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Planktonic Rotifer Assemblages of the Danube River at Budapest after the Red Sludge Pollution in Hungary

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Abstract In the autumn of 2010 an industrial red sludge spill occurred in Hungary. The toxic chemical waste with high alkalinity (pH 13.5) reached the Danube 2 days later, where no change was expected because of the high level of dilution. The planktonic rotifer assemblages of the Danube were investigated at Budapest during the contamination. The median of community density decreased from 500 ind. 100 L^{-1} to zero, the species richness from 3.00 to 0.00, Shannon–Weaver diversity from 1.10 to 0.00 after the arrival of the contamination. The rotifer assemblages seemed to have recovered after 3 weeks, but the initial levels of diversity and density were not reached again.

Keywords Red sludge · Danube · Zooplankton · Rotifer

On 4th October 2010 an industrial toxic red sludge spill occurred in western Hungary, after 6–700,000 m^3 chemical waste burst out of the containment reservoir of an aluminium plant near the town of Ajka. In general terms, composition of this red sludge was the following: Fe_2O_3 (40–45%), Al_2O_3 10–15%, SiO_2 10–15%, CaO 6–10%, TiO_2 4–5%, Na_2O 5–6%. According to the Hungarian government officials, the pollutant did not contain other harmful components, and the short-term toxic effect may have been caused mainly by the high alkalinity of the chemical waste (pH 13.5 in the contaminated local waters!). The pollution reached the Torna brook and after passing through the Marcal and then Rába rivers, a 120 km journey, on 7th October the contaminated water reached the main arm of the Danube at Győr (river kilometre 1,794, where the pH level rose to about 9). On the Torna brook and the Marcal River the effects were catastrophical, but according to the National Directorate General for Disaster Management, in the main arm of the Danube no visible change happened because of the very high level of contaminant dilution. The aim of our study was to investigate the possible effects of the contamination on the planktonic rotifer assemblages of the Danube River at the city of Budapest.

The members of the phylum Rotifera are aquatic, unsegmented, pseudocoelomate invertebrates with bilateral symmetry. The phylum contains about 2,000 species from all over the world. They are important in freshwater environments, because of their fast reproductive rate. They can produce up to 30% of the total plankton biomass by exploiting vacant niches with extreme rapidity. Because of their opportunism and adaptability, rotifers are widely distributed and play a significant role in the freshwater food web as converters of primary production into a form exploitable for secondary consumers (Wallace and Smith 2009). Hydrological and chemical fluctuations of lotic waters are well reflected in the quantitative and qualitative changes of the local planktonic rotifer assemblages.

The influence of abiotic and biotic factors on rotifer assemblages have been investigated in the last decades in detail (Dumont 1977; Hofmann 1977). The impact of changing pH and conductivity is well known (Epp and Winston 1978).

Field surveys about the effects of environmental contamination and heavy metal pollution on natural rotifer

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assemblages are rare; most findings are based on acidic mine-lakes (Horvath and Hummon 1980). Many more investigations have been made in the laboratory, where the toxicity of different contaminants on rotifer cultures have been analyzed under controlled conditions (Arnold et al. 2010; Cuillard et al. 1989). The effects of flow and mixing could have harsh influence on the toxicity on natural assemblages, especially under lotic conditions (Preston et al. 2001). The simultaneously present inorganic toxicants may enhance or even weaken the effects of each other (Buikema et al. 1977).

Our hypothesis was that there would not be any remarkable difference between diversity and density values of rotifer assemblages before and after the contamination passed this section of the Danube River. We did not expect any significant effect because of the relatively long hydrological distance and the high dilutional effects of the river (the mean discharge between 7th and 9th October was 2307 $m^3 s^{-1}$ in the Danube at Budapest while at the time of contamination in the Rába at Győr it was approximately 40–50 $m^3 s^{-1}$).

Materials and Methods

With a length of 2,860 km and a catchment area of about 817,000 km^2, the Danube is the second largest river in Europe. Sampling of planktonic rotifers was carried out in Budapest, at river kilometre 1643.8 on the right bank of the Danube (N 47°28′ 20.98″ E 019°03′ 51.72″) between 8th and 29th October in 2010. In this reach of the Danube, the mean discharge is 2,341 m^3s^{-1} with a minimum of 590 and a maximum of 8,200 m^3s^{-1}. Samples were collected on the day before and the day after the passing of the contaminated water body; and later at weekly intervals following the contamination event. The arrival of contaminated water body to Budapest was reported by the official Hungarian Water Monitoring Service (Ministry of Rural Development).

Samples were collected from the surface, 4–5 m distance from the shore, by using a plankton net (mesh size: 40 μm) filtering 30 L of water. On each occasion, five samples were collected. At the sampling site, water temperature and pH were measured with a Multiline-P4 field device. The samples were instantly preserved in a 4% formaldehyde solution. Living specimens were collected as well to make accurate identifications of the illoricate species. All living samples were identified within 4–5 h. Specimens in the preserved samples were counted in a Sedgewick-Rafter chamber.

