Original Research

Environmental Variables of Small Mid-Field Water Bodies and the Presence of Rotifera Groups of Different Ecological Requirements

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Abstract

The aim of this study was to examine relations between the density and species richness of rotifers and environmental factors in 55 small water bodies in the Wielkopolska region. Canonical correspondence analysis (CCA) revealed that typically pelagic rotifers (species of the genera *Brachionus*, *Keratella*, or *Polyarthra*) occurred in larger and deeper reservoirs in conjunction with open water and helophytes. Their distribution was conditioned by the presence of fish, by the lack of overshading, and high concentrations of phosphorus. Littoral rotifers (*Cephalodella*, *Lecane*, or *Lepadella*) were typical of small surface and shallow ponds and of areas with a high degree of spatial complexity – elodeids. They preferred fishless water bodies with strong overshading and high transparency of water. The distribution of pelagic species was dependant on high concentrations of chlorophyll *a*, while littoral species depended on high concentrations of dissolved organic matter.

Variance partitioning extracted the type of habitat and the associated degree of habitat heterogeny as very strong predictors of rotifer distribution in mid-field reservoirs.

Keywords: zooplankton, small water bodies, littoral vs. pelagic species, agricultural catchment area

Introduction

Small water bodies play various roles in the surrounding environment. In agricultural areas they vary a sometimes monotonous landscape, which consists of a mosaic of fields, meadows, pastures, or scattered villages. Ponds are known to contribute to the increase of local retention, particularly important in the case of rural areas, which are often characterized by water shortages, which in turn may have a strong impact on the functioning of the whole freshwater ecosystem. They also have a very important ecotonal function and together with the surrounding rush and terrestrial vegetation create a biogeochemical trap. As well as serving as field buffer strips, they also create ecological corridors that are responsible for connecting wildlife populations separated by human activities or man-made structures.

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Moreover, even though ponds are usually very small and shallow ecosystems, they offer highly suitable conditions for a variety of organisms, including rare and endangered species [1-5].

The particularly complex structure of a macrophyte habitat usually possesses various and abundant communities of inhabiting organisms as it provides zooplankton with safe concealment conditions (refuge) – for planktonic animals, as well as providing access to a variety of ecological niches – for littoral zooplankton [6-8]. Varying levels of habitat heterogeneity also will be reflected in different food conditions, which may also affect the community structure of organisms. Moreover, competition between crustaceans and rotifers is often responsible for the habitat selectivity of certain species [9-11]. Therefore, it was hypothesized that two various groups of rotifers distinguished on the basis of their ecological requirements (pelagic vs. littoral) will selectively choose different habitats during the day:

1) Littoral species will preferably be associated with the most heterogenic habitat, where they find most advantageous conditions for their development due to most desirable food conditions and a variety of available ecological niches;
2) Pelagic species with morphological adaptations against predators will remain in the open water area and those without such adaptations, seeking an anti-predator refuge, will choose loose and simply-built macrophyte beds so as to avoid competition from crustaceans which, in ponds with fish predation, will remain in the littoral zone during the daytime [12].

Furthermore, physical-chemical factors may also be of a great importance when analyzing the functioning of aquatic ecosystems [13, 14], and also rotifers associated with small water bodies [15]. Besides basic physical parameters (e.g. concentration of dissolved oxygen, pH, or conductivity) the level of overshading of the water surface, which may be caused by a surrounding tree band or a thick layer of nymphaeids and pleustophytes, should also be taken into consideration when analyzing rotifer occurrence. This is why the present study was performed in order to find the distribution pattern of rotifer species representing two various ecological requirements (pelagic vs. littoral) in relation to environmental factors, including, among others, the degree of heterogeny relating to various types of habitat (the open water area, zone of elodeids, helophytes and nymphaeids), the presence of fish in a water body, the overshading of the water surface, morphometric parameters, and physical-chemical factors of water.

