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Crustacean Zooplankton Biodiversity in Agricultural Drainage Ditches in Danubian Lowland, Slovakia

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Abstract: Drainage canals or ditches are man-made watercourses. Their zooplankton fauna is often neglected as these environments are not an optimal habitat for this community. Within a comparative environmental study, we explored zooplankton assemblages in 12 agricultural drainage ditches, in the Žitný Ostrov. A total of 58 species of zooplankton crustaceans were identified: 38 of Cladocera and 20 of Copepoda. The most frequent species was *Pleuroxus aduncus*. Four non-native species occurred. The number of taxa found at particular ditches ranged from 5 to 22 with a mean of 12. The occurrence of numerous rare species was also confirmed, e.g. of *Lathonura rectirostris, Disparalona hamata*, *Tretocephala ambigua, Oxyurella tenuicaudis, Pseudochydorus globosus, Monospilus dispar* and *Megafenestra aurita.* The density of zooplankton was low and ranged from 2 to 64 ind L^{-1}. There are previous studies on the richness of Cladocera of stagnant waters and wetlands of Slovakia species, we cannot, however, equalise the character of individual ditches of the Žitný Ostrov with native, preserved biotopes in the area. Nevertheless, as suggested by the cumulatively high species richness in studied ditches and the substantial spatial presence of suitable habitats for rare species in the dense network of drainage ditches in the Žitný Ostrov, we can say that such artificial habitats have a considerable potential and already serve as a regional source of biological diversity.

Key words: zooplankton, Cladocera, Copepoda, artificial water bodies

Introduction

Water-filled drainage ditches are an important ecological feature of the Danubian Lowland. Originally dug to facilitate wetland drainage, ditches often provide refuges for aquatic fauna (Chester & Robson 2013). Ditches usually have a linear plan form, follow linear boundaries, often turning at right angles and show little relationship with natural landscape contours (De Bie et al. 2008). Their bottoms are usually reinforced but in the course of time they become clogged with sediments and overgrown macrophytes (Bitušík et al. 1996). As they are lotic, the research of biota is traditionally focused on macrozoobenthos, ichthyofauna and macrovegetation (Davies et al. 2008, Pekárik et al. 2014, Hrivnák et al. 2014). However, little is known of zooplankton patterns in lowland channels and other small lotic water bodies and Slovakia is not an exception. Only in recent years, within a comparative analysis of the aquatic invertebrate fauna (Verdonschot et al. 2011), a diversity research of zooplankton crustaceans started to focus more on lotic water bodies, including ditches (De Bie et al. 2008).

Generally, zooplankton research in the world's lowland areas focuses on lentic aquatic ecosystems, such as lakes, ponds, gravel pits and oxbows that, however, frequently occur within the dynamic lotic ecosystems and biotopes of floodplain areas, i.e. large rivers and their main arms, situated in riverine wetlands. The dynamic ecosystems of floodplain rivers and riverine water bodies are characterised by

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high habitat diversity (Junk et al. 1989, Amoros & Roux 1988, Ward & Stanford 1995). Commonly, they include natural, undisturbed standing waters, characterised by high alpha diversity of aquatic organisms (Ward et al. 1999, Bilton et al. 2009, Kiss 2004, Kiss et al. 2015, Hill et al. 2017). Artificial structures, especially the construction of large dams, have a negative impact on the dynamics of these ecosystems (Kiss & Schöll 2009, Farkas-Iványi & Guti 2014) as they decrease significantly the overall number of suitable habitats. In the area of the inland Danube Delta (Slovak-Hungarian stretch), after the Gabčíkovo Hydroelectric Power Plant has been put into operation (1992), the substantial changes of hydrological regime (Lisický & Mucha 2003) have caused very rapid extinction of numerous natural biotopes, e.g. that of old cut-off side arms (Vranovský 1997). The active water connection between the abandoned stretch of the Danube River and the side-arm system in the floodplain ceased to exist and the water supply of the cut-out floodplain was replaced by an artificial water recharge system (Kiss 2004). The decreasing hydrological connectivity between the river channel and the floodplain has also been confirmed by the long-term monitoring of several groups of aquatic organisms (Illyová & Matečný 2014, Beracko et al. 2016, Šporka et al. 2016). This monitoring has been followed by field surveys in the area, testing whether the small man-made aquatic habitats situated in the agricultural landscape, e.g. gravel pits, fish ponds, small brooks and ditches, could serve as a refuge for aquatic biota from destroyed biotopes (Davies et al. 2008, Céréghino et al. 2008). The aim of our study was to evaluate: (i) whether the drainage ditches of agricultural origin have a potential to serve as a refuge for zooplankton; (ii) whether they contribute to the regional biodiversity.

