the Vistula Lagoon and Lake Łebsko in 2010–2011.

form constituted 99.9%, along with *A. fissa*. Copepods were the second most numerous group, as in 2010 (Figure 3). In both reservoirs, this density was mainly determined by juvenile forms (i.e. nauplii and copepodits), whose numbers were 93 ind. dm^{-3} in the Vistula Lagoon and 237 ind. dm^{-3} in Lake Łebsko. Moreover, *E. affinis* was prominent in terms of numbers in the Vistula Lagoon, whereas *M. leuckarti*, *Paracyclops affinis* (Sars), and *M. gracilis* were numerous in Lake Łebsko. Cladocera was the least numerous group (Figure 3). *Diaphanosoma brachyurum* (Lievin) and *B. longirostris* were relatively numerous in the Vistula Lagoon, while *A. rectangula* was relatively numerous in Lake Łebsko.

Analyzing the differences in the numbers of zooplankton between the Vistula Lagoon and Lake Łebsko in the first study season (2010), the density of zooplankton was comparable, and there were no statistically significant differences in the numbers of zooplankton between the reservoirs (P = 0.726). In the second year (2011), a higher density of zooplankton was found in Lake Łebsko. Highly significant differences in the zooplankton numbers were recorded between the examined reservoirs (P = 0.005) (Table 4). Seasonal changes in zooplankton density are presented in Figure 4.

The analysis of zooplankton abundance also included an estimation of its biomass. In 2010, the total biomass of zooplankton was 1.84 mg dm^{-3} for the Vistula Lagoon and 0.38 mg dm^{-3} for Lake Łebsko. In the Vistula Lagoon, the volume of biomass was affected by plankton crustaceans, mainly Cladocera, as their proportion in the total biomass was 73% (Figure 5). Weight proportion was mainly determined by the organisms of *L. kindtii* (approximately 50%), but *B. longirostris* also constituted a substantial part (approximately 13%). Of copepods, *E. affinis* was a prominent species. A significantly lower biomass of rotifers was recorded (Figure 5), as these organisms constituted 13% of the total biomass of the investigated zooplankton.

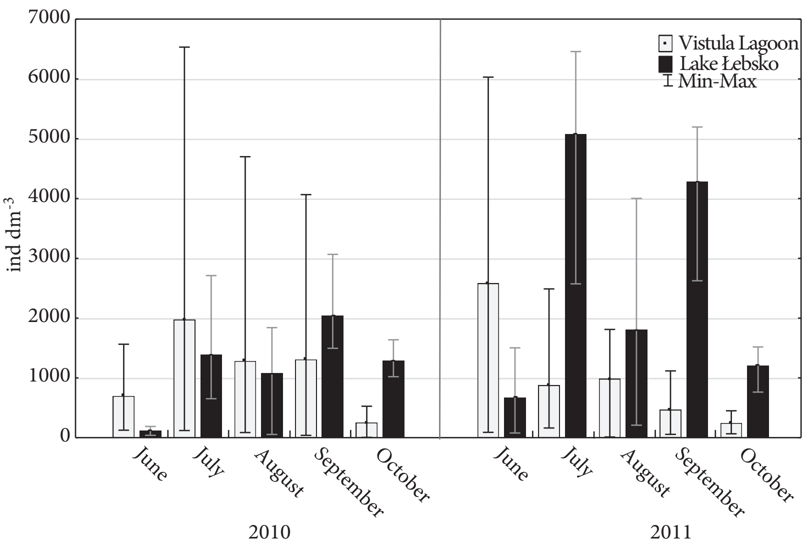

Figure 4. Seasonal (monthly) changes in the total zooplankton abundance (mean, minimum, and maximum densities) (ind. dm^{-3}) in the Vistula Lagoon and Lake Łebsko in 2010–2011.

