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Effect of surrounding trees and dry rush presence on spring zooplankton community in an urban pond complex

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Abstract – The role of both natural and artificial ponds in supporting biodiversity and as an infrequent habitat for aquatic organisms in urban areas may be greater than that in more rural landscapes. Moreover, biological succession and the dynamics of zooplankton can differ in urban ponds where we may observe a specific combination of environmental factors (*e.g.*, an increase of eutrophication and pollution) compared to other water ecosystems. Therefore, ten urban artificial ponds were examined and the type of direct catchment area was established as the most important factor in the determination of zooplankton distribution. Different environmental factors structured zooplankton distribution between forest and meadow ponds. Low concentrations of oxygen as well as lack of fish, which was an effect of high concentrations of ammonium nitrogen, were responsible for the occurrence of littoral species and large crustacean species (*e.g.*, *Daphnia hyalina* and *Megacyclops viridis*) in the case of forest ponds. Fish predation on large crustaceans and favourable food conditions (high concentration of chlorophyll a) created suitable conditions for the occurrence of pelagic species (*e.g.*, *Keratella cochlearis* and *K. quadrata*) in the case of meadow ponds. Moreover, soon after the ice cover melted and before new macrophytes developed, previous-year dry rush stems created valuable refuge conditions for zooplankton in this type of pond. Despite anthropogenic pollution resulting from the close vicinity of the agglomeration of Poznań and unfavourable conditions attributed to the spring season a diverse zooplankton community occurred, reaching the level of 119 species in total.

Key words: Ponds' catchment area / fish predation / cladocerans / rotifers

Introduction

Small water bodies create a specific and unique aquatic environment. Owing to their low water volume and shallowness, ponds are more affected by environmental changes compared to lakes. The characteristics and management of both the direct and indirect catchment area may be reflected in the water physicochemistry and it has therefore a significant effect on the inhabiting organisms (Ejsmont-Karabin and Kruk, 1998; Dodson *et al.*, 2007; Di Prinzio *et al.*, 2009; Grochowska and Brzozowska, 2013). In particular, the presence of urban areas in the vicinity of aquatic ecosystem and rivers can decrease water quality as well as the biodiversity of plants and invertebrates (Allan, 2004; Declerck *et al.*, 2006; De Paggi and Devercelli, 2011; Park *et al.*, 2011). However, tree formations in the immediate neighbourhood of a pond may, by chemical and physical filtration, buffer the inflow of pollutants from an urban catchment (Norris, 1993). On the other hand, falling leaves contribute a supply of organic matter to the water body (Sobczyński and Joniak, 2009) and can create an additional habitat for invertebrates. Moreover, instead of regarding the area and depth of ponds as restricted they may be divided into various microhabitats due to the occurrence of different macrophyte species that can build separate plant stands, even within a small area of a pond (Tessier *et al.*, 2004). Therefore, it is not only the abundance of different small water bodies in landscapes, but also the macrophyte mosaic within a single pond that will support as well as contribute to the increase of biological diversity. The presence of macrophyte species has a significant influence on the species richness and community structure (Balayla and Moss, 2003; Iglesias *et al.*, 2007; Ejsmont-Karabin and Hutorowicz, 2011; Dalu *et al.*, 2012). Additionally, the different plant habitats are fundamental for particular groups of zooplankton, creating various life conditions and anti-predator refuges of varying effectiveness

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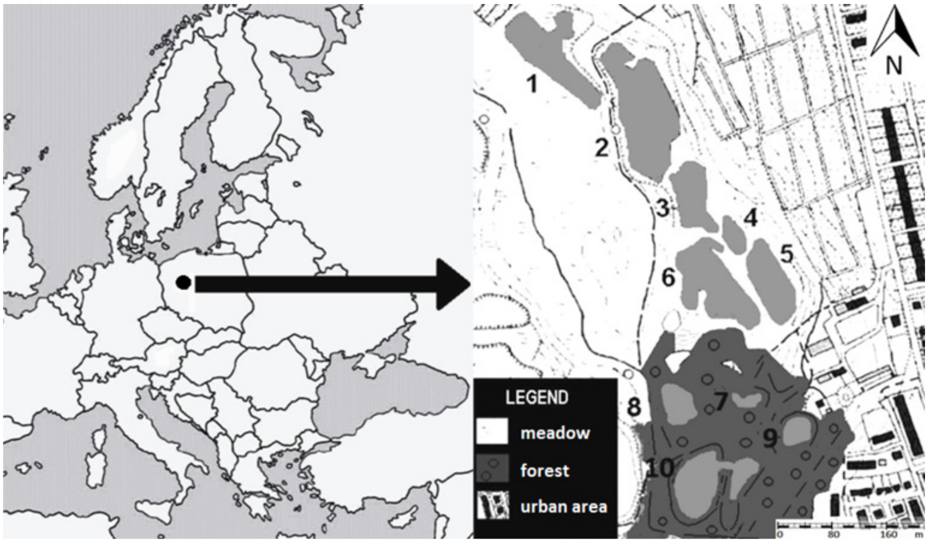

