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Analysis of zooplankton assemblages from man-made ditches in relation to current velocity

by

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Abstract

Because of the slow current velocity, man-made ditches may create distinct physical and ecological conditions that are suitable for the growth of zooplankton populations. However, the influence of drainage ditches on zooplankton communities has not been studied yet. This study aims to answer the following questions: i) Are man-made ditches a rich source of zooplankton? ii) What current velocity value leads to abundant zooplankton in man-made ditches? iii) Do zooplankton communities differ between man-made ditches and connected natural streams? In man-made drainage ditches with a water current lower than 0.1 m s^{-1}, the abundance of zooplankton was greater than in the majority of streams. Sometimes this level of abundance was equivalent to the densities of zooplankton in lakes or dammed reservoirs. The presence of zooplankton in man-made ditches may be of great importance to the establishment of food webs, particularly during periods of high water levels or heavy rainfall, both of which may accelerate the water current, causing the dispersion of zooplankton along the ditches and into natural streams.

Key words: stream ecology, Rotifera, Copepoda, Cladocera, biodiversity, land reclamation

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Introduction

The ecologists studying zooplankton in rivers seek to understand how the zooplankton reach the main channel from adjacent areas, lakes or floodplains (e.g. Lair 2006; Thorp et al. 2006, Czerniawski & Domagała 2010; Grabowska et al. 2013; Nielsen et al. 2013; Karpowicz 2014). However, few studies have focused on the presence of zooplankton and their reproduction in flowing water, which prevents them from reaching the main channel from the outside (Czerniawski 2012; Nielsen et al. 2013; Czerniawski & Domagała 2014). The velocity of the water current affects the movement of zooplankton and their reproductive success, which consequently influences the potential population growth (Vranovsky 1995; Lair 2006). Many authors claim that the water renewal time and the presence of transient storage areas is more important in zooplankton development (e.g. Reynolds 2000; Lair 2006). Moreover, we also know that the longer the retention time, the lower the values of current velocity determining the zooplankton reproduction. Some studies have defined limits for velocity values of water currents that permit the movement, reproduction, and assembly of zooplankton. However, opinions regarding this issue are divided, and water current velocity rates sufficient for the development of zooplankton vary from 0.01 m s^{-1} to as much as 0.4 m s^{-1} (Rzoska 1976; Richardson 1992; Ejsmont-Karabin et al. 1993; Lair 2006; Czerniawski 2012; Czerniawski & Domagała 2014). However, analyses of the above-mentioned studies may indicate that in addition to water current velocity, other hydrological factors, e.g. discharge, depth and width also play a significant role (Lair 2006; Czerniawski 2012; Nielsen et al. 2013; Czerniawski & Domagała 2014).

Man-made drainage ditches are channels created primarily for agricultural purposes, and which usually: (i) have a linear plan form, (ii) follow linear boundaries, often turning at right angles, and (iii) show little relationship with natural landscape contours (Williams et al. 2004; De Bie et al. 2008). Irrigation ditches play an important role in the drainage of agricultural areas because they reduce the surface flow of water (Lemly et al. 1993). Man-made ditches may be a very good example of flowing waters with a velocity that allows the development of zooplankton. Moreover, ditches, as new habitats, facilitate the migration of species to and from connected natural streams, thus contributing to the enrichment of species diversity and biodiversity in agricultural or meadow areas (Mauritzen et al. 1999; Urban & Grzywna 2006; Simon & Travis 2011). On the other hand, man-made ditches can shorten the retention period of water in the soil due to sudden outflow. Zalewski (2010, 2014) claims that the acceleration of surface water outflow from the landscape has been increased by drainage, deforestation and the expansion of impermeable surfaces. Furthermore, the frequent technical treatment of ditches may lead to a decrease in the biodiversity of aquatic vegetation (Kiryluk 2010; 2013). Consequently, ditches similar to other artificial basins are highly threatened by eutrophication or physical destruction and can therefore be expected to be affected by anthropogenic stress in different ways than natural basins (Boothby 2003; Declerc et al. 2006; De Bie et al. 2008). De Bie et al. (2008) claimed that good knowledge of species diversity patterns within and among different types of artificial or natural aquatic habitats is necessary to direct strategies for the management and protection of aquatic biodiversity at the landscape scale. Similar suggestion can be put forward regarding the types of ditches according to different current velocity values.

Few studies have investigated the influence of man-made ditches on the development of invertebrate communities. Some studies have examined connections between oxbows and river beds through ditches in wetlands, demonstrating that invertebrate communities in ditches supplied with river water are dominated by collector-gatherers (Obolewski 2011). Other studies have examined the relationship between flow filling and water flow rates and the composition of macrophyte communities (Urban & Grzywna 2006). Simon and Travis (2011) indicate that connected altered streams and ditch habitats harbor higher biodiversity of macroinvertebrates and fish fauna compared to natural streams. De Bie et al. (2008) recorded that ditches tended to have similar total richness of cladocerans as lakes. However, these results do not adequately explain the problems related to species and the quantitative diversity of zooplankton in ditches. To date, the influence of man-made ditches on zooplankton communities, including rotifers, cladocerans and copepods together, has not been examined. Ditches, as free-flowing lotic sections, may create distinct physical and ecological conditions that, depending on values of current velocity, are suitable for the growth of zooplankton populations. Therefore, it is anticipated that the conditions of man-made ditches would significantly shape the zooplankton community in a newly created environment.

The objective of the present study was to answer the following questions:

1) Are man-made ditches a rich source of zooplankton?

2) What current velocity value leads to abundant zooplankton in man-made ditches?

3) Do zooplankton communities differ between man-made ditches and connected natural streams?