Materials and Methods

Study area

On the territory of the Žitný Ostrov (South-Western Slovakia, the Danubian Lowland), a dense network of drainage ditches exists, including the main channels, which form the centre line of the network, and side ditches, that provide the gravitational drainage of surface and ground waters from a respective water harvesting area (Benetin et al. 1987). The Žitný Ostrov ditch system was initially constructed to drain wetlands; later on it was used also for irrigation during the vegetation period (Gyalokay 1972). First ditches had already been built after 1860 and before 1924 the length of the ditch system reached 700 km (Gyalokay 1960); at present their length stretches to almost 1000 km (Velísková & Dulovičová 2008). The study area comprises the territory between the villages of Trstená na Ostrove and Veľký Meder (between 47.92803°N, 17.48831°E and 47.8135°N, 17.70941°E). A list of sites and measured environmental variables are summarised in Tables 1 and 2.

Methods

One unrepeated sampling was carried out during the field survey in 12 ditches in July 2016. Qualitative zooplankton samples were taken from heterogeneous habitats: open water zones, the whole water column, the bottom and among the macrovegetation. Collected samples were filtered through a 70 μm mesh net and preserved in 4% formaldehyde. Quantitative samples (20 L) were taken from the open water zones using the Patalas sampler. Abundance (ind L^{-1}) was evaluated using standard methods (Hrbáček et al. 1972). The groups of Cladocera and Copepoda were determined at species level. Water pH, dissolved oxygen content (O_2), oxygen saturation (DO, %), water temperature (Wt) and conductivity (Con) were measured directly in the field, using a multiparameter meter (Hanna HI 9828).

Results

Faunistic findings

In total, 58 species of zooplankton were found: 38 species of Cladocera and 20 species of Copepoda. The average species richness of all ditches ranged between 5 – 22 taxa; circa nine for Cladocera (from 3 to 15) and four for Copepoda (from 1 to 9). The list of all collected species of Cladocera and Copepoda is given in Table 3. The species *Pleuroxus aduncus* reached the highest constant occurrence of 83%, followed by *Eucyclops serrulatus*, *Simocephalus vetulus* and *Chydorus sphaericus*. The remaining species have shown a constant occurrence below 50%. The planktonic or semi-planktonic species *Diaphanosoma orghidani*, *Bosmina longirostris* and *Diacyclops bicuspidatus* were recorded only in one ditch*, Acanthocyclops einslei, Cryptocyclops bicolor* – in two ditches and more often occurring were *Ceriodaphnia pulchella* and *Eurytemora velox.* Most of the remaining microcrustacean species are widespread and characteristic of the fauna of the littoral zone, benthic and macrophyte-associated assemblages. The occurrence of numerous rare species was also confirmed, e.g. of *Lathonura rectirostris, Disparalona hamata*, *Tretocephala ambigua, Oxyurella tenuicaudis, Psedochydorus globosus, Monospilus dispar* and *Megafenestra aurita*.

Table 1. List of the sampling sites with local names of ditches and geographic coordinates.

Site code	The site local name in (municipality)	Geographic coordinates (°N, °E)
d1	Vojka–Kračany canal (Moravské Kračany)	47.95734, 17.55631
d2	Boheľov canal (Boheľov)	47.91408, 17.68148
d3	Chotár canal (Jánošíkovo na Ostrove)	47.9002, 17.74118
d4	Ňárad–Vrbina canal (Baloň)	47.82848, 17.65384
d5	Veľký Meder–Holiare canal (Veľký Meder)	47.8791, 17.75542
d6	Šuľany–Jurová canal (Trstená na Ostrove)	47.92803, 17.48831
d7	Chotár canal (Ňárad)	47.84008, 17.60887
d8	Kračany–Boheľov canal (Padáň)	47.92952, 17.66159
d9	Červený canal (Čiližská Radvaň)	47.8135, 17.70941
d10	Milinovice–Vrbina canal (Čiližská Radvaň)	47.85625, 17.673832
d11	Medveďov–Kľúčovec canal (Medveďov)	47.79944, 17.68703
d12	Čiližský potok-brook (Pataš)	47.88457, 17.65910

Table 2. Physical and chemical variables measured during the sampling. For site codes, see Table 1.

