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The diversity and longitudinal changes of zooplankton in the lower course of a large, regulated European river (the lower Vistula River, Poland)

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Abstract: The diversity and longitudinal variation of zooplankton in the lower Vistula River were analyzed. Samples were taken from 40 stations located along a 272-km long section of the lower river course. During the study the unique technique of taking samples from "the same water" was used. The zooplankton community was dominated by rotifers and nauplii – larval stages of copepods. The most abundant species were: *Brachionus angularis, Brachionus calyciflorus* and *Brachionus budapestiensis.* The zooplankton species diversity in the main channel of the lower Vistula River was similar to other large European rivers; however, its abundance was lower. The diversity, abundance and biomass of potamoplankton steadily decreased downstream. This could be related both to scarcity of storage zones for potamoplankton development in the river due to the extensive regulation processes, and changes in hydrological conditions of the main channel (by the straightening of riverbed) where the samples were collected.

Key words: zooplankton; river; Rotifera; Crustacea; Vistula

Introduction

Zooplankton plays an essential role in water ecosystems, including rivers. The planktonic animals take part in the transformation and circulation of organic matter (Ejsmont-Karabin et al. 2004), regulate the biomass of phytoplankton (Lair 2005; Kentzer et al. 2010) and provide food for fish, especially for their larval stages and for fish fry (Pourriot et al. 1997). However, despite the increased interest in large river ecosystems (Tockner et al. 2009), our knowledge of potamoplankton is still incomplete. The lack of research on potamoplankton may have resulted from the opinion that rivers were not suitable environments for zooplankton. However, potamoplankton is usually abundant in the main channel of large rivers, although the factors regulating their spatial occurrence are not completely understood. Recent investigation has emphasized the importance of water residence time for zooplankton development (Basu & Pick 1996). Water residence time increases with the increasing river length and there is often a tendency for plankton to be more abundant downstream. Generally these downstream increases have been associated with the increases of time available for plankton to develop (Viroux 1999; Zimmermann-Timm et al. 2007). So we can say that the "Age of Water" (Baranyi et al. 2002) is very important for zooplankton development.

While zooplankton composition and abundance have been quite well documented in many large rivers of Europe (Lair & Reyes-Marchant 1997; Reckendorfer et al. 1999; Zimmermann-Timm et al. 2007; Rossetti et al. 2009; Vadadi-Fülöp et al. 2009, 2010) little is known of these communities in the mid-eastern European rivers such as the Vistula River. The Vistula River is one of the largest rivers of the Baltic Sea basin and its valley is an important ecological corridor in this part of Europe (Bij de Vaate et al. 2002).

Unfortunately very few studies have been undertaken in the Vistula River and even these have been restricted to such sections of the river as dam reservoirs (Starzykowa et al. 1972; Krzanowski 1987; Żurek & Kasza 2002; Żurek 2004; Kentzer et al. 2010) or the upper (Bednarz et al. 1988) and middle reaches (Praszkiewicz et al. 1983; Papińska 1990; Słoń & Kowalczewski 1991).

To address the dearth of information on zooplankton in the Vistula River at a large spatial scale, the present study was carried out to determine species diversity, abundance and biomass of these organisms in the main channel along a 272-km long section of the lower river course.

According to the River Continuum Concept (RCC) (Vanote et al. 1980) physical variables present a continuous gradient in hydrological conditions in an ideal, freely flowing river, which conforms to the biological organization. The RCC also provides a theory for dynamics of plankton communities in lotic water. Regulation of the rivers and dam construction is considered to be major factor contributing to significant modification of the river ecosystem (Pourriot et al. 1997; Kentzer et al. 2010). The studied section of the Vistula River was regulated in the nineteenth century. Authors of this study try to answer whether the regulation of the studied river considerably modified the river ecosystem and if it could be observed in structure of potamoplankton. Based on previous literature on freely flowing rivers (van Dijk & van Zanten 1995) it was expected that potamoplankton diversity and abundance should increase downstream

Our specific objective was to describe the species composition and abundance of zooplankton communities in a standard manner to allow inter-population comparisons of past and future studies. This would be especially important in relation to the next planned dam reservoir that could substantially disturb the river continuum and change the taxonomic composition of zooplankton communities in this part of the river.