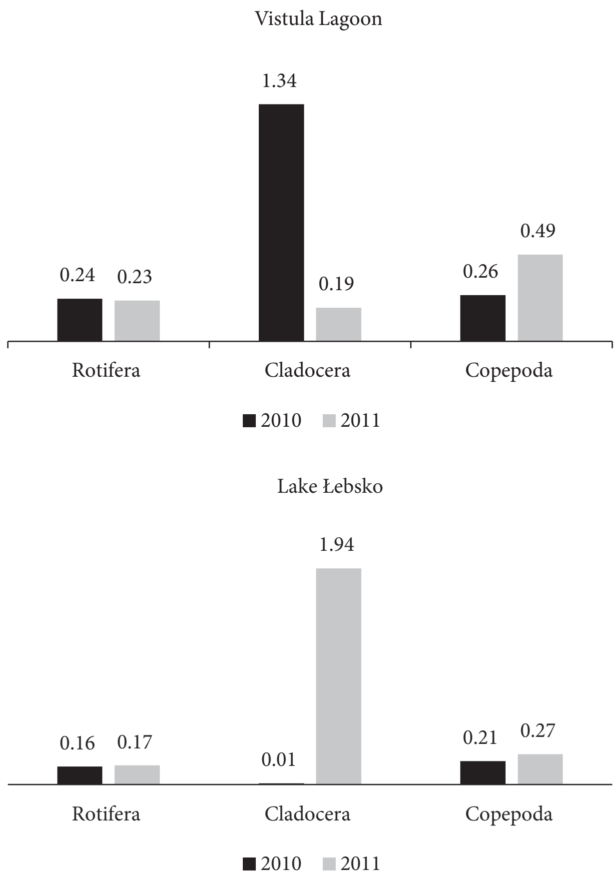

Figure 5. Biomass (mg dm^{-3}) of zooplankton in the Vistula Lagoon and Lake Łebsko in 2010–2011.

The recorded weight proportion of rotifers included such species as *P. longiremis*, *K. cochlearis*, *B. calyciflorus*, *B. angularis*, and *A. priodonta*. In Lake Łebsko, 55% of the total biomass of zooplankton was composed of copepods (Figure 5), in which *M. leuckarti* and *M. gracilis* had a decisive role. Rotifers also had a substantial share (42%) in the biomass of zooplankton, and these were mainly 2 species: *P. longiremis* and *K. cochlearis*. The biomass of Cladocera constituted only 2.6% of the total biomass of investigated zooplankton. In the next experimental year (2011), the total biomass of zooplankton was 0.91 mg dm^{-3} in the Vistula Lagoon and 2.38 mg dm^{-3} in Lake Łebsko. In the first reservoir, 53.8% of the biomass was composed of copepods (Figure 5), mainly *E. affinis* (44%). The weight proportion of the 2 other zooplankton groups in the total biomass was on a comparable level (Figure 5). Rotifers constituted a slightly higher proportion (25.3%), which was impacted by the biomass of such organisms as *B. angularis*, *F. longiseta*, and *K. cochlearis*. The lowest proportion was recorded for Cladocera (20.9%), with *D. brachyurum* being the predominant species. In Lake Łebsko, over 82% of the volume of the biomass was composed of Cladocera, of which the most prominent was the biomass of *L. kindtii* (80%). Copepods were the second most important component of the biomass with such species as *M. leuckarti* and *M. gracilis*. Of rotifers, only *K. cochlearis* was prominent (Figure 5).

The volume of the zooplankton biomass of both the Vistula Lagoon and Lake Lebsko differed between the 2 experimental years (Table 4). Significant differences were not found between the studied water bodies, however ($P = 0.201$ in 2010; $P = 0.283$ in 2011). When comparing the 2 experimental seasons, the volume of zooplankton biomass in the Vistula Lagoon and Lake Łebsko was found to differ; however, in 2010 and 2011, no significant differences were noted in zooplankton between the water bodies. Seasonal changes in zooplankton biomass are presented in Figure 6.

Drainage basin type affected the zooplankton assemblages, as indicated by the statistically significant differences occurring in the number of zooplankton taxa at research stations located in drainage basins affected by anthropogenic factors ($P < 0.0001$), those that were forested ($P = 0.005$), and those that were waterlogged ($P = 0.04$). No statistically significant differences were noted with regard to agricultural drainage basins. Cluster analysis based on the Bray–Curtis coefficient identified clusters of zooplankton assemblages in Lake Łebsko at station 9 in both study years and at stations 7 and 8 in 2011. Zooplankton assemblages occurring at the remaining stations in this lake also formed a cluster (stations 7 and 8 in 2010). The zooplankton confirmed at station 2 in 2010 and at station 3 in 2011 formed a cluster among the assemblages identified in the Vistula Lagoon that could be considered significant (Figure 7). The zooplankton assemblage at station 1 differed taxonomically from those of this ecological group observed at all the other research stations during the investigation.