Fig. 1. The location of the city of Poznań (Poland) and detailed surrounding areas of studied ponds (geographical position for groups of ponds: meadow ponds N 52°21′52.31″, E 16°52′27.83″; forest ponds N 52°21′41.78″, E 16°52′30.19″).

(Stansfield *et al.*, 1997; Balayla and Moss, 2003; Špoljar *et al.*, 2012).

Even though research on ponds has been often neglected we now realize that they make up a vital and specific aquatic habitat (Céréghino *et al.*, 2008; Boix *et al.*, 2012). Moreover, most research on small water bodies has concerned the summer season (Tõnno *et al.*, 2003; Iglesias *et al.*, 2007; Lucena-Moya and Duggan, 2011; McGavigan, 2012), when the majority of environmental factors, *e.g.*, availability of a suitable food source or heterogeneity relating to the complexity of macrophyte cover, occur within optimum values. Hence, life conditions for inhabiting organisms are very advantageous at that time. Therefore, it was expected that during the spring season, when the study was carried out, the structure of zooplankton communities in the ponds would be less diverse in comparison with the summer. The spring season is also crucial for fish, which usually restrict zooplankton development in temperate climate zones. Most fish species in shallow macrophyte-dominated lakes and ponds begin to reproduce in March or April when the water temperature reaches 10° (Brylińska, 1991). During the spring fish *e.g.*, roach can have a great influence on zooplankton communities, even on those occurring among plant stands (Hansson *et al.*, 2007; Nicolle *et al.*, 2010).

Therefore, the general aim of this study was to identify the most important environmental factors (physiochemistry, predators, catchment area type and dry rush presence) structuring the zooplankton community in a set of urban ponds during the spring period.

Considering the two aspects relating to the type of pond catchment and predation pressure we hypothesized that (1) even though the ponds were located within a short distance of each other and were of the same origin the effect of direct tree formations, or their absence, will be significant for the zooplankton structuring in ponds, and (2) predators would be responsible for the zooplankton species distribution within habitat.

Material and methods

Study site

The examined ponds are situated within the administrative borders of the city of Poznań in the Wielkopolska region (Western Poland). This complex of ten ponds resulted from the clay extraction which took place in this area over a hundred years ago. Since this time the whole area has been exposed to indifferent management and the inflow of various types of pollutants originating from municipal wastewater rich in organic matter and nutrients. This in turn has had a significant impact on the increase of trophic conditions, deterioration of water quality and an intense growth of aquatic and wetland vegetation within the area (Pawuła-Piwowarczyk, 1992). In the examined ponds, defined as meadow types, macrophyte beds (*e.g.*, *Ceratophyllum demersum* L., *Utricularia vulgaris* L., *Phragmites australis* (Cav.) Trin. ex Steudel and *Typha angustifolia* L.) were present from the end of the spring season (end of May – beginning of June) to the end of autumn. However, the present study was carried out in April when new aquatic vegetation has not yet been developed, as the ice cover had only recently disappeared in the Wielkopolska region and only old and dry shoots of rushes were still present.

The examined clay-pits were situated within a very short distance from each other (between 2 and 20 m), however, the surroundings of particular ponds, as regards the percentage of trees, divided the direct catchment area in two separate groups: forest and meadow (Fig. 1; Table 1).