Material and methods

The lower Vistula is the longest segment (391 km) of Vistula (1068 km). It starts at the inlet of the Narew River (52°25′54″ N, 20°40′31″ E) and ends at the mouth to the Baltic Sea (54°21′32″ N, 18°57′01″ E). The area of the drainage basin in the lower course is 34,116 km^2, which constitutes 17.6% of the entire basin area. This segment has all the characteristics of the lowland river with a slight fall of the water level (ca. 0.20‰) and flow velocities (ca. 0.3–0.9 m s^{-1}). The mean discharge, which reached ca. 900 m^3 s^{-1} downstream from the Narew's mouth, increases slightly, reaching ca. 1050 m^3 s^{-1} at the mouth. Włocławek Reservoir (WR) which lies between 618 and 675 kilometer of the river course (rkm) is also part of the lower Vistula (Głogowska 2000).

The section of the river, which is the object of our studies is over 275 km long and stretches from Włocławek – downstream from the WR (675 rkm) to the mouth of the River to the Baltic Sea (950 rkm) (Fig. 1).

The research was conducted between 22nd and 27th of August 2000 during a special scientific cruise on the lower Vistula. During the study the unique technique of taking samples from "the same water" was used. The samples were collected in the main channel from a boat that flowed down the river with the speed of water flow.

The material came from 40 stations located along the Vistula River, starting from station 1 (678 rkm) – 3 km below the WR (52°39′23″ N; 19°08′02″ E), ending at station 40 (ca. 950 rkm) near the mouth (54°18′26″ N; 18°56′01″ E) (Fig. 1). Samples were taken at ca. 5 and 10 km.

All zooplankton samples (both qualitative and quantitative), were taken from the main channel (as is typical in studies of all water courses) (Greenberg 1992; Viroux 1997; Lair 2005) from the depth of 0.5 to 1 m using standard methods by means of a 5 dm^3 Patalas sampler. Water was filtered through a plankton net with mesh diameter of ca. 50 µm. In order to obtain one sample of zooplankton, 20 litres of water were filtered. All samples were preserved with Lugol's solution. Altogether, 40 samples were collected. The identification of zooplankton was performed with the use of a

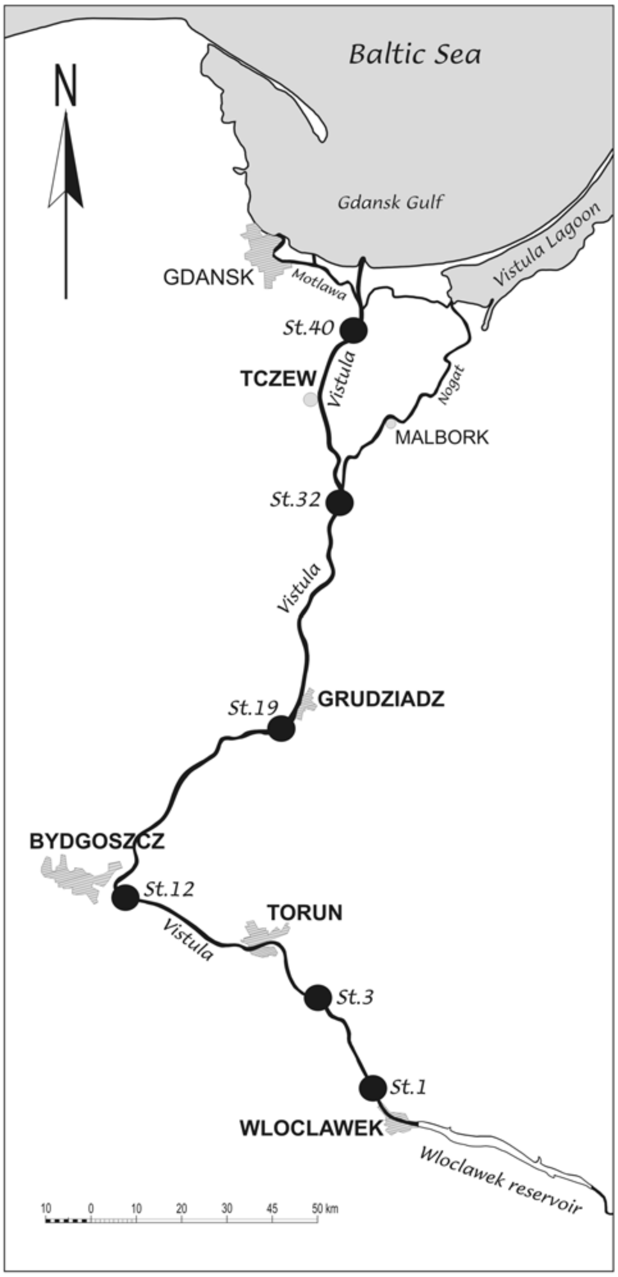

Fig. 1. The lower Vistula River with selected sampling sites.