Methods

This study was conducted at 80 man-made ditch sites in the Drawa catchment area (Western Pomerania, NW Poland) (Figure 1). All of the streams are located in agricultural and meadow areas. Ditches in forests were intentionally excluded from the analysis because zooplankton assemblages tend to be larger in flowing waters located in agricultural and meadow areas (Ejsmont-Karabin & Kruk 1998; Czerniawski 2013). Moreover, the surface run-off from agricultural fields results in the increased water eutrophication (Allan 2004; Bednarek et al. 2014; Hunke et al. 2015) and thus may facilitate the zooplankton production. Therefore, drainage ditches can be suitable for the study of zooplankton as part of zoogenic communities in lotic waters with high levels of organic production.

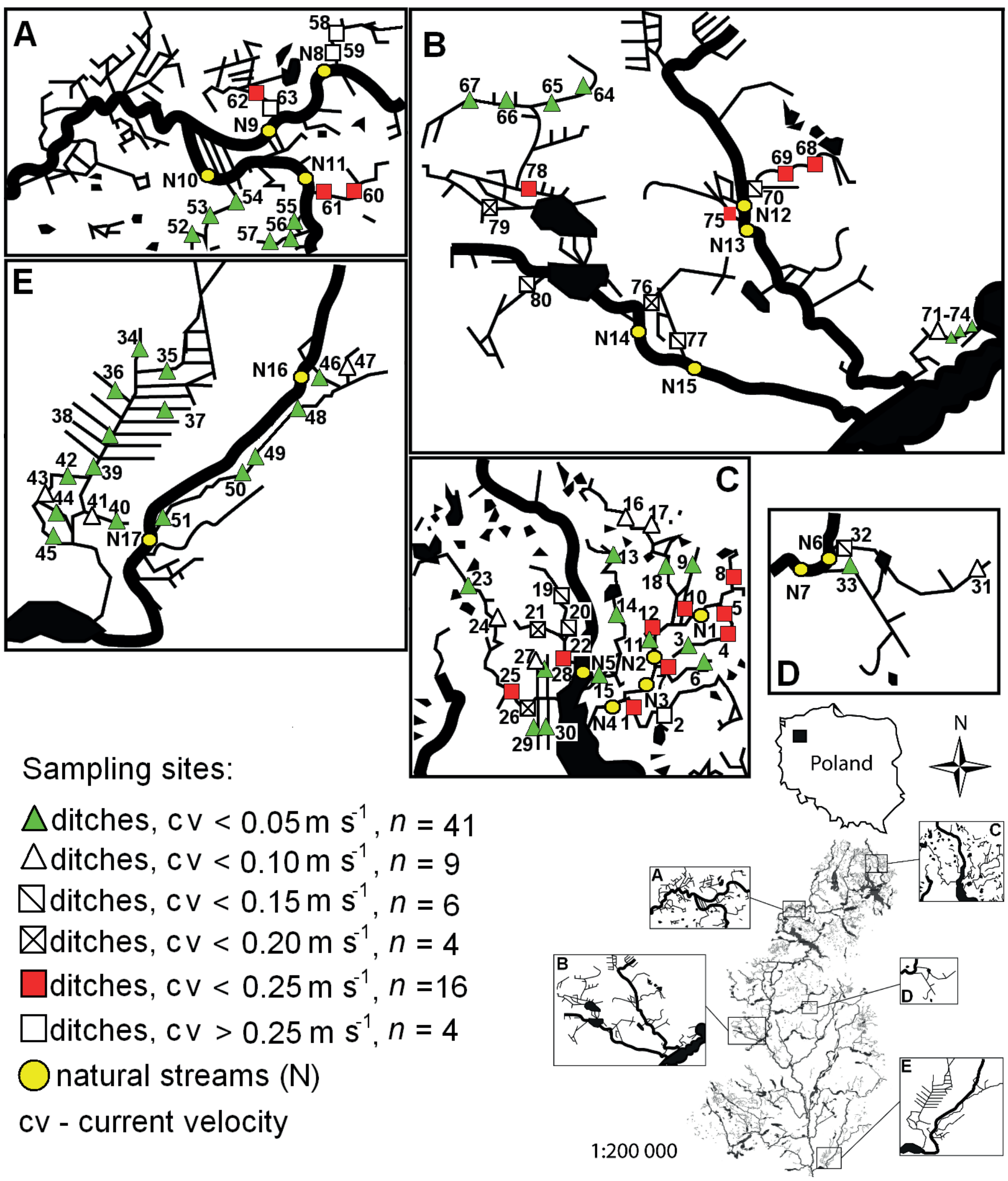

Figure 1

Study area – Drawa catchment area. The examined ditches are shown in the rectangular areas.

The bottoms of the streams at each site were overgrown with macrophytes. Additionally, the ecotone zones of the streams comprised meadow plants and bushes. There are many drainage ditches in the Drawa catchment area, but ditches through which water flows continuously are difficult to find in the summer. However, we identified 80 such sites at man-made ditches. To eliminate or minimize the likelihood that zooplankton in reservoirs would be transferred or dispersed into the main channel, we selected ditches with a continuous water flow and sections with no natural streams, marginal wetlands or stagnant waters between the sample collection sites. We selected also 17 sites at natural streams, below the mouths of ditches, to evaluate the impact of ditches on the zooplankton communities in these streams.

In the temperate climate of the study region, the highest density of zooplankton is observed in summer, hence this season was chosen for our study. Zooplankton were sampled in summer 2014 (between 17 and 30 June). Using a 5 l bucket at each site, 50 l of water was collected from the stream current and filtered through a plankton net with a mesh size of 25 µm. The samples were concentrated to 250 ml and fixed in 4% formalin solution. The contents of the samples were counted in a Sedgwick-Rafter counting chamber as ten 3 ml subsamples. A Nikon Eclipse 50i microscope was used for species identification. Species were identified using the identification keys presented by Nogrady et al. (1993), Radwan (2004), Dussart and Defaye (2006), and Rybak and Błędzki (2010). Temperature (°C), pH, conductivity (µS cm^{-1}), dissolved oxygen (mg l^{-1}) and chlorophyll *a* (µg l^{-1}) content were measured using a multi-parameter Hydrolab DS 5 sonde (USA). At each site, the velocity (m s^{-1}), width (m) and depth (m) were measured using an electromagnetic water flow sensor OTT (Germany) to evaluate the discharge of water (m^3 s^{-1}).