Thus, four ponds were situated within an old park and as the percentage of the tree coverage (*e.g.*, *Acer platanoides* L., *A. pseudoplatanus* L., *Corylus avellana* L. and *Alnus glutinosa* Gaertn.) in their neighbourhood was high, accounting for 85%, they were classified as forest ponds. The high density of trees around these ponds hindered the growth of rush vegetation but provided an

Table 1. Average values of limnological parameters between different types of water bodies with additional helophyte habitat in meadow ponds. Trees reflect the percentage cover of closest pond surroundings. TP – total phosphorus.

	Forest ponds	Meadow ponds	
	Water	Water	Rushes
Physical properties			
Ponds surface (ha)	0.29 ± 0.17	0.78 ± 0.45	0.81 ± 0.5
Depth (m)	0.95 ± 0.66	2.48 ± 1.1	2.48 ± 1.1
Water temperature (°C)	10.8 ± 0.63	15.5 ± 0.72	15.7 ± 0.7
O_2 concentration ($mg.L^{-1}$)	4.27 ± 1.9	8.02 ± 1.4	7.88 ± 1.1
pH	7.78 ± 0.11	7.95 ± 0.39	8.02 ± 0.28
Conductivity ($\mu S.cm^{-1}$)	994 ± 96.3	957 ± 51.3	969 ± 64.36
Seston (mg $DM.L^{-1}$)	7 ± 2	8 ± 5	12 ± 5
Trees (%)	85 ± 11.2	9 ± 6.7	7.8 ± 6.8
Chemical properties			
TP ($mg.L^{-1}$)	0.31 ± 0.34	0.13 ± 0.12	0.19 ± 0.13
$N\text{-}NO_3$ ($mg.L^{-1}$)	0.15 ± 0.06	0.23 ± 0.18	0.36 ± 0.25
$N\text{-}NO_2$ ($mg.L^{-1}$)	0.006 ± 0.003	0.009 ± 0.007	0.01 ± 0.008
$N\text{-}NH_4$ ($mg.L^{-1}$)	1.65 ± 0.34	0.34 ± 0.18	0.58 ± 0.13
Chlorophyll *a* ($\mu g.L^{-1}$)	9.19 ± 3.9	16.71 ± 10.3	15.28 ± 9.0
Biological properties ($ind.L^{-1}$)			
Chaoborus larvae	1 ± 0.5	0	0
Odonata larvae	2 ± 1	0	0.4 ± 1

abundant supply of leaves which created a thick layer of leaf litter on the bottom throughout the year.

The second group of water bodies consisted of six ponds where only single trees were in the direct catchment area were referred to as meadow ponds. They were surrounded by a helophyte belt (mainly composed by *Phragmites australis* with a small participation of *Typha angustifolia*), wastelands and meadows. These water bodies were larger and deeper compared to the forest ponds (Table 1). They were abundantly inhabited by fish, contrary to the forest ponds where fish were not observed (in one pond) or occurred only in very small densities (in three ponds). The fish species frequently encountered in macrophyte-dominated small water bodies in Poland are: crucian carp (*Carassius carassius* L.), roach (*Rutilus rutilus* L.), rudd (*Scardinius erythrophthalmus* L.) and perch (*Perca fluviatilis* L.) (Brylińska, 1991).

In the forest ponds filamentous chlorophytes dominated, with a smaller participation of diatoms, chrysophytes and dinoflagellates. In the meadow clay-pits algae, assemblages were more diverse with a dominance of diatoms (in two ponds), chrysophytes and diatoms (in three ponds) and filamentous chlorophytes along with diatoms (in one pond), depending on the pond.

Field and laboratory methods

The field study was carried out over three consecutive days in the spring period (April) of 2009. In order to avoid vertical differentiation in abiotic parameters and zooplankton distribution samples were collected from the surface layer in the open water stations of each water body. 20-L (pelagic) and 5-L (littoral) samples were taken in triplicate using a calibrated vessel. Each sample was concentrated using a 45-μm plankton up to 20 or 5 mL, respectively and fixed immediately with 4% formaldehyde. The zooplankton species abundance was expressed as the number of individuals per Litre. Moreover, in the case of meadow ponds the dry rush stems were cut from the same water volume at every littoral station. Subsequently, the collected shoots were measured and weighed after drying in 80 °C to obtain the biometric parameters of the rush stands. Individuals were identified to species level using keys (Flößner, 2000; Radwan *et al.*, 2004; Rybak and Błędzki, 2010). Only Bdelloidea, Harpacticoida, *Chaoborus* and Odonata larvae were not identified to the species level.