Site code	Wt	pH	Con	O_2	DO	Sal	TDS	Q	Mac
Unit	°C		µS/cm	mg/L	%	PSU	mg/L	m^3/s	
d1	21	8.1	284	6.8	78	0.14	145	0.3	1
d2	19	8.5	273	8.6	94	0.13	137	0.2	2
d3	18	8.2	341	8.2	98.8	0.16	171	0.2	2
d4	19	7.9	383	6.6	71	0.19	196	0.3	3
d5	20	8.2	321	5.5	60.7	0.15	161	0.1	3
d6	22	8.2	280	6.5	69	0.16	146	0.2	2
d7	19	7.8	479	6.8	68	0.24	243	0.2	3
d8	18	7.4	587	3.2	28	0.29	297	0.01	3
d9	18	7.8	442	6.5	71	0.22	225	0.3	3
d10	20	7.6	356	4	45	0.17	178	0.3	3
d11	20	7.5	716	1.5	17	0.35	360	0.3	3
d12	21	7.8	236	3.3	37	0.14	150	0.2	3

Note: Wt – water temperature (˚C), Con – conductivity (µS/m), O_2 – oxygen concentration (mg/L), DO – oxygen saturation (%), Sal – salinity (PSU), TDS – turbidity (mg/L), Q – flow velocity (m^3/s), Mac – macrovegetation (1: 10-30%; 2: 40-60%; 3: 70-90%).

Besides this, we have recorded four non-native species for Slovakia in surveyed ditches: *Disparalona leei*, *Pleuroxus denticulatus*, *Eurytemora velox* and *Nitocra hibernica*.

Zooplankton abundance

Zooplankton abundance values in individual ditches are given in Fig. 1. The average value was 16.9 ind L^{-1}, ranging from 2 to 64 ind L^{-1}. The rotifers dominated half of the ditches (Fig. 2), with abundance from 1.5 to 23 ind L^{-1}. In the remaining six ditches, the copepods, predominantly nauplia and copepodite stages, dominated with the abundancefrom 0.3 to 37 ind L^{-1}. Adults of only two species, *Eucyclops serrulatus* and *Elaphoidella gracilis*, were discovered in the quantitative samples. The abundance of species of Cladocera ranged from 0.3 to 9.5 and L^{-1}. Twenty species exhibited very low density in quantitative samples (Table 3). *Ceriodaphnia laticaudata, Chydorus sphaericus, Pleuroxus aduncus* and *Pleuroxus denticulatus* dominated in terms of abundance (Table 3).

Discussion

It is known that in both rural and urban areas drainage ditches and canals may support biodiversity comparable to the one in streams and rivers in the same landscapes (Armitage et al. 2003, Stammler et al. 2008, Vermonden et al. 2009, Simon & Travis 2011). Comparative studies have shown a surprising proportion of native species found in anthropogenic

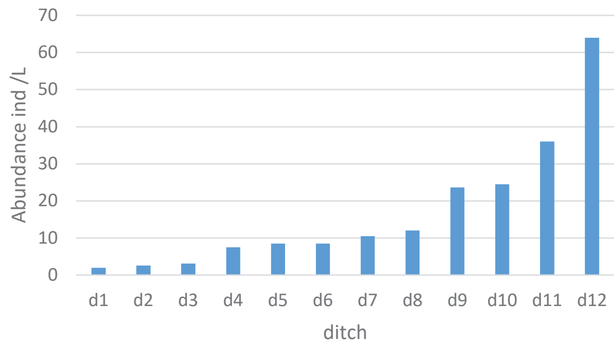

Fig. 1.

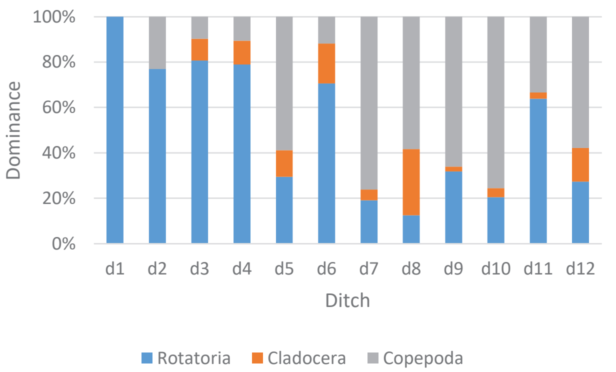

Fig. 2.