To detect the shift in taxa of zooplankton communities caused by the varying environmental conditions of drainage ditches, especially current velocity, we compared the abundance, Shannon's index (to evaluate the biodiversity index of zooplankton) and the number of zooplankton taxa between six groups of sites with a current velocity 1) <0.05 m s^{-1} (n = 41), 2) <0.10 m s^{-1} (n = 9), 3) <0.15 m s^{-1} (n = 6), 4) <0.20 m s^{-1} (n = 4), 5) <0.25 m s^{-1} (n = 16) and 6) >0.25 m s^{-1} (n = 4). We compared also the abundance, Shannon's index and the number of zooplankton species between sites with a current velocity <0.1 m s^{-1} (n = 50) vs. >0.1 m s^{-1} (n = 30). This division was established based on the opinions of Richardson (1992) and Lair (2006) that the majority of microfauna are unable to persist in the current with a velocity greater than 0.1 m s^{-1}. Moreover, Czerniawski (2012) and Czerniawski and Domagała (2014) observed large numbers of zooplankton in sections of streams and in floodplains where the water velocity did not exceed 0.1 m s^{-1}.

The taxonomic similarity between the sites at ditches and the sites at natural streams was evaluated using Jaccard's index. To illustrate the similarities between the sites at ditches and the sites at natural streams in terms of total zooplankton abundance, nonmetric multidimensional scaling ordination (nMDS) was used, the grouping in the nMDS ordination was based on the Bray-Curtis distances (Oksanen 2009). To calculate the statistical significance of differences between the two groups of ditches in terms of abiotic variables, abundance and biodiversity indices of zooplankton, the non-parametric Mann-Whitney U test was applied ($p<0.05$). Moreover, the rarefaction method for the comparisons of Shannon's index between six groups of sites with different current velocity values was used (Błędzki 2007; Chao et al. 2014). Rarefaction curves were created using the EstimateS software, version 9 (Colwell 2013). In order to determine the influence of the environmental variables of the stream on the abundance of zooplankton, Canonical Correspondence Analysis (CCA) with the forward selection procedure of variables by the permutation test was applied ($p<0.05$) (Oksanen, 2009). To assess the influence of current velocity on the environmental variables, the Pearson's index was calculated ($p<0.05$). The relationship between the values obtained for the current velocity of ditches and Jaccard similarity was evaluated using the Spearman's index ($p<0.05$).

Results

The groups of ditches divided according to current velocity, differed significantly in all physicochemical and hydrological variables ($p<0.05$) (Figure 2). Generally, values of physicochemical variables and chlorophyll *a* at sites with a current velocity <0.10 m s^{-1} were more different than in ditches with a current velocity >0.10 m s^{-1}. Moreover, values of current velocity were significantly negatively correlated with temperature, conductivity and chlorophyll *a* values and positively with pH ($p<0.05$).

In all ditches, planktonic rotifers accounted for 31% of the total zooplankton abundance, whereas benthic rotifers accounted for 34%. The highest mean abundance in all ditches was achieved by *Keratella* sp. and Daphniidae. *Bdelloidea,* Nauplii Cyclopoida, *Lecane* sp. and *Lepadella* sp. were less abundant (Figure 3).

Although eight taxa occurred with the highest abundance at sites with a current velocity <0.05 m s^{-1}, four of them – Bdelloidea, *Keratella* sp., Daphnidae and adult Copepoda were also abundant at sites with <0.1 m s^{-1} (p>0.05). Moreover, two taxa (*Colurella* sp. and Bosminidae) achieved similar abundance at sites with a current velocity <0.05 m s^{-1} and at sites with >0.1 m s^{-1} (p>0.05) (Figure 3).

Thirteen taxa achieved higher abundance at all sites with a current velocity <0.1 m s^{-1} compared to sites with a current velocity <0.15 m s^{-1}, but the abundance of only two taxa (*Lepadella* sp., *Pompholyx* sp.) differed significantly between all sites with a current velocity <0.1 m s^{-1} and all sites with a current velocity <0.15 m s^{-1}. Four taxa occurred with higher abundance at sites with a current velocity <0.15 m s^{-1}. In contrast to Daphnidae – large cladocerans, small cladocerans (Alonidae, Bosminidae and Chydoridae) occurred with statistically similar abundance at all sites (p>0.05).

The division into two groups (<0.10 m s^{-1} and >0.1 m s^{-1}) showed that most taxa occurred with the highest abundance at sites with a current velocity <0.10 m s^{-1}. However, only four taxa – Bdelloidea, *Keratella* sp., *Polyarthra* sp. and Daphniidae – achieved a significantly higher abundance in ditches with a current velocity <0.1 m s^{-1} compared to ditches with a current velocity >0.1 m s^{-1} (p<0.05) (Table 1). Other taxa were characterized by insignificant differences in zooplankton abundance between these two groups of ditches, even though all taxa (except *Conochilus* sp., *Synchaeta* sp. and copepodites) had higher densities in ditches with a lower current velocity value. Moreover, the total zooplankton abundance was significantly higher in ditches with a current velocity <0.1 m s^{-1}, whereas Shannon's index and the number of taxa were significantly higher in ditches with a current velocity >0.1 m s^{-1} (p<0.05) (Table 1, Figure 4). Rarefaction curves of Shannon's index of zooplankton also show differences between the ditches with current velocities lower than 0.10 m s^{-1} and higher than 0.10 m s^{-1} (Figure 5). A very good indicator of the influence exerted by the water current on zooplankton communities was the presence of Daphniidae in the groups of ditches. In ditches with a water current velocity <0.1 m s^{-1}, Daphniidae were present in 64% of the sites. Whereas in ditches with a water current velocity >0.1 m s^{-1}, Daphniidae were present in 23% of the sites in significantly smaller numbers (Table 1).