light microscope Nikon Alphashot, as well as a Panasonic camera and a MultiScan computer software for image analysis. For the identification of zooplankton the commonly available studies and keys were used (Flössner 1972; Kiefer 1978; Smirnov 1996; Einsle 1996; Nogrady et al. 1993; Radwan et al. 2004; Rybak & Błędzki 2010).

Biomass of the zooplankton was counted based on formula from Downing et al. (1984) and Radwan et al. (2004).

The species frequency was calculated. It is the number of times a zooplankton species is present in a given number of sample sites. (Usually expressed as a percentage).

In order to determine the dominance structure of a zooplankton assemblage at the Lower Vistula River, the formula of Kasprzak and Niedbała (1981) was applied. Depending on the percentage contribution of a given species in a given community, that species was classified within a

Table 1. List of species identified during studies.(terminology by Segers 2007; Rybak & Błędzki 2010).

Rotifera	Cladocera	Copepoda
Ascomorpha ecaudis Perty, 1850	*Alona guttata* Sars, 1862	Calanoida
Asplanchna priodonta Gosse, 1850	*Alonella exigua* (Lilljeborg, 1853)	*Eudiaptomus gracilis* (Sars, 1863)
Bdelloidea non det.	*Bosmina longirostris* (Müller, 1785)	*Eudiaptomus graciloides* (Lilljeborg, 1888)
Brachionus angularis Gosse, 1851	*Ceriodaphnia pulchella* Sars, 1862	*Eurytemora affinis* (Poppe, 1880)
Brachionus budapestiensis Daday, 1885	*Ceriodaphnia quadrangularis* (Müller, 1785)	*Eurytemora lacustris* (Poppe, 1887)
Brachionus calyciflorus Pallas, 1766	*Chydorus sphaericus* (Müller, 1776)	
Brachionus diversicornis (Daday, 1883)	*Daphnia cucullata* Sars, 1862	Cyclopoida
Brachionus falcatus Zacharias, 1898	*Daphnia hyalina* Leydig, 1860	*Acanthocyclops robustus* (Sars, 1863)
Brachionus quadridentatus Herman, 1783	*Daphnia longispina* (Müller, 1776)	*Acanthocyclops vernalis* (Fisher, 1853)
Brachionus urceolaris Müller, 1786	*Diaphanosoma brachyurum* (Lievin, 1848)	*Megacyclops viridis* (Jurine, 1820)
Cephalodella gibba Ehrenberg, 1830	*Eubosmina coregoni* (Baird, 1857)	*Microcyclops sp.*(Sars, 1863)
Cephalodella catelina Müller, 1786	*Leptodora kindti* (Focke, 1844)	
Collurella obtusa Gosse, 1886	*Peracantha truncata* (Müller, 1785)	
Conochilus sp. Ehrenberg, 1834	*Rhynchotalona rostrata* (Koch, 1841)	
Filinia longiseta Ehrenberg, 1834		
Filinia terminalis (Plate, 1886)		
Gastropus stylifer (Imhof, 1891)		
Kellicottia longispina (Kellicott, 1879)		
Keratella cochlearis (Gosse, 1851)		
Keratella tecta (Gosse, 1851)		
Keratella quadrata (Müller, 1786)		
Keratella tropica (Apstein, 1907)		
Keratella valga (Ehrenberg, 1834)		
Lecane bulla (Gosse, 1851)		
Lecane closterocerca (Schmarda, 1859)		
Lecane flexilis (Gosse, 1886)		
Lecane luna (Müller, 1776)		
Lecane lunaris (Ehrenberg, 1832)		
Lepadella patella (Müller, 1773)		
Notholca squamula (Müller, 1786)		
Polyarthra longiremis Carlin, 1943		
Polyarthra major Burckhard, 1900		
Polyarthra remata Skorikov, 1896		
Pompholyx complanata Gosse, 1851		
Pompholyx sulcata Husdson, 1885		
Proales sp. (Gosse, 1886)		
Ptygura sp. (Ehrenberg, 1832)		
Synchaeta kitina Rousselet, 1902		
Synchaeta oblonga Ehrenberg, 1832		
Synchaeta pectinata Ehrenberg, 1832		
Synchaeta tremula Müller, 1786		
Testudinella truncata (Gosse, 1886)		
Trichocerca capucina (Wierz. et Zach., 1893)		
Trichocerca pusilla (Jennings, 1903)		
Trichocerca similis (Wierzejski, 1983)		
Trichocerca stylata (Gosse, 1851)		
Rotifera non det.		