4. Discussion

The locations of water reservoirs, their morphology, hydrology, and drainage basin management determine the environmental factors indirectly impacting organisms living in a given ecosystem. The occurrence of zooplankton assemblages depends on a number of ecological factors, both abiotic (such as water temperature, concentration of biogenes, content of oxygen in water, availability of light or salinity) and biotic (such as limited feed resources, pressure of plankton-eating fish, or competition) (Joyce et al., 2005; Marques et al., 2006). Salinity is the main factor that influences the composition of zooplankton in shallow coastal lagoons (Joyce et al., 2005; Anton-Pardo and Armengol, 2012). Variations in salinity may indirectly or directly impact the structure of plankton. They may cause some forms to disappear while provoking others to

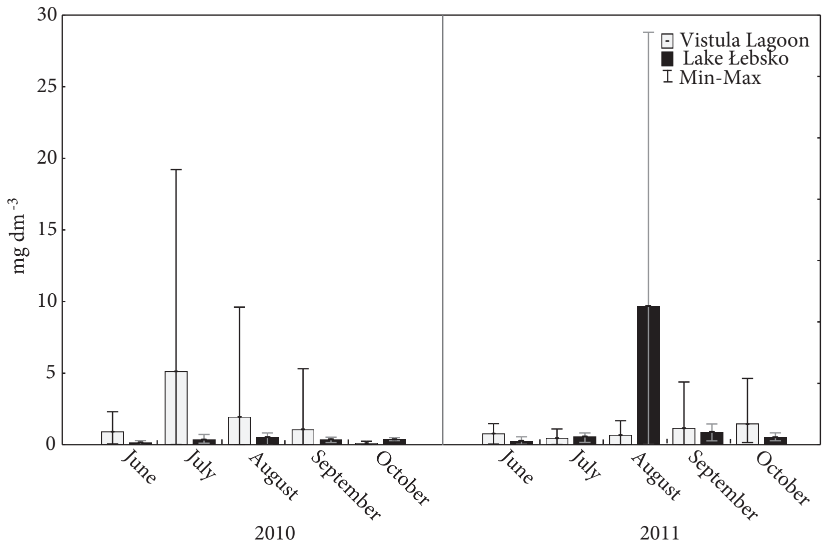

Figure 6. Seasonal (monthly) changes in the total zooplankton biomass (mean, minimum, and maximum values) (mg. dm^{-3}) in the Vistula Lagoon and Lake Łebsko in 2010–2011.

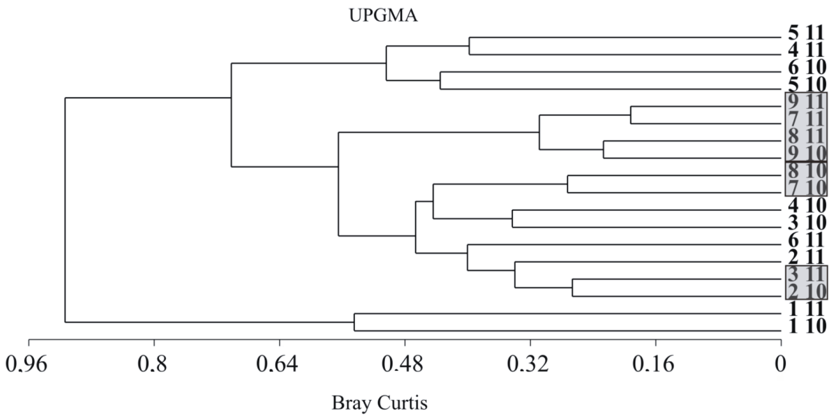

Figure 7. Dendrogram of station clusters identified from the Bray–Curtis dissimilarity matrix using unweighted pair group method with arithmetic mean sorting. The station clusters of the Vistula Lagoon and Łebsko Lake are presented for each survey year.