The Jaccard index revealed small taxonomical similarities between natural streams and the two groups of ditches (<0.10 m s^{-1} and >0.1 m s^{-1}) (Table 2). However, the similarity between natural streams and ditches with a velocity <0.1 m s^{-1} was smaller than for those with a velocity >0.1 m s^{-1}, even though this

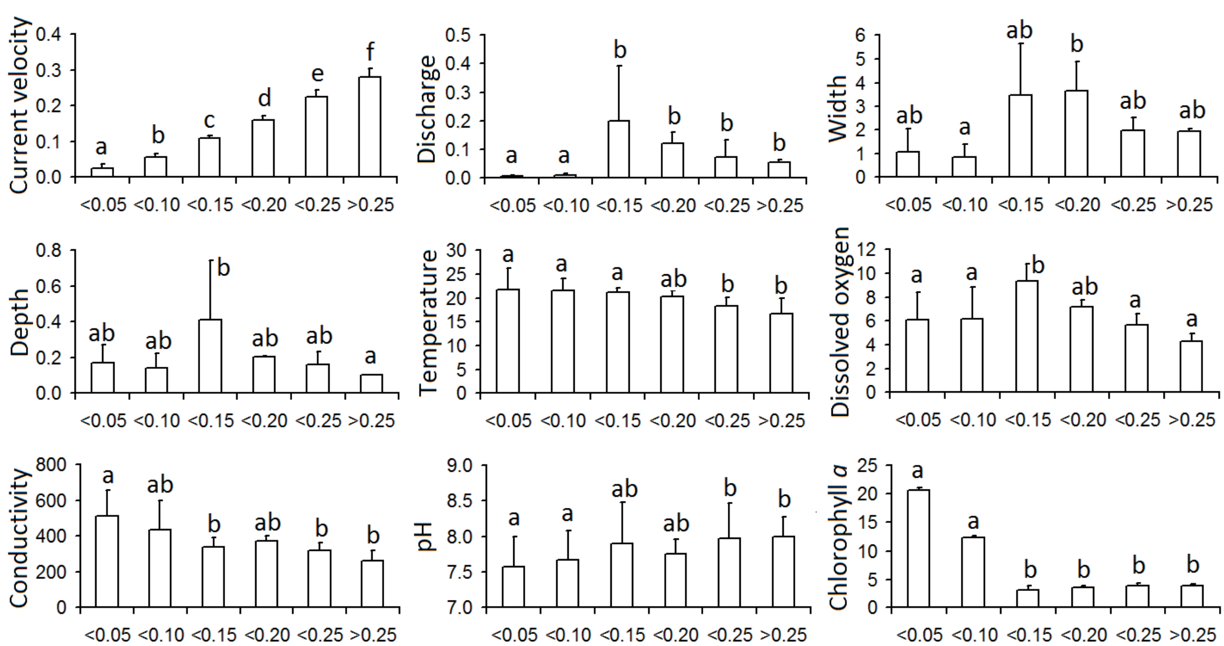

Figure 2

Mean + SD values of physicochemical and hydrological variables for the examined ditches divided into six groups according to the current velocity values: 1) <0.05 m s^{-1}, 2) <0.10 m s^{-1}, 3) <0.15 m s^{-1}, 4) <0.20 m s^{-1}, 5) <0.25 m s^{-1} and 6) >0.25 m s^{-1}. Different letters indicate significant differences p<0.05 in values of variables between groups of ditches.