specific dominance class. The dominance index was divided into 5 classes:

– subrecedents (species whose individuals constitute $\leq$ 1.0% of all individuals in a community)

– recedents (species whose individuals constitute 1.1–2.0% of all individuals in a community)

– subdominants (species whose individuals constitute 2.1–5.0% of all individuals in a community)

– dominants (species whose individuals constitute 5.1–10.0% of all individuals in a community)

– eudominants (species whose individuals constitute $>$ 10.0% of all individuals in a community)

In order to present the relationships between the number of species, the abundance, the biomass of zooplankton and sites along the river, Spearman's rank correlation coefficient (rho) was applied using IBM SPSS Statistics 19.0.

Measurements of physical and chemical parameters of water such as oxygen concentration, pH, conductivity and temperature were performed by instruments of WTW company. Chemical analyses PO_4, TP, NH_4 were conducted with standards methods using Merc-Aquaquant tests. All physical and chemical parameters were analysed once at the beginning of the experiment.

Data on the water discharge and level of the Vistula River in Toruń were obtained from the Institute of Meteorology and Water Management (National Research Institute in Poland) – the Regional Station in Toruń. Majority of hydrological dates was also available at internet page of the Institute (http://www.pogodynka.pl/stany).

Results

The research on zooplankton revealed the presence of 65 species altogether, including 45 species of Rotifera,

Table 2. The frequency of zooplankton (%) at sites in the lower Vistula River.

Frequency (%)	Species of zooplankton
100%	*Brachionus angularis, Brachionus budapestiensis, Brachionus urceolaris*
90–100%	*Brachionus calyciflorus, Brachionus quadridentatus, Keratella cochlearis, Keratella tecta, Lecane closterocerca, Polyarthra longiremis, Trichocerca pussila*, larval stages of copepods: nauplii
50–90%	*Ascomorpha ecaudis, Asplanchna priodonta, Filinia terminalis, Synchaeta kitina, Synchaeta tremula, Lecane lunaris* and cladoceran: *Bosmina longirostris*

Table 3. The number of species, average number (ind. dm^{-3}) and biomass (mg w.w. dm^{-3}) of the lower Vistula River zooplankton.

	Number of species		Number		Biomass	
	T	%	N	%	B	%
Rotifers	45	69	84	81	0.087	29
Cladocerans	12	18	1	1	0.011	4
Copepods	8	13	19	18	0.199	67
SUM	65	100	104	100	0.297	100

Table 4. The dominant species in zooplankton of the lower Vistula River.

Class of domination	Species of zooplankton
Eudominants	*Brachionus angularis, Brachionus calyciflorus,* larval stages of copepods: nauplii and copepodites
Dominants	*Brachionus budapestiensis*
Subdominants	*Brachionus urceolaris, Keratella cochlearis, Keratella tecta, Lecane closterocerca*

which constitutes 69% of all determined species, 12 species of Cladocera, i.e., 18% of the total number of species and 8 species of Copepoda, i.e., 13% contribution in the species structure of the community (Fig. 2). List of species identified during study was at the Table 1.

Three species of rotifers *Brachionus angularis, Brachionus budapestiensis* and *Brachionus urceolari* were present at all sites (100% frequency). Seven other species of Rotifera and nauplii – copepod larval forms, had a frequency of more than 90% showed. Data on the frequency of zooplankton are presented in Table 2.

The ecological diversity of zooplankton – among the 65 species recorded in the lower Vistula River 85% (55) were euplanktonic and only 15% (10) were tychoplanktonic species.