appear, or may induce migrations of organisms trying to evade high or low salinity. Indirectly, variations in salinity may influence the availability of feed and, consequently, the abundance of the zooplankton population (Perumal et al., 2009). At low salinity, more Cladocera appear in the structure of the zooplankton population, i.e. typically freshwater organisms; at higher salinity, copepods (mainly Calanoida) and rotifers (mainly euryhaline species of the genus *Brachionus* or *Colurella*) predominate. The disappearance of Cladocera with increasing salt concentration in water creates favorable conditions for the growth of rotifers, as the representatives of these 2 groups are mainly filtrates and there is competition for feed between them (Anton-Pardo and Armengol, 2012). Moreover, a reduction in species diversity of zooplankton has been observed together with increasing salinity (Nielsen et al., 2007; Boix et al., 2008; Jensen et al., 2010). In the present study, the following species were predominant in the composition of zooplankton: *Keratella cochlearis*, *Filinia longiseta*, *Polyarthra longiremis*, *Trichocerca pusilla* (Lauternborn), *Brachionus angularis*, or *Pompholyx sulcata* Hudson—euryhaline rotifer species that tolerate salinity of up to approximately 5.0 PSU (O'Reilly, 2001; Fontaneto et al., 2006). The distinct impact of salinity on the species structure of zooplankton was reflected in the presence of *Eurytemora affinis*, a copepod that is typical in brackish waters (Lee and Petersen, 2002), and marine species of the genus *Acartia*: *A. tonsa*, *A. longiremis*, and *A. bifilosa* (Cervetto et al., 1999; Boxshall, 2001), as well as sporadic occurrence of Cladocera that, as typically freshwater species, do not tolerate high concentrations of salt (Boix et al., 2008; Brucet et al., 2009). Among the most numerous Cladocera, the following euryhaline taxa were observed: *Bosmina longirostris*, *Eubosmina coregoni*, and *Chydorus sphaericus* (Brucet et al., 2009). However, only the dominant rotifer species were constantly found in the biocoenoses of the investigated water reservoirs. Cladocera and copepods were reported at high density only periodically, except for juvenile Copepoda stages. Zooplankton assemblages follow a similar path in another coastal brackish water body, the Curonian Lagoon. In this reservoir, of freshwater organisms that are constantly present, Cladocera are predominant with such species as *Bosmina* spp., *Ch. sphaericus*, *Daphnia* spp., *Diaphanosoma brachyurum*, and *Leptodora kindtii*, and copepods such as *Cyclops strenuus*, *Eudiaptomus graciloides*, and *Mesocyclops leuckarti*. Among the rotifers, *Keratella* spp. and *Brachionus* spp. were the main components. Typical brackish fauna was recorded only during inflows of Baltic seawater, and was represented by the copepod species *Acartia bifilosa*, *Eurytemora hirundoides* (Nordquist), and *Temora longicornis* (Müller), and such Cladocera as *Podon polyphemoides* (Leuckart) and *Evadne nordmanni* Lovén (Gasiūnaitė et al., 2008). In near-sea lakes, there is a predominance of species that are typical in freshwater. In Lake Gardno, these were such rotifers as *K. cochlearis*, genus *Brachionus*, *T. pusilla*, and *P. sulcata*, as well as a single Cladocera species, namely *Ch. sphaericus*. The zooplankton of Lake Jamno was mainly composed of the genus *Keratella*, *B. longirostris*, *Ch. sphaericus*, *Daphnia longispina*, and *Cyclops vicinus*. No taxa typical of brackish waters were recorded (Paturej, 2005a, 2005b).

Salinity determines not only the structure of zooplankton, but also its abundance. Badsi et al. (2010) demonstrated a highly significant positive correlation between the density of zooplankton and concentration of salt in water. Similar observations were reported by Gao et al. (2008), who found that salinity impacts the number of individual zooplankton species and consequently determines the total density of zooplankton. Furthermore, salinity determines the biomass of zooplankton to a large extent. Similar to density, higher biomass of zooplankton is recorded at higher salt concentrations (Echaniz et al., 2012). Earlier studies conducted by Paturej and Gutkowska (2012) on the Vistula Lagoon showed a slight positive correlation between salinity and the number and biomass of zooplankton.