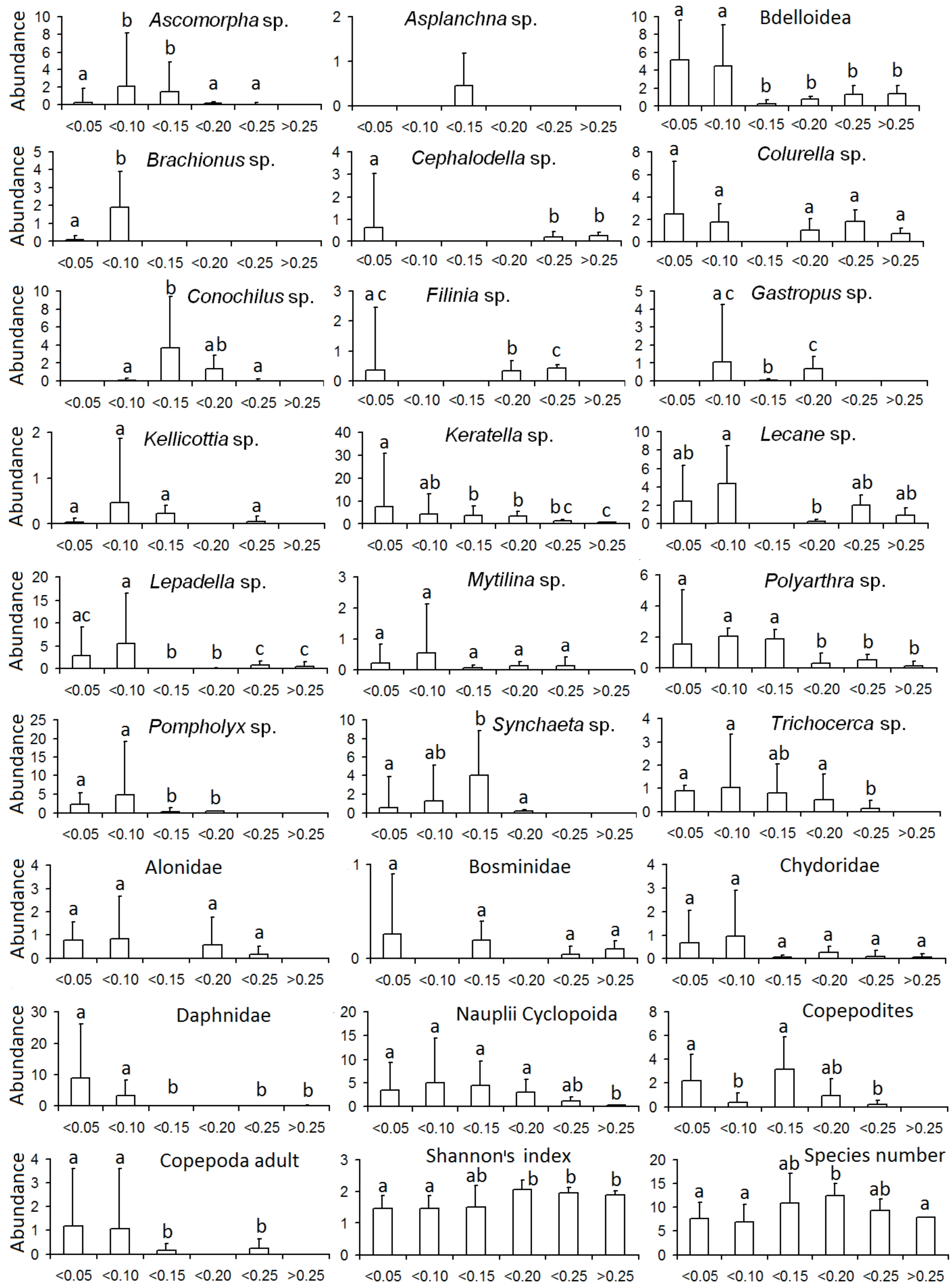

Figure 3

Mean + SD values of zooplankton abundance (ind. l^{-1}), Shannon's index and the number of species for the examined ditches divided into six groups according to the current velocity values: 1) <0.05 m s^{-1}, 2) <0.10 m s^{-1}, 3) <0.15 m s^{-1}, 4) <0.20 m s^{-1}, 5) <0.25 m s^{-1} and 6) >0.25 m s^{-1}. Different letters indicate significant differences p<0.05 in values of variables between groups of ditches.

Table 1

Significant differences in mean values ± SD of zooplankton abundance (ind. l^{-1}), Shannon's index and the number of species for the ditches divided into two groups according to the current velocity values: <0.10 m s^{-1} vs. >0.10 m s^{-1}. ** p<0.01, *** p<0.001

Taxa	<0.1 m s^{-1}; n = 50	p	>0.1 m s^{-1}; n = 30
Bdelloidea	5.01 ± 4.46	***	1.03 ± 0.90
Keratella sp.	6.99 ± 21.42	**	1.96 ± 2.25
Polyarthra sp.	1.28 ± 3.25	***	0.94 ± 0.84
Daphnidae	7.79 ± 16.00	***	0.05 ± 0.08
Total zooplankton	41.29 ± 33.71	***	14.31 ± 10.39
Shannon-Wiener index	1.46 ± 0.40	***	1.87 ± 0.37
Number of species	7.5 ± 3.5	**	9.9 ± 3.5

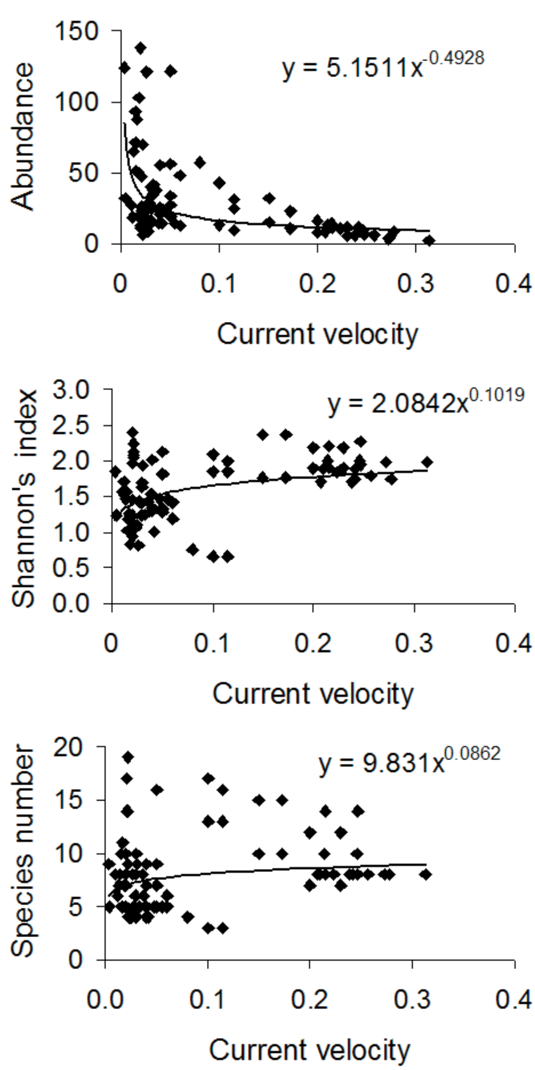

Figure 4

Relationship between values for zooplankton abundance (ind. l^{-1}), Shannon's index, the number of species vs. current velocity (m s^{-1})

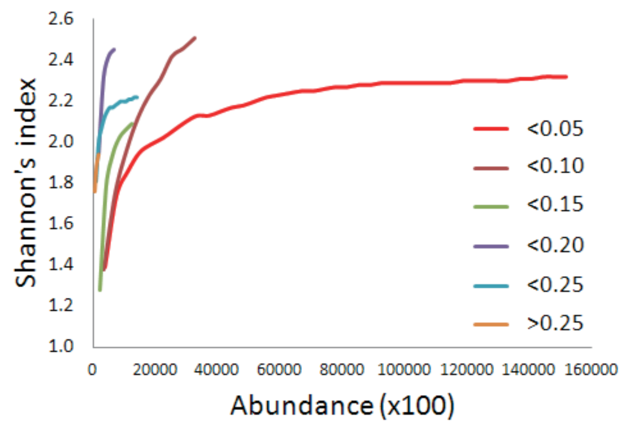

Figure 5

Rarefaction curves of Shannon's index of zooplankton for the examined ditches divided into six groups according to the current velocity values: 1) <0.05 m s^{-1}, 2) <0.10 m s^{-1}, 3) <0.15 m s^{-1}, 4) <0.20 m s^{-1}, 5) <0.25 m s^{-1} and 6) >0.25 m s^{-1}

difference was not significant (p>0.05). The Spearman's correlation between the values obtained for the Jaccard index and the current velocity was positive (r = 0.42) but not significant (p>0.05). A similar pattern was observed in the nMDS model. The similarity in zooplankton abundance between the sites at natural streams and the sites at ditches with a current velocity >0.1 m s^{-1} was higher compared to the sites with a current velocity <0.1 m s^{-1} (Figure 6).