water bodies. For example, artificial drainage ditches contained a similar diversity of total taxa and rare species as did natural wetlands in the Netherlands and beta diversity was higher in ditches (Verdonschot et al. 2011). In southern England, ditches were found to harbour uncommon species (Watson & Ormerod 2004): ponds, including artificial ponds, supported many rare species, had the greatest beta diversity, displaying a regional biodiversity comparable with natural water bodies (Williams et al. 2003). It is likely that the viability of ditches and canals serving as possible refuges for aquatic species may largely depend on the complexity and biodiversity of submerged and emergent vegetation (Armitage et al. 2003, Watson & Ormerod 2004, Simon & Travis 2011). In this sense, the main objective of our research was to assess the zooplankton diversity of the studied ditches at site scale. If the sites had been evaluated individually, i.e. in terms of water and wetland biotopes based on the species richness of Cladocera, sampling frequency and geographic location (Hudec 1999), the Žitný Ostrov ditches might be considered as relatively poor. According to Hudec (1999), based on one-series sampling, more than 18 species of Cladocera at a site are expected to occur in natural and undisturbed habitats in the Danubian Lowland. In the case of ditches, the maximum of only 15 or less species Cladocera was detected. A similarly low species richness of zooplankton crustaceans was discovered (in most cases less than 18 species) in artificial gravel pits (Illyová & Šulíková 2016). Thus, the alpha diversity of planktonic crustaceans in anthropogenic habitats is low. However, the overall species richness of 58 taxa of zooplankton crustaceans in 12 ditches along with 85 taxa of zooplankton crustaceans in 33 gravel pits (Illyová & Šulíková 2016) make these anthropogenic habitats valuable in terms of the regional biodiversity. If we imagine the density of almost 1000 km of ditch network being of about 1 km/1.25 km^2, then the current spatial extent of suitable habitats can be regarded as considerable (Velísková & Dulovičová 2008). During the single summer sampling, we have detected 38 cladoceran and 20 copepod species in the Žitný Ostrov ditches. The results show similarities as compared to Vranovský & Ertl (1958) species list from the same territory. Of 30 recorded species of Cladocera, 17 matched with our results. To compare to De Bie et al. (2008) in 26 ditches in Flanders (Belgium) the mean richness of 4.1 ranged between 1–10.8 species per sample. We could assume that the zooplankton fauna of the Žitný Ostrov is significantly positively influenced by the proximity of the Danube River floodplain area. The study area is situated along the migratory bird routes, and in Slovakia – in the vicinity of a Dropie bird sanctuary. So far, an overall richness of 72 species of Cladocera was detected in the study area (Illyová & Matečný 2014) and the ditches harboured more than half of them. We have recorded a total of 50 copepod taxa in the area (Illyová et al. 2017) with less than a half (20 taxa) in the ditches. Overall, as far as 50% of the species recorded in the waters of the Danube River floodplain area occurred in the ditches. Of 59 zooplankton species (Cladocera and Copepoda) reported by Kiss et al. (2015), during the years of their research in various types of waters in the Szigetköz Region, we have identified 38 zooplankton species in the Žitný Ostrov ditches. This numbers are probably influenced by the way zooplankton spreads, as zooplankton species easily spread passively: by wind, water or by birds, mainly due to their ability to create resting eggs (Havel et al. 1995).

Zooplankton species richness in ditches can be assessed as relatively high for a lotic system as crustacean zooplankton tends to be underrepresented in flowing zones of lotic systems (Dole-Olivier et al. 2000). However, macrovegetation and slow water flowing may have a significant impact on the occurrence of littoral and macrophyte-associated species like *Alonella exigua, Ceriodaphnia reticulata, Camptocercus rectirostris, Megafenestra*

Table 3. List of crustacean (Cladocera and Copepoda) species occurring at 12 ditches in South-western Slovakia (+ occurrence of species; number 0.1, 0.2, 0.5 = abundance ind L^{-1}). For site codes, see Table 1.