Among the euplanktonic species, 30 are defined as non-specific for a particular zone of open water; the rest almost equally formed typical pelagic (13) and littoral-pond species (12). 8 of 10 tychoplanktonic species were bentho-periphyton and 2 typical periphyton taxons.

The average density of zooplankton in the lower Vistula River during the entire research period was 104 ind. dm^{-3} and varied from 34 ind. dm^{-3} to 348 ind. dm^{-3} (Table 3). Rotifera were the dominant group, which with an average count of 84 ind. dm^{-3} comprised 81% of zooplankton. Copepoda were dominant among crustaceans. The average count of copepods was 19 ind. dm^{-3}, comprising 18% of the zooplankton. Cladocera accounted for only 1%, with the average count of 1 ind. dm^{-3} (Table 3).

Rotifers were the most abundant species (in the class of eudominants and dominants) in the whole collected material: *Brachionus angularis, Brachionus calyciflorus, Brachionus budapestiensis.* Larval stages of Copepoda: nauplii and copepodites also belong to class of eudominants and dominants.

The dominance structure of zooplankton at lower Vistula River is presented in Table 4. The average zooplankton biomass in the studied river was 0.297 mg dm^{-3} and varied from 0.024 mg dm^{-3} to 2.445 mg dm^{-3}. Copepods had the highest contribution in the biomass – 67%, rotifers – 29%, and cladocerans – 4% of the average biomass (Table 3).

The number of species (rho = –0.750, $P \leq 0.05$), abundance (rho = –0.844, $P \leq 0.05$) and biomass (rho = –0.790, $P \leq 0.05$) of zooplankton are steadily decreasing downstream the lower Vistula River (Figs 2–4). The first eleven sites to 770 rkm are influenced by WR, and last two sites were under the influence of the strong northerly winds associated with the Baltic Sea. The results of basic physical and chemical analyses were presented at Table 5.

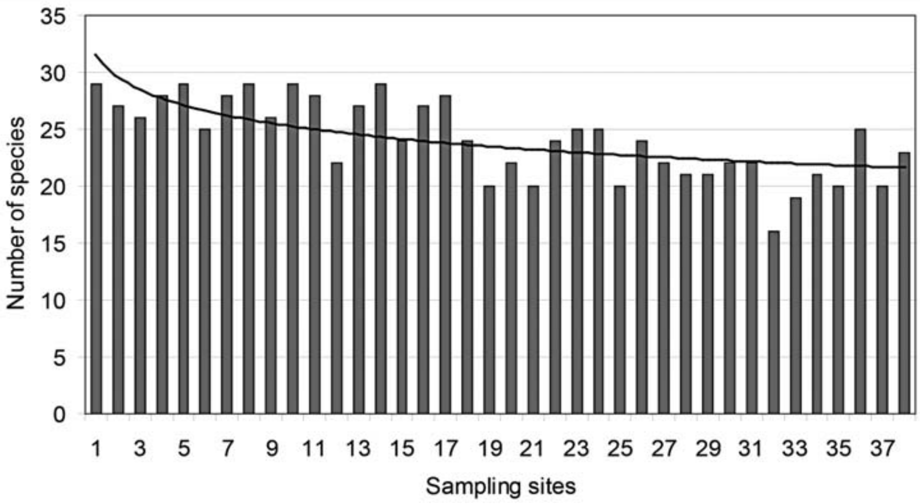

Fig. 2. Longitudinal changes of zooplankton species diversity in the lower Vistula River (rho = –0.750, $P \leq 0.05$).