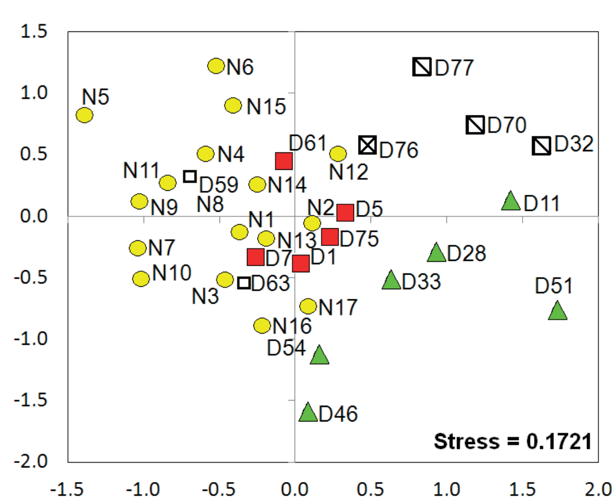

Figure 6

nMDS ordination for the total zooplankton abundance at sites in the natural stream (recipient) and ditches (tributary) with different values of current velocity. The grouping in nMDS ordination was based on the Bray-Curtis distances. For symbols, refer to Figure 1.

Table 2

Jaccard's similarity index values between sites at natural streams and two groups of ditches according to their current velocity value: 1) <0.1 m s^{-1} and 2) >0.1 m s^{-1}

< 0.1 m s^{-1}		> 0.1 m s^{-1}	
N2 *vs.* 11	42.1	N4 *vs.* 1	55.6
N5 *vs.* 28	36.4	N3 *vs.* 7	66.7
N7 *vs.* 33	21.4	N1 *vs.* 5	71.4
N16 *vs.* 46	57.1	N6 *vs.* 32	27.8
N17 *vs.* 51	58.3	N8 *vs.* 59	46.2
N10 *vs.* 54	33.3	N9 *vs.* 63	45.5
		N11 *vs.* 61	64.3
		N12 *vs.* 70	37.5
		N13 *vs.* 75	66.7
		N14 *vs.* 76	45.5
		N15 *vs.* 77	46.7
Mean	41.5	NS p>0.05	52.1

NS – not significant difference between two groups of sites

CCA analysis of zooplankton abundance with the forward selection procedure of environmental variables showed that the discharge explained the largest part of the variability in the zooplankton abundance (Table 3). The permutation test revealed that each variable, except depth and pH, had a significant impact on improving the fit of the model (Table 3). These variables together explained 89.6% of the total variability in zooplankton abundance. The discharge, ditch width and conductivity correlated best with the first axis (Figure 7) and temperature was less correlated with the first axis. The best correlation with the second axis was found for the content of chlorophyll *a*, dissolved oxygen and current velocity. Daphniidae and Chydoridae or large rotifers *Mytilina* sp. correlated negatively with the current velocity.

Table 3

Results of Canonical Correspondence Analysis of zooplankton abundance with the forward selection procedure of environmental variables. Order – Order of integration of variables for analysis

Order	Variable	Variance	Variance explained (%)	Permutation test	
				F	p
1	Discharge	0.20	26.0	2.72	0.005
2	Conductivity	0.10	13.0	5.32	0.005
3	Velocity	0.11	14.3	2.77	0.005
4	Dissolved oxygen	0.09	11.7	3.69	0.005
5	Width	0.08	10.4	2.72	0.005
6	Chlorophyll *a*	0.06	7.80	2.35	0.005
7	Temperature	0.05	6.50	1.91	0.045
8	Depth	0.04	5.20	1.94	0.055
9	pH	0.04	5.20	1.72	0.075

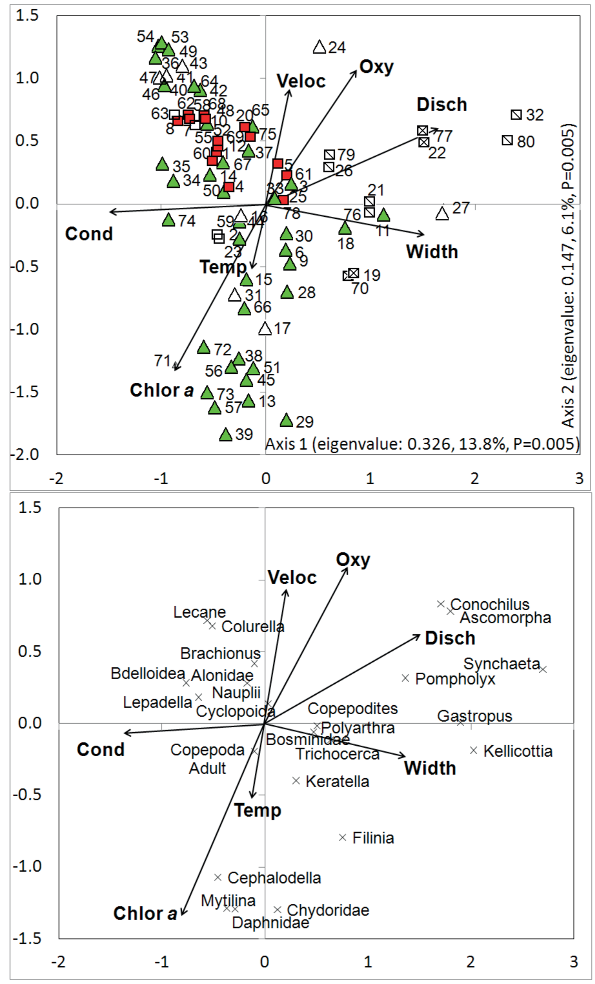

Figure 7

Zooplankton abundance along environmental factors: CCA constrained ordination of samples and taxa from sites with different current velocity in ditches with the forward selection procedure of environmental variables. Numbers indicate the sites. Environmental variables: Veloc – current velocity; Disch – discharge; Temp. – temperature; Cond. – conductivity; Oxy – dissolved oxygen; Chlor *a* – chlorophyll *a*. For symbols, refer to Figure 1.