The predominance of Rotifera and sporadic occurrence of Cladocera may be explained by the impact of other abiotic parameters, such as temperature or wave motion, as well as with numerous biocoenotic links (Paturej, 2010), and also by the high degree of eutrophication of both reservoirs (Margoński and Horbowa, 2003; Jarosiewicz, 2009). Studies conducted earlier by other authors have shown that the structure and abundance of zooplankton are closely correlated with the trophic status of a reservoir (Pinto-Coelho et al., 2005; Paturej, 2006b; Wang et al., 2007; Yıldız et al., 2007; Kudari and Kanamadi, 2008). This is manifested as the predominance of herbivorous forms with large body sizes (copepods *Calanoida*, large Cladocera) at low trophic states, and the abundance of detritus-eating and predatory small forms (copepods *Cyclopoida*, small Cladocera, rotifers) in fertile waters. A correlation between the biomass of zooplankton and the trophic status is difficult to assess as zooplankton are composed of a great variety of species with an extensive range of sizes (Sendacz et al., 2006; González et al., 2011). Considering the fact that with progressive eutrophication the structure of zooplankton is reconstructed towards species with smaller sizes, it may be assumed that the biomass of Rotifera will increase. This was confirmed by Ejsmont-Karabin (2012), who concluded that due to increasing feed resources, i.e. bacterial plankton and phytoplankton, the biomass of rotifers increases.

The Vistula Lagoon is highly eutrophicated. Since the beginning of the studies on zooplankton, the zooplankton of this reservoir was numerically dominated by small organisms of the Rotifera group (Paturej et al., 2012). Moreover, the taxonomic composition was dominated by species that are, according to Karabin (1985a, 1985b) the indicators of high water trophic state, namely, specimens of the genera *Keratella* and *Brachionus*, *F. longiseta*, *P. sulcata*, *T. pusilla*, *B. longirostris*, *Ch. sphaericus*, *D. brachyurum*, and *M. leuckarti* (Margoński and Horbowa, 2003; Paturej and Kruk, 2011; Kruk et al., 2012). An analogous situation was recorded in the present study. In 2010, of 50 identified species, 33 belonged to Rotifera. In 2011, this number increased to 47 taxa, of which as many as 33 belonged to this group. The density of rotifers was 929 ind. dm^{-3} (2010) and 901 ind. dm^{-3} (2011), which corresponded to 84.3% and 87.6%, respectively, of the total zooplankton abundance. The species composition was dominated by indicator organisms that are typical of eutrophy. Analogous structure and species composition that are comparable to those of the Vistula Lagoon are characteristic for other near-Baltic lagoons, such as the Curonian Lagoon. Naumenko (2009) found that of 136 identified taxa, as many as 79 belonged to Rotifera, and their numerical proportion was 43%. In addition, among common species there were the same taxa, reflecting the high trophic state of the reservoir. The Darß-Zingst Bodden chain was also characterized by a predominance of rotifers. Of 102 species, 66 belonged to Rotifera. Plankton organisms typical of eutrophicated reservoirs were also identified, namely *K. cochlearis*, *Keratella quadrata* (Müller), *F. longiseta*, *Brachionus calyciflorus*, and *Brachionus quadridentatus* (Schiewer, 2008).

Lake Łebsko's waters are also eutrophic, which impacts the structure zooplankton structure. As in Vistula Lagoon, rotifers were predominant in the species composition. Studies by Paturej (2000) demonstrated that in 1985–1996, in summer zooplankton assemblages, Rotifera constituted 49.3%–93.5% of the total number of zooplankton. The qualitative profile also included species typical of a high water trophic state such as taxa of the genera *Brachionus* and *Keratella*, *F. longiseta*, *T. pusilla*, *B. longirostris*, *Ch. sphaericus*, and *D. brachyurum* (Paturej and Goździejewska, 2005). The present study also confirms the predominance of Rotifera in the quantitative structure of zooplankton. Of the 32 species recorded in 2010, as many as 26 belonged to Rotifera. In 2011, of 39 taxa, 25 were classified in this group. The density of rotifers was 1160 ind. dm^{-3} in 2010 and 2333 ind. dm^{-3} in 2011, which constituted 92.3% and 89.4% respectively of the total plankton abundance.