Taxa	**d1**	**d2**	**d3**	**d4**	**d5**	**d6**	**d7**	**d8**	**d9**	**d10**	**d11**	**d12**
Branchiopoda												
Ctenopoda												
Sididae												
Diaphanosoma orghidani Negrea									+			
Anomopoda												
Bosminidae												
Bosmina (Bosmina) longirostris (O.F.M)			0.1									
Daphniidae												
Daphnia (Daphnia) curvirostris Eylmann											0.4	
Simocephalus vetulus (O.F.M.)				0.2	+	+	+		0.1	+	0.5	+
Simocephalus exspinosus (Koch)								+				
Simocephalus congener Schoedler									+		+	
Ceriodaphnia reticulata (Jurine)											+	
Ceriodaphnia laticaudata P.E.M.								3			0.7	
Ceriodaphnia pulchella Sars				+					0.1	+		1.5
Scapholeberis mucronata (O.F.M.)		1	+							+		
Megafenestra aurita (Fischer)											+	
Macrothricidae												
Lathonura rectirostris (O.F.M.)				+		+			+			
Chydoridae												
Eurycercus lamellatus (O.F.Muller)		1		0.1			0.5		0.1	+		
Tretocephala ambigua (Lilljeborg)											+	
Camptocercus rectirostris Schöedler				+								
Acroperus neglectus Lilljeborg			+	0.1	+				+			0.5
Acroperus harpae (Baird)						0.5	+			+		
Oxyurella tenuicaudis (Sars)												0.5
Alona affinis (Leydig)			+				+					
Alona quadrangularis (O.F.M)	1		+									
Alona costata Sars	1					0.5	+					
Alona guttata Sars			+	+			+					+
Alona rectangula Sars			+	+						+		+
Graptoleberis testudinaria (Fischer)				+					+	+		+
Monospilus dispar Sars	1											
Psedochydorus globosus (Baird)				+					+			
Chydorus sphaericus (O.F.M.)		1		0.3	0.5		+		0.3	1		0.5
Alonella excisa (Fischer)												0.5
Alonella exigua (Lilljeborg)												0.5
Alonella nana (Baird)					0.5							0.5
Disparalona rostrata (Koch)			0.1		+							+
Disparalona leei Chien			0.2									
Disparalona hamata (Birge)			+									
Pleuroxus (Tylopleuroxus) aduncus (Jurine)		1	+	0.1	+	+		0.5	0.1	+	+	0.5
Pleuroxus (Pleuroxus) uncinatus Baird				+								
Pleuroxus (Picripleuroxus) laevis Sars			+			+						
Pleuroxus (Picripleuroxus) denticulatus Birge	1	1	+	0.1					+			
Pleuroxus (Peracantha) truncatus O.F.M.		1	+	0.1					+	+		
Copepoda												
Calanoida												
Temoridae												

Table 3. Continuation.

Taxa	d1	d2	d3	d4	d5	d6	d7	d8	d9	d10	d11	d12
Eurytemora velox (Lilljeborg)						+			+	+		
Cyclopoida												
Cyclopidae												
Macrocyclops albidus (Jurine)			+	+						+	+	
Macrocyclops distinctus (Richard)						+						
Macrocyclops fuscus (Jurine)				+			+		+	+		
Eucyclops macruroides (Lilljeborg)									+	+		
Eucyclops serrulatus (Fischer)		1	+	+	+			+	+	+	+	1
Eucyclops speratus (Lilljeborg)				+		+				+		+
Paracyclops affinis (Sars)					+							
Ectocyclops phaleratus (Koch)					+			+	+		+	
Megacyclops viridis (Jurine)								+			+	
Acanthocyclops einslei Mirabdullayev & Defaye				+			+					
Diacylops bicuspidatus (Claus)										+		
Metacyclops minutus (Claus)				+								
Cryptocyclops bicolor (Sars)						+					+	
Mesocyclops leuckarti (Claus)										+		
Thermocyclops crassus (Fischer)										+		
Harpacticoida												
Ameiridae												
Nitocra hibernica (Brady)	1		+	+		+						
Canthocamptidae												
Atteyella (Brehmiella) trispinosa (Brady)											+	
Elaphoidella gracilis (Sars)												2
Elaphoidella bidens (Schmeil)		1										

aurita, Oxyurella tenuicaudis, Pleuroxus truncatus, Tretocephala ambigua, and many others. On the other hand, the absence of pelagial zone and the low water level are likely the reason the pelagic zooplankton species of the genera *Daphnia* (except *D. curvirostris*), *Moina*, or *Eudiaptomus* to be completely missing in the zooplankton crustacean community. We assume that the absence of phytoplankton had influenced the species composition of Copepoda, where mainly predatory species dominated (Gaviria et al. 2002), whereas among the species of Cladocera were not recorded the typical phytoplankton filtrators. Ditches were dominated by species like *Ceriodaphnia laticaudata, Chydorus sphaericus, Pleuroxus aduncus* and *Pleuroxus denticulatus*. Our results on the zooplankton crustacean community composition are much simal to those reported by De Bie et al. (2008) for ditches and small lotic waters in Flanders.