Most of the planktonic rotifers correlated positively with discharge and width and negatively with conductivity, whereas some benthic rotifers (*Colurella* sp. and *Lecane* sp.) correlated positively with conductivity and current velocity. CCA showed that abundance values at different sites according to current velocity (<0.10 m s^{-1} and >0.1 m s^{-1}) were mainly differentiated along the first axis. The second axis differentiated mainly between the sites with a current velocity <0.10 m s^{-1} and the sites with a current velocity >0.25 m s^{-1}.

Discussion

In general, the taxonomic composition of the studied ditches did not differ much from other running waters in the area, regardless of the water current velocity (e.g. Czerniawski and Domagała 2010; Czerniawski and Pilecka-Rapacz 2011; Czerniawski 2012). Differences were observed only for the abundance of zooplankton, consisting mainly of large crustaceans (Daphniidae in particular). In streams, rotifers and Nauplii can be found more frequently and in larger numbers than adult crustaceans. This phenomenon is associated with their smaller sizes, which, in addition to their shorter life cycle, helps them avoid being eaten by fish (Jack & Torp 2002; Walks & Cyr 2004; Chang et al. 2008; Czerniawski & Domagała 2013).

We observed a relatively large number of zooplankton taxa in the studied ditches regardless of the current velocity values. The same taxa are observed in lakes and other basins. De Bie et al. (2008) claimed that the total number of cladoceran species supported by lakes is larger than in ponds, pools and ditches. Lakes tend to have the highest total richness of cladocerans, but the difference for ponds and ditches is not significant.

Moreover, the abundance of planktonic rotifers and crustaceans in the studied ditches was higher at some sites than in some limnetic basins in this area (e.g. Sługocki et al. 2012; Czerniawski and Domagała 2014). Clearly, the majority of ditches assessed herein offered favorable conditions for the development not only of crustaceans but also of planktonic rotifers that are typical of limnetic basins. Thus, generally the conditions of ditches were good enough for zooplankton development. However, the best conditions for the maintenance of zooplankton were in sections with a current velocity <0.1 m s^{-1}.

Rzoska (1976) claimed that zooplankton reproduction is unlikely in water with a current velocity >0.40 m s^{-1}. This value still seems to be too high for shallow streams. The majority of microfauna are unable to thrive in water with a current velocity greater than 0.10 m s^{-1} (Richardson 1992; Lair 2006), which was also confirmed in our study. In drainage ditches with a current velocity <0.10 m s^{-1}, the abundance of many taxa was much higher than in ditches with a current velocity >0.10 m s^{-1}. Similar results were observed by Czerniawski (2012) and Czerniawski and Domagała (2014) in a small field stream and in a small impoundment, respectively, where planktonic crustaceans and planktonic rotifers could thrive and reproduce in the presence of a current velocity oscillating at approximately 0.05 m s^{-1}. However, we observed some small cladocerans (*Alona* sp., *Pleuroxus* sp., *Simocephalus* sp.) and some pelagic rotifers (*Ascomorpha* sp., *Keratella* sp., *Polyarthra* sp., *Trichocerca* sp.) at all sites. Grabowska et al. (2013) and Czerniawski and Pilecka-Rapacz (2011) also observed higher percentage dominance of small cladocerans in a shallow riverine section compared to a dam section of a river. Richardson (1992) and De Bie et al. (2008) claimed that the predominance of small cladocerans in lotic waters may be due to the fact that their species live in close association with a substrate or show a strong habitat selection in favor of well-structured littoral zones, which may reduce their vulnerability to downstream washout. Richardson recorded also that complete washout of microcrustacean populations can occur at water velocities >2.5 cm s^{-1} for *Daphnia*, >3.2 cm s^{-1} for *Scapholeberis* and >7.73 cm s^{-1} for cyclopoids. In the studied ditches, these taxa were observed in small numbers at sites with a current velocity higher than 10 cm s^{-1} and their persistence in those lotic systems was probably also strongly determined by the availability of flow refugia and strong swimming ability of species or the use of benthic habitats and flow avoidance (Robertson 2000; De Bie et al. 2008). Thus, some taxa could reach higher abundance at sites with a current velocity <0.10 m s^{-1} compared to ditches with a current velocity <0.05 m s^{-1}. Additionally, some rotifer species with relatively short periods of development occur with high densities in large rivers (Holst et al. 2002).

We observed an increase in Shannon's index and the number of taxa with a higher current velocity and a greater density of zooplankton with a lower current velocity. Therefore, biodiversity and the number of taxa are reduced with a slower water current, enabling the occurrence of dominant taxa. However, the abundance of zooplankton decreases at sites with stronger water currents, while the number of taxa increases. This phenomenon is caused by the washout of numerous benthic taxa from macrophytes or the substrate, and by the water retention time, which is too short and hinders the development of dominant planktonic forms. Krylov (2002, 2008) observed a similar correlation when comparing zooplankton communities in slow sections of streams with beaver impoundments. He found that the abundance of zooplankton increased and the biodiversity decreased at beaver impoundments.