The presence of previously identified species typical of high water trophic states was also recorded. Zooplankton in Lake Łebsko and in other near-sea lakes are of a similar nature. The predominance of small organisms such as Rotifera and the occurrence of taxa as indicators of water eutrophication were observed (Paturej, 2005a, 2005b, 2006b). In 2010–2011, in both investigated reservoirs, a predominance of Rotifera was recorded in the total density of zooplankton. Their numerical proportion was 80% in the Vistula Lagoon and approx. 90% in Lake Łebsko. Among Cladocera, small organisms of the genera *Bosmina* or *Chydorus* were found. The presence of species typical of waters with a poor trophic status was also detected, which confirms the high eutrophication of the examined reservoirs. However, there were no specific tendencies in the biomass of zooplankton often associated with high trophic states. Rotifera biomass was low (0.24 mg dm^{-3} in the Vistula Lagoon and 0.16 mg dm^{-3} in Lake Łebsko), while the total biomass of zooplankton was dominated by Cladocera and Copepoda in both water bodies.

The variability in abundance and species composition was also associated with seasonality, i.e. monthly changes in temperature. Zervoudaki et al. (2009) report that in estuaries, in contrast to freshwaters where Copepoda predominate in winter and autumn and Cladocera in summer, a seasonal peak of crustaceans is recorded in midsummer and autumn, while the maximum number of Rotifera is seen in spring and summer. In the present study, this situation was impossible to verify as the studies were carried out between June and October. In general, higher abundance of zooplankton in both reservoirs was recorded in summer months (VI–VIII), whereas in autumn the number of zooplankton decreased (Figure 4). In the case of biomass, the tendency was similar, except for 2011 in the Vistula Lagoon, when a substantial increase in the biomass was measured in autumn (Figure 6). This was associated with the occurrence of *E. affinis*, a copepod, in the zooplankton structure. Dmitrieva and Semenova (2011) provided an excellent presentation of seasonal variability in zooplankton in the Curonian Lagoon. These authors report that intensive growth of zooplankton, mainly rotifers and copepods, occurred after the melting of ice cover (March–April). In early summer, there was a 4- to 10-fold increase in the abundance of zooplankton, with Rotifera and Cladocera being predominant in its structure. Summer zooplankton (July–September) was dominated by small Cladocera and Cyclopoida species, whereas in autumn (October–November) rotifers of the genus *Keratella*, Cladocera of the genus *Daphnia*, and Cyclopida copepods were predominant. In another near-Baltic lagoon, Darß-Zingst, there was a stable tendency in seasonal zooplankton variations, with predominance of copepods in spring and late summer and of rotifers in summer (Heerkloss et al., 2006). It may be thus supposed that Rotifera would be predominant in spring and summer, and Copepoda in late summer and autumn in the Vistula Lagoon. The seasonal dynamics of zooplankton changes were thoroughly investigated by Paturej (2005a) in Lake Łebsko and in other near-sea lakes in Poland. The author recorded the highest numbers in the spring–summer seasons, which was mainly determined by rotifers; thereafter, the abundance of zooplankton decreased in the autumn–winter seasons with crustaceans being predominant in the structure of zooplankton assemblages. The biomass of zooplankton had a similar tendency, with the maximum recorded in summer, which resulted from a massive occurrence of Cladocera. In autumn, there was a decrease in the biomass up to the lowest value in winter, when it was determined by copepods. Therefore, it may be concluded that in Lake Łebsko seasonal dynamics will be of the same profile as demonstrated by Paturej (2005a).

In conclusion, differences in location in the investigated water bodies impacted the structure and abundance of the zooplankton assemblages.

The zooplankton of the examined coastal brackish waters was dominated mainly by small eurytopic organisms belonging to Rotifera. Plankton crustaceans were also found, although they showed a limited diversity of species. Copepods were predominant, whereas Cladocera were observed sporadically in more freshwater habitats. Zooplankton was of a similar nature in other brackish reservoirs located on the coast of the Baltic Sea. Drainage basin type appeared to have a significant impact on zooplankton assemblages. Drainage basins affected by anthropogenic factors, those that were forested, or those with waterlogged areas can have a significant impact on the zooplankton species richness in the region of the coastal brackish water bodies investigated. Since the observed differences were seasonal, long-term observations are required to investigate, in a wider context, the changes in the structure and abundance of zooplankton in coastal brackish waters.

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