As for non-native species, they were found in both gravel-pits and ditches. While in the gravel-pits (Illyová & Šulíková 2016) we have recorded up to eight species (*Daphnia ambigua, Daphnia parvula, Diaphanosoma mongolianum, Disparalona leei, Moina weismanni, Pleuroxus denticulatus* and *Eurytemora velox*), the ditches harboured only four (*N. hibernica, P. denticulatus, E. velox* and *D. leei*). The occurrence and prevalence of non-native species of crustaceans in anthropogenic habitats can also be related to fish stocking (Hudec 1998) when habitats are then used for sport fishing. *Pleuroxus denticulatus* and *Eurytemora velox* species reached the territory long time ago (Terek 1997, Vranovský 1994), but in recent years they have largely expanded not only in Slovakia, (Hudec & Illyová 1998) but also in north-western Iceland (Pandourski & Evtimova (2006) and in Hungary (Kiss & Schöll 2009, Kiss et al. 2015).

Besides the primary drainage functions, the ditches represent valuable biotopes for hydrobiocenoses with the occurrence of several rare, endangered and protected species (Dorotovičová 2013, Hajdú & Kováč 2002, Pekárik et al. 2014). This corresponds with our findings: we detected several rare species: *Lathonura rectirostris*, *Tretocephala ambigua*, *Oxyurella tenuicaudis*, *Psedochydorus globosus*, *Monospilus dispar, Megafenestra aurita* and *Acanthocyclops einslei*. They represent the inhabitants of indigenous undisturbed biotopes (Hudec 2010). The Holarctic species *Lathonura* *rectirostris* has been recorded only in one locality during the long-term research of the Danubian floodplain, in the plesiopotamal arm (Illyová & Matečný 2014). Since it had been found in ditches in the past (Vranovský & Ertl 1958), it could mean that it has still survived there. Similarly, the *Lathonura rectirostris* is a rare species for the Szigetköz, where it was found only in the active floodplain (Kiss 2004). *Monospilus dispar* has also disappeared from this area. According to Kiss (2004), the reasons are in altering the alluvial conditions, decreased current velocity and increased eutrophication. We have detected this species in the eutrophic ditch (Vojka–Kračany Canal) and also in gravel pits (Illyová & Šulíková 2016), but only sporadically in both. The occurrence of *Disparalona hamata* in the Chotárny Canal is the most notable. We have detected this species for the first time in Slovakia (Illyová & Hudec, 2004) and the second in Europe (Šrámek-Hušek et al. 1962). Later, we have also discovered it in a gravel-pit in the Žitný Ostrov (Illyová & Šulíková 2016). The species was recorded in North and South America, South Asia and Africa (Smirnov 1996). *Acanthocyclops einslei* prefers polluted pools, ditches and small ponds, poor in phytoplankton (Mirabdullayev & Defaye 2004). We believe that this species has been recorded in the past as *A. robustus*. Molecular-genetic analysis based on two genes revealed that the three species described at the end of the nineteenth century, *A. robustus*, *A. americanus* and *A. vernalis*, are well-differentiated, with genetic distances between them of around 20%. The recently described species *A. trajani* corresponds to *A. americanus*, and *A. einslei* to *A. robustus* (Miracle et al. 2013). In ditches, we have detected an extremely low abundance of zooplankton. In this case, as if the unfavourable character of the flowing water impact on the development of a community fully manifested itself, because the water flow in lotic systems may act as an important source of disturbance for zooplankton communities (De Bie et al. 2008). With increasing the flow rate in running waters, the zooplankton biomass exponentially decreases (Vranovský 1995). Additionally, the persistence of a crustacean zooplankton population in a lotic system is strongly determined by the availability of flow refuges and specific traits of the species (Robertson 2000). The occurrence and predominance of the genera *Pleuroxus, Alonella, Simocephalus, Eucyclops, Chydorus, Eurycercus* and *Oxyurella* in a lotic system is likely due to the fact that their species live in a close association with macrophyte vegetation and exhibit a well-pronounced habitat selection in favour of littoral zone, thus minimising their vulnerability to being washout (Richard et al. 1985). One more variable that might have affected zooplankton quantity in the study area is a relatively high abundance of fish in the ditches. The fish species richness ranged from 2 (at site d11) to 15 (in d8; Pekárik et al. in press). Some ditches are directly used as fishing grounds and there zooplankton serves as primary food for fish (Hrbáček 1962). This negatively correlates with the structure of the community in the ditches and there the most tiny zooplankton organisms dominated, e.g. Copepoda in various non-adult stages and Rotifera.

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