In lotic waters, significant correlations between physicochemical variables, chlorophyll *a* values and zooplankton communities have rarely been observed. In the present study, however, these variables explained a large part of the zooplankton abundance variability. It seems that this pattern is caused by low values of current velocity, which have a significant impact on abiotic conditions of rivers and through-flow water basins (Allan 2004). This was confirmed by a strong significant correlation between the values of current velocity and chlorophyll a and some physico-chemical variables. It is therefore reasonable to expect that the effect of current velocity on physicochemical conditions and chlorophyll a content is exerted directly at low values of ditch current velocity. The abundance of zooplankton significantly correlated with the concentration of chlorophyll a, which is clearly due to the associated improved nutritional conditions for filter-feeding plankters. Such a correlation is more frequently observed in stagnant waters (Gołdyn & Kowalczewska-Madura 2008; Kamarainen et al. 2008; Levesque et al. 2010) and slow-flowing waters (Czerniawski 2012). In faster-flowing rivers, this correlation is not observed (Basu and Pick 2007).

The width and discharge of a ditch exerted a statistically significant impact on zooplankton abundance, but the current velocity also depended on these variables. As the sections of the stream widened, a slowdown of the current velocity was observed. Some authors conducted their studies in large and deep rivers with water current velocity above 0.4 m s^{-1} and observed large abundance of planktonic rotifers (Rzoska 1976; Holst et al. 2002; Czerniawski et al. 2013) which should be attributed to the large discharge, depth and width of rivers, and hence the improved contact with small lentic basins in riparian zones.

Furthermore, despite significant correlations between the abundance of zooplankton and the values of the environmental variables, the obtained correlations can explain the zooplankton diversity to a relatively small extent only, even though they are comparable to the findings reported by other authors. It is possible that other environmental variables, which were not taken into consideration, play a significant role in the abundance of zooplankton occurring in ditches, such as nutritional conditions, macrophyte composition, sediment components, and catchment area conditions. Moreover, due to a small number of replicate values (even though appropriate for non-parametric analysis) for ditches with a current velocity <0.20 m s^{-1} (n = 4) and <0.25 m s^{-1} (n = 4), the results of statistical variations can be inaccurate. However, most of the significant differences refer to the division of ditches into two groups with a current velocity <0.1 m s^{-1} and >0.1 m s^{-1}, where the number of replicates was suitable for the analysis, i.e. n = 50 and n = 30, respectively. Although sometimes two or even four sites were located along the same small ditch, the CCA revealed that they were mostly not similar, especially sites with different current velocity. Thus, the occurrence of pseudoreplicates was rather unlikely.

Low Jaccard similarity values between natural streams and ditches and the results of nMDS demonstrate the minor influence of ditches on their recipients. Some authors indicate that tributaries have an insignificant impact on the zooplankton communities in their recipients (Czerniawski & Domagała 2010; Czerniawski & Pilecka-Rapacz 2011; Czerniawski 2012). Greater channelization of streams is conducive to the dispersion of zooplankton over larger distances, whereas the dispersion in natural streams is significantly reduced (Czerniawski & Domagała 2010; Czerniawski & Pilecka-Rapacz 2011). In both cases, however, the distances traveled by zooplankton depend on the water current velocity, which is the most significant variable affecting this pattern (Vranovsky 1995; Campbell 2002; Walks & Cyr 2004). We are aware that the general supposition concerning the minor influence of drainage ditches on natural streams is rather speculative, because it has been confirmed only in the summer season. In spring and autumn, when both the water volume and the current velocity are higher, the impact of drainage ditches could be stronger. This supposition is extremely likely and is based on the dispersion of zooplankton by the water current (e.g. Holst et al. 2002; Chang et al. 2008; Czerniawski & Pilecka-Rapacz 2011). On the other hand, a positive correlation between the current velocity and the similarity index can reveal greater impact of ditches on zooplankton communities and their dispersion to natural streams during seasons of increased water flow and current velocity. Therefore, it is very likely that in the case of sudden heavy rainfall and, consequently, an increase in the water current velocity in the studied ditches, a sudden drift of zooplankton from the ditches to the natural stream could occur, potentially resulting in a sudden enrichment with organic matter and simultaneous alteration of the trophic structure.

Zalewski (2010) claims that the quantification and integration of hydrological and biological processes at the basin scale is based on the assumption that abiotic factors are of primary importance and become stable and predictable when biotic interactions begin to develop. The results of the present study can be related to the above-mentioned statement. The drainage ditches developed hydrological and nutritional conditions that facilitated sufficient primary production to allow reproduction of the primary consumers – zooplankton. Thus, a self-sufficient biocenotic system was formed.

In conclusion, in man-made drainage ditches with the water current slower than 0.1 m s^{-1}, larger abundance of zooplankton occurs compared to the majority of streams. Whereas in ditches with a current velocity >0.1 m s^{-1}, Shannon's index and the number of zooplankton taxa are higher. A slow water current in drainage ditches facilitates the reproduction of zooplankton and, consequently, the production of large amounts of organic matter that would otherwise not be produced in these areas devoid of limnetic basins. Therefore, the absence of drainage ditches would preclude the occurrence of zooplankton assemblages in certain areas. At the same time, it is clear that zooplankton are a good indicator of both trophic (Jeppesen et al. 2011) and hydrological changes. The results of the present study confirm this supposition, as do many other studies that have investigated the influence of small natural or artificial dams (Krylov 2002; Krylov 2008; Zhou et al. 2008; Czerniawski & Domagała 2014). Zooplankton abundance rapidly and positively reacts to hydrological changes that increase the retention time of water in streams (Ejsmont-Karabin et al. 1993; Vranovsky 1995; Thorp et al. 2006). The abundance of zooplankton occurring in ditches is sometimes equivalent to the density of zooplankton in lakes or dammed reservoirs. Therefore, zooplankton in such man-made ditches may be of great importance to the establishment of food webs, particularly during periods of high water levels or heavy rainfall. These phenomena increase the amount of water and accelerate the current, which results in the dispersion of zooplankton along ditches and into natural streams, and consequently increases the amount of organic matter within a very short time and enhances the primary production.

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