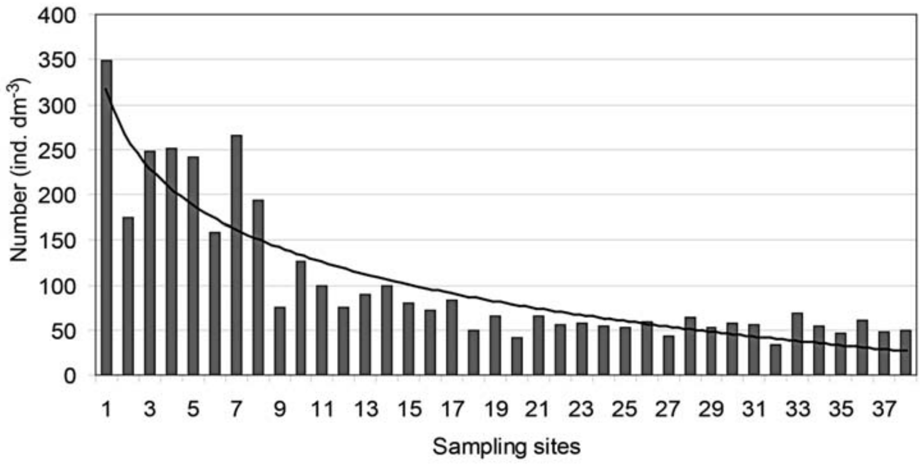

Fig. 3. Longitudinal changes of zooplankton abundace (ind. dm^{-3}) in the lower Vistula River (rho = –0.844, $P \leq 0.05$)

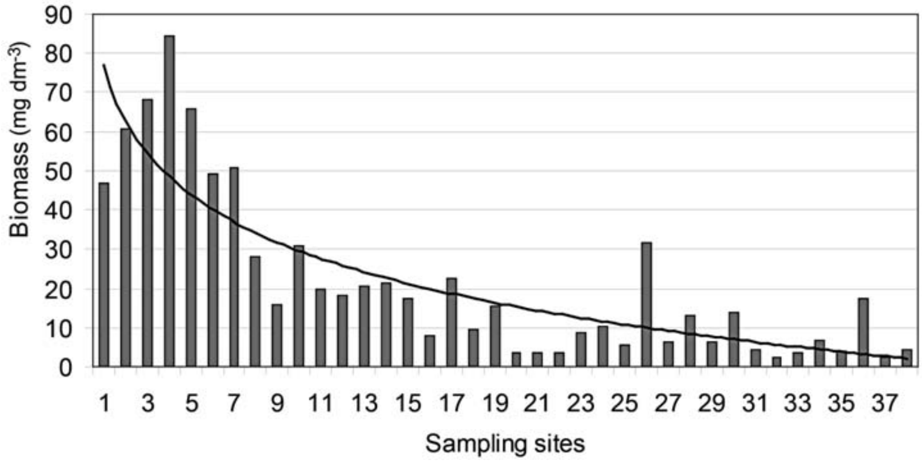

Fig. 4. Longitudinal changes of zooplankton biomass (mg dm^{-3}) in the lower Vistula River (rho = –0.790, $P \leq 0.05$)

Discussion

In the latter half of the 20^{th} century the Vistula River was heavily polluted, However increased sewage plant capacity, which reduced the organic pollution, resulted in the 1990s in the gradual improvement of water quality which was recorded in research carried out since 1986 (Kentzer 2009; Pastuszek et al. 2012; Kowalkowski et al. 2012). In most cases (Mieszczankin 2009), the values of physical and chemical water parameters (T, pH,

Table 5. The results of physical and chemical analyses of the lower Vistula River.

Site	pH	EC (µS)	TP (mg L^{-1})	P_{PO4} (mg L^{-1})	N_{NH4} (mg L^{-1})	O_2 (mg L^{-1})	T (°C)
1	8.1	549	0.26	0.08	0.05	6.2	21.5