Dominant groups in phytoplankton assemblage (*Bacillariophyceae*, *Chlorophyceae*, *Dinophyceae*) were identified using a scaled Olympus microscope in order to characterize the available food sources for zooplankton in both groups of ponds (Starmach, 1989).

Temperature, pH, conductivity and oxygen concentration were measured *in situ* and water for chemical analyses was taken from same stations. Laboratory determination of the concentration of nitrogen and phosphorus forms as well as on chlorophyll *a* concentration was conducted according to APHA (1998). In order to measure the dry mass of seston in water, samples were filtrated through glass-fibre filters. The dried filter weight was measured before and after filtration.

Data analysis

To compare species richness and the abundance of zooplankton groups between the two types of ponds: meadow versus forest ($n = 30$) and between two types of habitats: water versus rush zone ($n = 36$) the non-parametric U Mann–Whitney's test was used. The non-parametric U Mann–Whitney's test was also applied for

Table 2. Average abundance (ind.L^{-1}) and diversity (species number) in two pond types (Mann–Whitney *U* test, $P < 0.05$).

	Forest	Meadow	Meadow	M–W test 1		M–W test 2	
	Water	Water	Rushes	Z	P	Z	P
Rotifer abundance	211 ± 249	2265 ± 3169	1519 ± 1433	-4.02	0.01	–	0.5
Number of rotifer species	11 ± 5.58	13 ± 4.17	18 ± 6.98	–	0.2	-2.10	0.04
Crustacean abundance	1062 ± 186	20 ± 16	149 ± 256	3.97	0.01	-3.03	0.01
Number of crustacean species	9.8 ± 4.4	4.3 ± 2.7	9 ± 4.14	2.15	0.04	-3.48	0.01

M–W test 1 – Mann–Whitney *U* test: results concerning differences between zooplankton communities inhabiting open water (Water) of forest and meadow water bodies.

M–W test 2 – Mann–Whitney *U* test: results concerning differences between zooplankton communities inhabiting open water (Water) and rushes (Rushes) of meadow water bodies.

comparison of physicochemical parameters between the pelagic area of the two types of ponds: meadow versus forest ($n = 30$).

To study the biotic relationship between particular taxa of zooplankton and invertebrate predators as well as the morphometric features of a macrophyte habitat (stem length and mass), Spearman's Correlation Coefficient was applied.

To describe the environmental preferences of particular species, Redundancy Analysis (RDA) CANOCO 4.5 software (Lepš and Šmilauer, 2003) was applied. We used square-root data transformation and automatic selection in the procedure. The Monte Carlo Permutation Test (MCPT) of 999 permutations was used to test statistical significance. Rarely occurring species were excluded from the RDA analysis. Zooplankton species, which occurred in the examined material with at least 30% frequency, were taken into consideration. Fish presence and invertebrate predator numbers were also considered in the redundancy analysis.

Results

Environmental characteristics

The physiochemical parameters differed in relation to the type of pond surroundings. Forest ponds, shallower and of smaller area on average, were characterized by higher concentrations of ammonium ($Z = 4.62$; $P < 0.005$), TP ($Z = 2.18$; $P < 0.05$) and lower oxygen concentrations ($Z = -4.69$; $P < 0.005$) in the pelagic zone. In meadow ponds higher, pH values ($Z = -2.18$; $P < 0.05$), oxygen ($Z = -4.69$; $P < 0.005$) and nitrate concentrations ($Z = -2.09$; $P < 0.05$) were found (Table 1).

Zooplankton characteristics in the open water of forest and meadow ponds

119 zooplankton species were found in total (Rotifera – 71, Cladocera – 27, Copepoda – 20) in the ten examined ponds during the spring examination with 79 species in forest and 66 in meadow ponds, respectively.

Moreover, the mean number of species differed in relation to the type of pond surroundings. The meadow ponds were characterized by a higher diversity of rotifers and a significantly lower crustacean diversity compared to the forest ponds (Table 2).

Lecane (five species), *Keratella* (four species), *Polyarthra* (four species), *Brachionus* (three species) and *Mesocyclops* (three species) were the most diverse genera in the meadow clay-pits, while *Cephalodella* (six species), *Acanthocyclops* (six species) and *Daphnia* (five species) predominated in the forest water bodies.