Material and Methods

The study was carried out on small water bodies located within the region of Wielkopolska (30,000 km^2) in west-central Poland. Ponds varied in respect to depth (from 0.1 to 4.5 m) and size (0.02 to 5 ha). They were situated in typical rural landscape, within fields and meadows or in the vicinity of rural settlements. Fifty-five small water bodies were taken into consideration. They represented three types of origin: dominating type – glacial ponds, then oxbows, and finally artificial water bodies such as clay-pits or turf excavation pits.

In total 117 various stations were examined, including 46 located within open water, 49 within elodeids (e.g. *Ceratophyllum demersum*, *C. submersum*, *Chara tomentosa*, *Elodea canadensis*, *Myriophyllum spicatum*, *Najas marina*, *Nitellopsis obtusa*, *Potamogeton lucens*, *P. pectinatus*), 19 within helophytes (e.g. *Phragmites australis*, *Typha angustifolia*, *T. latifolia*), and 3 stations within nymphaeids (e.g. *Potamogeton natans*). The presence or absence of fish was recorded from each small water body.

Research on the distribution of rotifers in various types of habitats within small water bodies was conducted during the optimum vegetative season (June-July) between 2004 and 2011. On each occasion 20 L of water were collected from sites situated in the zone of open water, while at each site located among aquatic vegetation rotifer samples accounted for 10 L.

The material was taken in triplicate at each site, then concentrated using a 45-μm plankton net and finally fixed with a 4% formalin solution. Samples from the open water area were collected in a calibrated vessel while a plexiglass core sampler (∅ 50 mm) was used for collecting samples from among macrophytes. In the case of vegetated sites subsamples of ca. 1-2 l were taken from randomly chosen places within each vegetated site to make up a 10 L sample. Oxygen saturation, conductivity, and pH were measured *in-situ*, while phosphorus (total phosphorus, phosphates), nitrogen forms (ammonium, nitrate), total hardness, and chlorophyll *a* concentration *ex-situ*. The chemical analyses were conducted according to Standard Methods (1992). Chlorophyll *a* concentration (corrected for pheopigments) was determined fluorometrically according to the procedures described by Strickland and Parsons (1972). Biometric features of each macrophyte bed referred to the length and biomass of macrophyte stems in 1 L of water.

Rotifer identification as well as dividing particular species into ecological groups was performed using appropriate identification keys [18-24]. Among littoral rotifers those typically associated with aquatic vegetation as well as benthic forms were included.

Canonical correspondence analysis (CCA) was used to identify the major relationships between rotifer species and environmental features, among which habitat type (the open water zone, elodeids, nymphaeids, and helophytes), biometric features of a plant stand (length, mass, volume), fish presence, the level of overshading (percentage of trees and surface – pleustophytes), morphometric features of small water bodies (area, depth) and physical-chemical variables (total phosphorus – TP, dissolved inorganic nitrogen – DIN, dissolved organic matter – DOM, hardness – Hard, pH, dissolved oxygen – DO, electric conductivity – EC, Secchi disc visibility – SDV, chlorophyll *a* concentration – CHL) were chosen (N=351). Statistical tests were performed using the Vegan 1.15.1 package for R statistical computing environment [25]. In addition to CCA the variance partitioning procedure was performed in order to determine the effects of significant environmental factors that were responsible for the abundant distribution of rotifers.

Only those species of rotifers that exceeded 5% of frequency in the examined material (combining all samples) were selected for statistical analysis and CCA analysis so as to avoid the effect of accidentality in the final calculations.

Results

The study, covering a total of 117 sites, carried out on 55 water bodies located in agricultural areas of the Wielkopolska region, revealed a total of 208 rotifer taxa, among which 50 were of pelagic and 158 were of littoral origins.