The abundance-dominance relationships were characterized using several different metrics: the Shannon–Weaver ($H = -\sum P_i * \ln P_i$, where P_i represents the relative abundance of each species) and Simpson ($D = 1/\sum P_i^2$) diversity indices, and measures of dominance ($D' = (\sum P_i)/i$) and evenness ($E = H/H_{\max}$) (Magurran 1988).

Shannon–Weaver diversity values were compared by using Hutcheson's T test (Hutcheson 1970), and, owing to the non-normal data distribution, the changes in species richness (S) and density were analysed by the non-parametric Kruskal–Wallis test using the Statistica 8.0 software (StatSoft Inc 2008).

Diversities at different sampling times were compared using Rarefaction Analysis (Gotelli and Colvell 2001). The curves for investigating the relationship between species number and density were computed using the PAST software-package (Hammer et al. 2001).

Results and Discussion

The water level, discharge and pH values of the Danube did not change notably during the sampling period (Table 1). Altogether, 11 planktonic rotifer species occurred in the samples (Table 2).

Comparing species richness on the different sampling dates, richness was greatest on 8th October, the day before the arrival of the main mass of contaminated water. A few hours after its passing, on 9th October, richness decreased notably. During the following weeks the assemblages seems to have recovered, but richness did not reach the starting value again (Table 2).

The species richness, the Shannon–Weaver diversity, Simpson diversity and density values showed similar patterns during the one-month-long sampling period (Figs. 1, 2; Table 3). On 8th October, about 12 h before the arrival of the contaminated water body, normal assemblages were present with moderate diversity (Shannon–Weaver median: 1.10; Simpson median: 0.67) and density values (median: 500 ind/100 L) (Table 3). The dominance was low and the evenness relatively high, as in an ordinary potamoplanktonic community. The occurring taxa were well known and

Table 1 Date of samplings, water level, discharge, water temperature and pH values measured

Date	Water level (cm)	Discharge ($m^3 s^{-1}$)	Temperature (°C)	pH
08.10.2010	275	2,330	12.4	8.1
09.10.2010	258	2,190	12.3	8.2
15.10.2010	193	1,710	12.0	8.1
22.10.2010	189	1,680	10.2	7.9
29.10.2010	211	1,830	8.7	8.0

Table 2 Planktonic rotifer species occurring in the samples taken in October 2010

	08.10	09.10	15.10	22.10	29.10
Anuraeopsis fissa Gosse, 1851	+	+	+	+	+
Brachionus angularis Gosse, 1851			+		+
Keratella cochlearis (Gosse, 1851)	+		+	+	
Keratella quadrata (O. F. Müller, 1786)	+				
Keratella tecta (Gosse, 1851)	+	+	+	+	+
Lecane luna (O. F. Müller, 1776)				+	
Lepadella patella (O. F. Müller, 1773)				+	
Polyarthra vulgaris Carlin, 1943					+
Synchaeta sp.	+				
Trichocerca pusilla (Jennings, 1903)	+				
Total number of taxa	6	2	4	5	4

typical in the Hungarian reach of the Danube (Kertész 1967; Schöll and Kiss 2009).

The contamination reached Budapest on 8th October, about 12 h. In the samples collected on the next day (9th October), the density and species richness had decreased drastically (Figs. 1, 2; Table 3). The Kruskall-Wallis test showed significant differences in density and species richness values at the different sampling times [H (4, $N = 25$) = 15.87 $P = 0.0032$ and H (4, $N = 25$) = 16.11 $P = 0.0029$]. The Shannon–Weaver diversity also decreased significantly, because on 9th October zero or only one taxon was present in the 5 replicate samples ($t = 23.66$, $df = 424.66$, $P < 0.00001$) (Table 3).

During the following weeks (15th, 22nd and 29th October) the rotifer assemblages seem to have recovered gradually. Density increased but did not reach the value obtained on 8th October. The value measured on 29th October differed again significantly from the lowest value immediately after the pollution (Fig. 1). Species richness increased similarly after the pollution and significantly differed from the lowest value (9th October) on 22nd October. On 29th October the species richness decreased slightly, presumably due to the decreasing water temperature (Galkovskaya 1987) (Table 1; Fig. 2).

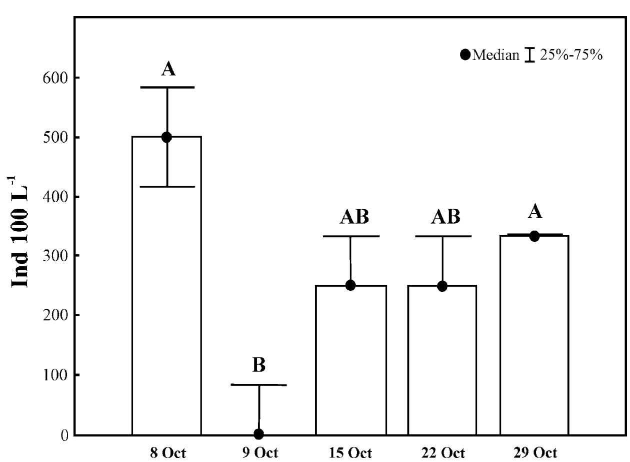

Fig. 1 Changes in the rotifer density values (ind 100 L^{-1}) during the sampling period in 2010. Density values with different letters are statistically different at 0.05 level

We compared diversities at the different sampling times by using rarefaction analysis. The results showed that the highest diversity occurred on 8th October, 12 h before the arrival of the contamination (Fig. 3). The diversity on 9th October, just a few h after the contamination arrived was significantly lower than all other values. The diversity increased during the next weeks, but did not reach the value of 8th October before the end of the sampling period (Fig. 3).