Analysing the abundance distribution between both types of ponds it was found that rotifers were significantly more abundant in the meadow ponds and crustaceans prevailed in forest ponds (Table 2). Among rotifers forest ponds were characterized by the dominance of *Notholca acuminata* and bdelloids. Furthermore, crustaceans such as *Bosmina longirostris*, *Daphnia hyalina* and *Megacyclops viridis* occurred each with more than 10% of the total crustacean abundance in this set of ponds. In meadow ponds, a strong domination of rotifers was found, especially that of *Asplanchna priodonta*, *Keratella cochlearis* and *K. quadrata*, each of which contributed more than 20% to the total rotifer abundance.

Spatial differentiation between the open water and rush zone in meadow ponds

Both rotifers and crustaceans built more diverse assemblages within the zone of rushes in comparison with the open water zone within the meadow ponds (Table 2). Additionally, zooplankton abundances differed between these two types of habitat. Total abundance of crustaceans was significantly higher in rushes. Rotifers dominated in the pelagic zone, but these differences were not significant (Table 2).

Furthermore, the abundances and diversity of some rotifer (*Brachionus calyciflorus*, *Pompholyx complanata*) and cladoceran (*Acroperus harpae*, *Ceriodaphnia pulchella*, *Scapholeberis mucronata* and *Sida crystallina*) species (Table 3) correlated positively with the length (0.195 ± 0.1 m.L^{-1}) and dry mass (0.611 ± 0.3 g.L^{-1}) rush stems which overwintered in the ponds.

Relationships between environmental characteristics and zooplankton

The results of multivariate analysis and the Monte Carlo test identified the forest type of pond catchment,

Table 3. Significant Spearman correlation coefficients ($P < 0.05$) between biocoenotic features of zooplankton and environmental parameters: water temperature – °C, plant stem length – cm.L^{-1} and dry mass – g.L^{-1}. Additionally, the relation with invertebrate predator numbers (Chaoborus and Odonata larvae ind.L^{-1}).

	Temperature	Stem length	Stem dry mass	*Chaoborus* larvae	Odonata larvae
Rotifer abundance	0.6				
Number of rotifer species		0.4	0.4		
Cladoceran abundance	– 0.4				0.3
Number of cladocerans species		0.4	0.4		
Copepods abundance	– 0.5				
Number of copepods species	– 0.3				
Asplanchna priodonta	0.6	0.3			
Bdelloidea	– 0.4				
Brachionus angularis	0.5				
Brachionus calyciflorus	0.6				0.3
Keratella cochlearis	0.6				
Keratella quadrata	0.5				
Lepadella quadricarinata	– 0.4				
Notholca acuminata	– 0.7				
Pompholyx complanata	0.4	0.4	0.4		
Acroperus harpae		0.5	0.5		
Bosmina longirostris					0.3
Ceriodaphnia pulchella		0.6	0.6		
Daphnia cucullata	– 0.3	– 0.3	– 0.3	0.3	
Daphnia hyalina	– 0.3			0.4	0.3
Daphnia pulex	– 0.6	– 0.3	– 0.3	0.3	
Scapholeberis mucronata		0.3	0.3		
Sida crystallina		0.6	0.6		
Harpacticoida	– 0.3			0.3	
Megacyclops viridis	– 0.6				
Thermocycylops oithonoides	– 0.3				0.4

seston and conductivity as significant factors for the zooplankton distribution pattern (Fig. 2; Table 4).

Two groups of zooplankton species could be identified from the RDA plot. The first group, in forest ponds, relating to the higher percentage of trees in the direct catchment area and higher ammonium concentration, was formed exclusively of crustacean species (both pelagic and littoral). In the forest ponds rotifers, excluding *Notholca* (pelagic), were represented by littoral taxa (*e.g.*, bdelloids, *Lepadella quadricarinata*). The forest-associated crustaceans (representatives of *Daphnia* genus, *C. sphaericus* and copepods) also displayed a negative relationship with oxygen content, pH and morphometric features such as pond depth and size (Fig. 2). Furthermore, abundance of *L. quadricarinata*, Harpacticoida, Bdelloidea and *C. sphaericus* were positively related to total phosphorus content.