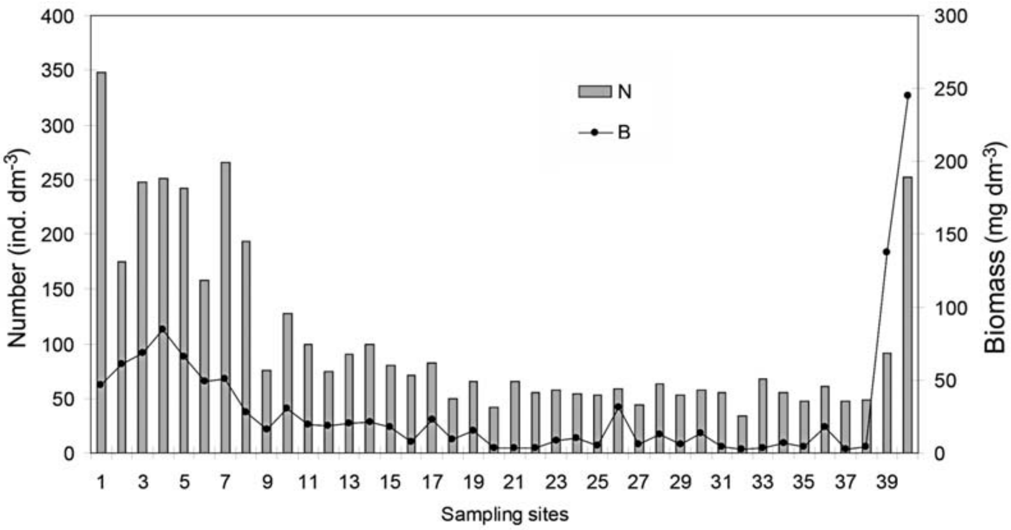

Fig. 5. Longitudinal changes of zooplankton abundance (ind. dm^{-3}) and zooplankton biomass (mg dm^{-3}) in the lower Vistula River (include sites 39 and 40).

O_2, BOD_5, N-NH_4, Cond., Salinity, P-PO_4, TP and Chl-*a*) correspond to I class and rarely to II class by ecological state of water quality in accordance with the requirements for surface flowing waters (DzU 2008) of Poland. However, the lower Vistula River, as moderately eutrophic river (Table 5), still could provides the advantageous conditions for a distinct longitudinal zooplankton development.

As the samples will be collected from "the same water", the authors conducted physical and chemical analyzes of the samples only once at the beginning of the experiment (Table 5). At the studied part of the river there were no significant inflows of the other rivers. The effluents fed to the river were sufficiently treated so that they did not change the quality of the water in main channel of the river (Mieszczankin 2009). According to RCC and assumed that hydrological condition change slowly along the Vistula River (Głogowska 2000) we decided to turn our attention to the hydrological conditions and their influence on zooplankton.

The number of zooplankton taxa (65) identified in the lower Vistula River is quite high compared to other similar rivers. The same number of species was recorded in the lower Odra River (Szlauer & Szlauer 1994). Whereas about half as many species were identified in the Rhine – 35 (van Dijk & van Zanten 1995) and in the Danube River – 30 (Reckendorfer et al. 1999). Some authors (Welker & Walz 1998; Lair 2006) emphasize that the fluvial zooplankton is usually a community poor in species, when you compare its structure with the richness of species in lakes and dam reservoirs.

The zooplankton community of the lower Vistula River is dominated by rotifers (Table 3). Similar domination of rotifers was observed in several rivers including the Elbe (Zimmermann-Timm et al. 2007), the Danube (Reckendorfer et al. 1999), the Loire (Lair & Reyes-Marchant 1997), the Rhine (Friedrich & Pohlmann 2009), the Po (Rossetti et al. 2009) and the Darling (Shiel 1985). It has been suggested that the apparent dominance of rotifers in rivers maybe due to their relatively short generation times compared to the larger crustacean zooplankton (van Dijk & van Zanten 1995; Lair 2006). Furthermore, Pourriot et al. (1997) reports that small rotifers are eliminated to a lesser extend by the preying fish. Simply, rotifers are better adapted to the adverse conditions of lotic habitats than crustacean species (Marneffe et al. 1996; Demetraki-Paleolog 2004).

The highest frequency (100%) was observed among brachionids: *Brachionus angularis, Brachionus budapestiensis* and *Brachionus urceolaris.* Slightly lower frequency characterized *Brachionus calyciflorus, Brachionus quadridentatus* and *Keratella cochlearis* (Table 2).

Rotifers species also were most abundant (in the class of eudominants and dominants): *Brachionus angularis, Brachionus calyciflorus* and Brachionus *budapestiensis* (Table 4). Similar dominance was observed by Ferrari et al. (1989), Schöll (2009) and Rossetti et al. (2009).

All the most frequent and dominant species belong to loricata. Recent attempts to examine specific adaptation of rotifers have shown that among several planktonic forms, the loricate species appeared to be better adapted to the river current than soft bodies or littoral epibenthic species (Lair 2005). Planktonic loricate species dominated not only in the lower Vistula River but also in the middle Loire (Lair & Reyes-Marchant 1997), the Thames (May & Bass 1998) and the lower Rhine (Fredrich & Pohlmann 2009). Dominance of them in numerous rivers may be explained by the capacity of several species to continue growing in currents in excess of 0.2 m s^{-1}(Lair 2005). At the mean discharge, the current was estimated at 0.3–0.5 m s^{-1} in the lower Vistula River (Głogowska 2000) which proved suitable for the Brachionids development.