In contrast with our hypothesis we found notable differences in ecological characteristics of rotifer assemblages after the passing of the main contaminated water body. All diversity indices and the density values decreased significantly within 24 h. Due to the seasonal succession in autumn a gradual decrease in species richness and density was to be expected (Galkovskaya 1987; Kertész 1967), but this abrupt collapse of the assemblages could not be explained by any seasonal changes. Our samples from previous year (7th, 14th and 28th October, 2009) from near the same reach of the Danube (riverkilometer 1669) showed also a slow, gradual seasonal change. The density values decreased from 570 to 445 ind. 100 L^{-1}, while species richness changed between 5 and 6 in the samples (Schöll, unpublished data). A strong water level increase or a drastic change in the water temperature could induce such changes (Nielsen et al. 2005), but these values were nearly constant in this interval. The following relatively slow and gradual recovery also confirmed the role of the contamination event, and contradicted that of seasonal effects.

This case-study attracts attention to the hardly traceable, non-trivial, medium-term consequences of such an environmental catastrophe. Several direct and indirect causes for this phenomenon may be suggested, such as: changes in

Table 3 Ecological characteristics of the rotifer assemblages (* no dominance and evenness values when the density value is zero)

Date			08.10		09.10		15.10		22.10		29.10	
Species richness	Median		3		0		2		3		3	
	Min.	Max.	2	4	0	1	2	3	2	3	2	3
Density (ind. 100 L^{-1})	Median		500		0		250		250		333	
	Min.	Max.	249	583	0	83	250	334	249	335	250	416
Shannon-W. diversity	Median		1.10		0.00		0.64		1.04		0.95	
	Min.	Max.	0.67	1.28	0.00	0.00	0.64	1.04	0.64	1.10	0.64	1.04
Simpson diversity	Median		0.67		0.00		0.44		0.62		0.56	
	Min.	Max.	0.48	0.67	0.00	0.00	0.44	0.62	0.44	0.67	0.44	0.62
Dominance	Median		0.33		*		0.56		0.38		0.44	
	Min.	Max.	0.31	0.52	*	*	0.38	0.56	0.33	0.56	0.38	0.56
Evenness	Median		0.92		*		0.94		0.94		0.94	
	Min.	Max.	0.90	1.00	*	*	0.94	1.00	0.94	1.00	0.86	1.00

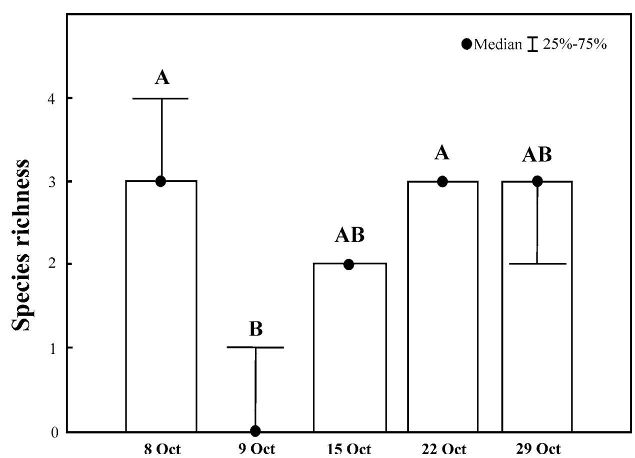

Fig. 2 Changes in the rotifer species richness during the sampling period in 2010

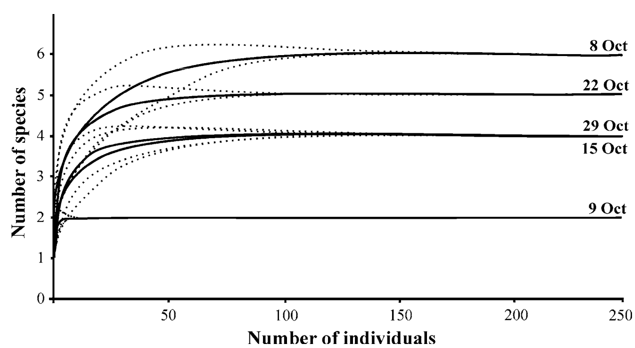

Fig. 3 Rarefaction analysis of the planktonic rotifer assemblages at different sampling times (*solid lines* denote the number of species estimated and the dotted curves are the 95% interval of confidence)

osmotic conditions, inhibition of reproduction or maybe the most plausible cause might be the temporary disappearance of food organisms arriving from the upper reaches of the river system affected by the pollution (Lair and Reyes-Marchant 1997).

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