The second group, related to meadow ponds, was characterized by the dominance of pelagic rotifers of the genus *Polyarthra* and *B. calyciflorus*, which showed a positive relationship with seston content. *B. angularis* and *F. terminalis* correlated positively with chlorophyll *a*, nitrate and nitrite concentrations, while they were negatively associated with ammonium concentration. Moreover, *Spartina pectinata* was shown to have a positive relationship with water conductivity, nitrate and nitrite concentrations.

The abundance of particular zooplankton species was additionally analysed in relation to fish presence in all ponds. *Daphnia pulex* ($Z = -4.1$; $P < 0.01$), Harpacticoida ($Z = -2.8$; $P < 0.01$) and *M. viridis* ($Z = -1.9$; $P < 0.05$) were found in significantly higher abundances in fishless forest ponds. Contrary to this, both rotifer diversity ($Z = 2.8$; $P < 0.01$) and their abundance ($Z = 2.6$; $P < 0.01$) were significantly higher in meadow ponds with fish.

The invertebrate predators (*Chaoborus* and Odonata larvae) and zooplankton species abundances showed only a positive correlation, *e.g.*, the crustacean and copepod abundance increased with Odonata larvae abundance (Fig. 2; Table 3).

Discussion

The results of our study showed that despite the fact that the ten investigated small water bodies were located within the area of the Poznań agglomeration and had been exposed to urban pollution and degradation for decades, their species composition was highly diverse (119 species). We presume that this is a consequence of the occurrence of zooplankters with various life-cycles during this season, including low water temperature associated cryophilic (such as *e.g., N. acuminata*, *P. dolichoptera* and *M. viridis*),