Juvenile stages of copepods were observed at all the sites along the Vistula River at eudominant frequencies (Table 4) which implies that they are particularly resistant to hydraulic stress (Ejsmont-Karabin & Węgleńska 1996).

The abundance and biomass of zooplankton of the lower Vistula River, were low in comparison to other European rivers (van Dijk & van Zanten 1995; Marneffe et al. 1996). There can be no doubt that the extensive river regulation and subsequent regimes of the river flow have had negative effect on the floodplain and (as a consequence) on river communities. The growth of invertebrates in transit is insufficient and under unregulated conditions riverine zooplankton is supplemented from adjoining stagnant water bodies connected to the river (Lair 2005). Although lentic (stagnant) water bodies (including river margins, side channels and floodplain habitats) which act as storage zones exist along the periphery of the Vistula river channels discharge for the studied section is too low (under 580 m^3 s^{-1}) to connect these storage zones and the main channel of the river, preventing import of organisms into the river (Napiórkowski 2010; Dembowska & Napiórkowski 2012). This explains the low abundance and biomass of the zooplankton in the lower Vistula River recorded during the study.

Why do density, biomass and species richness of the zooplankton decrease downstream in the lower Vistula River? Probably if the river is regulated by the straightening of the main channel the conditions for zooplankton development will become worse and hence the population of potamoplankton decline.

The low water level in the river could make the situation worse by cutting off stagnant water bodies exist along the river channel and stopping import of zooplankton.

Among identified species of lower Vistula zooplankton, 85% belonged to euplanktonic taxons and only 15% to tychoplanktonic ones. In comparison nearly all of the taxons in the Danube River were euplanktonic (Reckendorfer et al. 1999).

The number of species and abundance of zooplankton are steadily decreasing downstream the lower Vistula River in contrast to the Loire River (Lair 1980) and the Thames (May & Bass 1998) (Figs 2–4). One of the most important factors that affect the longitudinal pattern of zooplankton distribution in the lower Vistula River is the presence of the dam reservoir. The first eleven sites to 770 rkm are clearly influenced by WR (Fig. 3).

The longitudinal discontinuities in regulated rivers, such as lateral dams and reservoirs (WR) are suspected to play an important role in the production of potamoplankton downstream (Thorp et al. 1994; Akopian et al. 1999; Kentzer et al. 2010).

Napiórkowski et al. (2006) noticed that the effect of the WR on the zooplankton was so persistent that the change was recorded as far away as at 735 rkm in Toruń. However, the results presented in this article show that that the impact of WR can be observed even further down the river at 770 rkm – 95 km downstream the dam.

Below the eleventh site the species diversity, abundance and biomass continue to decline, but at a much slower rate (Figs 2–4).

The last two sites (39 and 40) differ strongly from previous sites along the lower Vistula in regard to the species composition, abundance and biomass. These sites were under the influence of the backwater of the Baltic Sea (estuary water). There were the species more specific for the estuary of the Gulf of Gdańsk, among others adult copepods: *Eurytemora affinis* and *Eurytemora lacustris* (Kruk-Dowgiałło & Szaniawska 2008). Because the sites 39 and 40 differ so much from the others, they were not included in Figs 2–4.

In conclusion, the data presented confirm that the zooplankton species diversity in the lower Vistula River was similar to other large European rivers, however abundance of zooplankton was lower. The study shows that hydrological conditions determine the potamoplankton abundance in the river. During the average-low water level in the Vistula, zooplankton were able to weakly develop in the mainstream, but there were barriers preventing import from the storage zones. So lower abundance in the lower Vistula compared to comparable rivers could be explained in the following way: development of zooplankton in the current was suboptimal and the import from storage zones was impossible.

The lower Vistula River provides a case of study how the extensive regulation of a river (and associated changes in hydrological conditions) could reduce potamoplankton development by removal of connectivity with storage zones. The present research was the first attempt to determine the species composition and abundance of zooplankton in the lower Vistula River on such a large spatial scale, and has proved viable, and merits the continuation of this research.

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