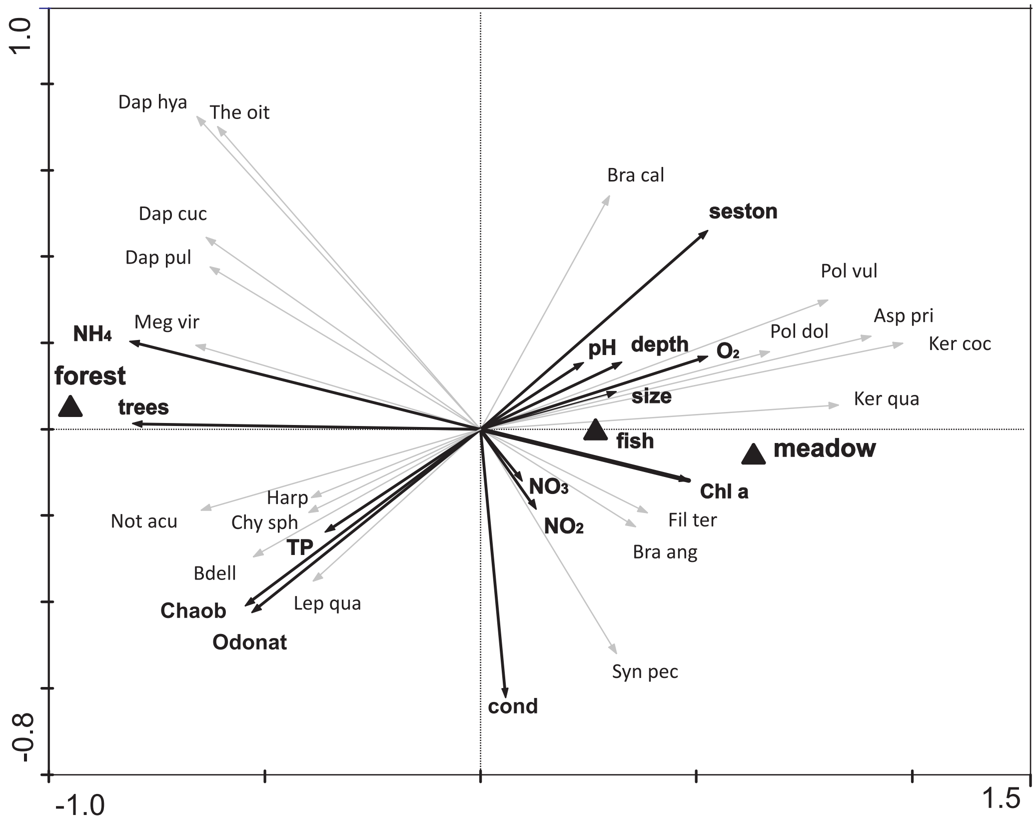

Fig. 2. RDA diagram of zooplankton abundance and environmental variables (Chl a – chlorophyll *a*, cond – conductivity, NH_4 – ammonium, NO_3 – nitrate, NO_2 – nitrite, O_2 – oxygen concentration, pH – water reactivity, TP – total phosphorus, trees – percentage of trees in the pond surroundings, size and depth – morphometric features of a pond), Chaob – *Chaoborus* sp. Larvae, Odonat – Odonata larvae, meadow and forest – pond surroundings, fish – presence. Rotifers: Asp pri – *Asplanchna priodonta* (Gosse 1850), Bdell – *Bdelloidea* (Hudson 1884), Bra ang – *Brachionus angularis* (Gosse 1851), Bra cal – *B. calyciflorus* (Pallas 1766), Fil ter – *Filinia terminalis* (Plate 1886), Ker coc – *Keratella cochlearis* (Gosse 1851), Ker qua – *K. quadrata* (Müller 1786), Lep qua – *Lepadella quadricarinata* (Stenroos 1898), Not acu – *Notholca acuminata* (Ehrenberg 1832), Pol dol – *Polyarthra dolichoptera* (Idelson 1925), Pol vul – *P. vulgaris* (Carlin 1943), Syn pec – *Synchaeta pectinata* (Ehrenberg 1832). Crustaceans: Chy sph – *Chydorus sphaericus* (O. F. Müller 1776), Dap cuc – *Daphnia cucullata* (G. O. Sars 1862), Dap hya – *D. hyalina* (Leydig 1860), Dap pul – *D. pulex* (Leydig 1860), Harpac – *Harpacticoida* (Sars 1903), Meg vir – *Megacyclops viridis* (Jurine 1820), The oit – *Thermocyclops ointhonoides* (G. O. Sars 1863).

thermophilic (*e.g., P. complanata* and *P. vulgaris*) as well as eurythermic species (*e.g., K. cochlearis* and *S. pectinata*) (Radwan *et al*., 2004). Environmental variables which are responsible for structuring zooplankton communities may be specific in the spring season when the weather conditions can be poor and few complex habitats are available for the inhabiting organisms. It was found that the most significant factor responsible for the zooplankton assemblage was the presence of surrounding forest. Therefore, a strict division of species groups into two types of ponds: forest, those with a large density of trees in the immediate surroundings and meadow, those lacking nearby trees, was confirmed.

The majority of large crustaceans, such as daphnids, were present in the open water area of forest ponds. This was possibly related to an absence of fish pressure caused by specific morphometric features (small and very shallow ponds) and unfavourable oxygen conditions. Hanazato and Yasuno (1989) and Lampert *et al*. (2010) suggested that *Daphnia* adults, which often overwinter, can build their populations faster than smaller zooplankton forms, which possibly happened in the case of the studied forest ponds. Additionally, the occurrence of some littoral species, such as *e.g., M. viridis* which is known to be well adapted for living in ponds characterized by rich organic matter and oxygen deficiencies, proves these arguments (Tinson and Laybourn-Parry, 1985; Rybak and Błędzki, 2010). In the forest ponds, a high concentration of ammonium was also observed, which is likely to have come from leaf decomposition in anaerobic conditions. Leaf litter presence can contribute to an increase in both phosphorus and nitrogen content in ponds (Sobczyński and Joniak, 2009). The litter sediments have created an additional habitat for littoral species present in forest ponds. The only pelagic rotifer which dominated in this type of pond was *N. acuminata*, which is a typical cold-stenotherm species and is known to favour lower pH levels (Radwan *et al*., 2004).

Table 4. Monte Carlo test for the significance of environmental factors in the zooplankton assemblage. Variables that appeared are marked in bold. Legend: cond – water conductivity, fish – presence/absence, size – pond area, trees – percentage of trees in pond surroundings.

	Conditional effects		
Variable	LambdaA	*P*	*F*
Forest	**0.47**	**0.001**	**7.16**
Seston	**0.18**	**0.004**	**3.45**
Cond	**0.16**	**0.005**	**5.4**
Fish	0.06	0.098	2.08
Size	0.02	0.463	1
Trees	0.05	0.105	2.46
pH	0.02	0.419	1.18
O_2	0.02	0.434	1.3
Depth	0.02	1	0

Different environmental factors structured zooplankton in the meadow ponds. Among them were factors, which either directly or indirectly affected zooplankton, *e.g.*, the quality of food or the effect of nutrient recycling (Sterner, 1989; Symons *et al.*, 2012). In the case of the studied meadow clay-pits, where algae assemblages were diverse (with a dominance of diatoms, chrysophytes or filamentous chlorophytes), only pelagic rotifers occurred. Abundance of these rotifer species positively associated with phytoplankton biomass, represented by chlorophyll *a* concentration (*B. angularis* and *F. terminalis*) and seston content in water (*Polyarthra* species and *B. calyciflorus*). Moreover, the obtained results may also be related to the food requirements of these rotifers. They are microfilterfeeders, which mainly live on detritus along with associated bacteria, however, they also often utilize algae, especially representatives of Chlorococcales, diatoms and chrysophytes (Pourriot, 1970, 1977; Ruttner-Kolisko, 1980), dominated in the meadow ponds. On the other hand *F. terminalis, A. priodonta, K. quadrata*, and *Polyarthra* spp., reach their highest densities at high oxygen concentrations (Elliott, 1977), which was found to be the case in all the meadow ponds.

The Hanazato and Yasuno (1989) as well as Warfe and Barmuta (2004) suggest that in small water bodies a various combination of both vertebrate and/or invertebrate predators lead to a high diversity of zooplankton community structure. In the investigated ponds, invertebrate predators (*Chaoborus* and Odonata larvae) seem to have no strong negative impact on structuring either the rotifer or crustacean densities in the spring season. This was confirmed by the positive relationship between the abundance of zooplankton and this group of predators. Furthermore, large crustaceans such as *D. pulex*, *M. viridis* as well as Harpacticoida prevailed in the forest clay-pits where fish predation was of much weaker impact compared to the meadow ponds. Large crustaceans can make up a favourable food source for most fish inhabiting small water bodies as observed in the examined meadow ponds during the spring season, where fish commonly occur. This is a likely explanation for the dominance of small zooplankton taxa, *i.e.*, rotifers, in this group of investigated ponds. In spring, at the beginning of the vegetation season, macrophyte consists only of the previous-year's dry shoots. According to Hansson *et al.* (2007) and Nicolle *et al.* (2010) they do not provide a very efficient refuge for zooplankton organisms as fish are able to penetrate them. It was therefore expected that zooplankton in such simple and loose remains of rush vegetation, would not fare very differently from those in the homogenic open water area. However, the results of our study indicated that despite the fact that the littoral was composed only of dry stems of architecturally uncomplicated *P. australis* significant differences in zooplankton assemblages were found between the two studied habitats. Both rotifers and crustaceans were built with more diverse assemblages within the zone of rushes. Moreover, the total abundance of crustaceans was higher in the rushes, which shows that even such a poor architectural habitat creates perfect refuge conditions for large fractions of zooplankton, which constitute a preferred food source for fish.

We found that a variety of both littoral cladocerans (*e.g., C. pulchella* and *S. crystallina*) as well as two species of pelagic rotifers (*B. calyciflorus*, *P. complanata*) were positively related to the biometric features of the helophyte stand, dry mass and rush stem length, which reflect the complexity of the plant habitat (Lucena-Moya and Duggan, 2011).

To sum up, the most important factor for the urban ponds' zooplankton community during the spring period is the reflection of the direct catchment area. The distribution of zooplankton between the two sets of ponds can be directly attributed to the type of catchment area, seston concentration and conductivity. Various factors are responsible for zooplankton occurrence in the forest ponds (*e.g.*, low concentrations of oxygen and lack of fish resulting from high concentrations of ammonium nitrogen) and meadow ponds (*e.g.*, the presence of fish and better food conditions). Furthermore, the presence of additional habitats such as dry rush shoots had an impact on the within-pond distribution pattern of rotifer and crustacean distribution in the case of meadow water bodies, creating an anti-predator refuge for larger zooplankters. We also found that taxonomic composition may be rich even though the studied ponds were susceptible to degradation through being situated within an area of high anthropogenic transformation resulting from the closely neighbouring agglomeration of the city of Poznań. The crucial factor which supported zooplankton diversity and abundance was the presence of various microhabitats in the littoral zone and a great deal of detritus, presented as leaf litter and decomposed rush.

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