The ordination diagram of CCA with rotifer densities and environmental variables revealed a clear division of rotifer species in accordance with their ecological requirements. It was demonstrated that typically pelagic rotifers (including representatives of the genera *Brachionus* – e.g. *B. angularis*, *Filinia* – e.g. *F. longiseta*, *Hexarthra* – *H. mirra*, *Keratella* – e.g. *K. cochlearis*, *Polyarthra* – e.g. *P. remata*, or *Pompholyx* – e.g. *P. complanata*, *Synchaeta* – e.g. *S. pectinata*) were found in ponds that were larger and deeper. These species preferably chose the open water zone and helophytes and were also associated with the presence of fish as well as high concentrations of phosphorus in the examined water bodies. Moreover, their distribution was attributed to a lack of overshading caused by an absence of a surrounding band of trees and shrubs as well as by the layer of aquatic vegetation, referring to nymphaeids and pleustophytes. The distribution of this group of species depended on high concentrations of chlorophyll *a*. This group of rotifers also contained a large number of species indicating high trophic conditions. Species such as *Anuraeopsis fissa*, *Brachionus angularis*, *B. budapestinensis*, *B. calyciflorus*, *Filinia brachiata*, *F. longiseta*, *Keratella cochlearis* f. *tecta*, *K. quadrata*, *Pompholyx sulcata*, and *Trichocerca pusilla* (Fig. 1) were found to be gathered together.

The second group of rotifer species of a littoral nature (including representatives of the genera *Cephalodella* – *C. ventripes*, *Colurella* – *C. uncinata*, *Lecane* – e.g. *L. closterocerca*, *Lepadella* – e.g. *L. ovalis*, *Mytilina* – e.g. *M. mucronata*, *Trichocerca* – e.g. *T. weberi* or *Trichotria* – *T. pocillum*) occurred in fishless, small and shallow water bodies with high transparency of water and lower pH. They preferred elodeids and reservoirs that were characterized by a strong level of overshading. The distribution of the littoral species also was attributed to high concentrations of dissolved organic matter (Fig 1).

Data analysis with the use of variance partitioning showed that the type of habitat referring to the open water and macrophyte-dominated zones (11% of the explained variation) and the level of habitat heterogeny (12%) referring to the biometric features of a macrophyte habitat were among the strongest predictors of rotifer distribution in the case of small water bodies in the agricultural landscape.

Table 1. Variance partitioning showing the best predictors of the density of rotifer species.

Variance partitioning	Value	%
Total variance	2.309	
Explained variance	0.797	
Habitat only	0.068	2.94
Biometric parameters only	0.096	4.16
Remaining variables only	0.458	19.84
All groups together (redundant component)	0.175	7.58
Unexplained variance	1.512	65.48

Remaining variables, including physical-chemical features of water, morphometric parameters of small water bodies, the level of overshading, and the presence of fish explained 27% of the explained variation (Table 1).

Discussion of Results

The occurrence of Rotifera in small water bodies depends on a variety of environmental factors, but avoidance of predators (both invertebrate and vertebrate) and available nutritional conditions are among the most important [26-29]. Rotifers, depending on e.g. taxonomic affiliation, type of mastax or size of body, etc., can utilize different food sources. Many of them will preferably choose live nanoplanktonic algal cells, representing all taxonomic groups. However, a selectivity toward size and quality of food particles also is essential. A large number of animals also feed on dead organic particles accompanied by bacteria or protozoans [24, 30, 31]. In the case of the studied small water bodies a distinct segregation of feeding habits was observed where pelagic species were chlorophyll-dependent. Contrary to pelagic species, the growth of littoral species was positively affected by dissolved organic matter (DOM).

The only truly predacious species – *Asplanchna priodonta* – was found in reservoirs where pelagic species prevailed. This species, though it is very large and therefore vulnerable to fish predation, can remain in the open water zone of ponds due to its anti-predator adaptations. *Asplanchna*, which belongs to the group of soft sock-formed rotifers of changeable shape, in the process of evolution minimized its body coloration, becoming extremely transparent, so in the case of visual predators it can be 'unseen.'

Another feature that affected spatial distribution of particular rotifer species was the level of water surface overshading. This was caused by two different factors. The first one, the band of trees surrounding a pond, is a factor that will strongly affect especially small water bodies. The tree band around a small-surface pond will diminish the wind action, thus enabling pleustophyte cover to develop, accel-

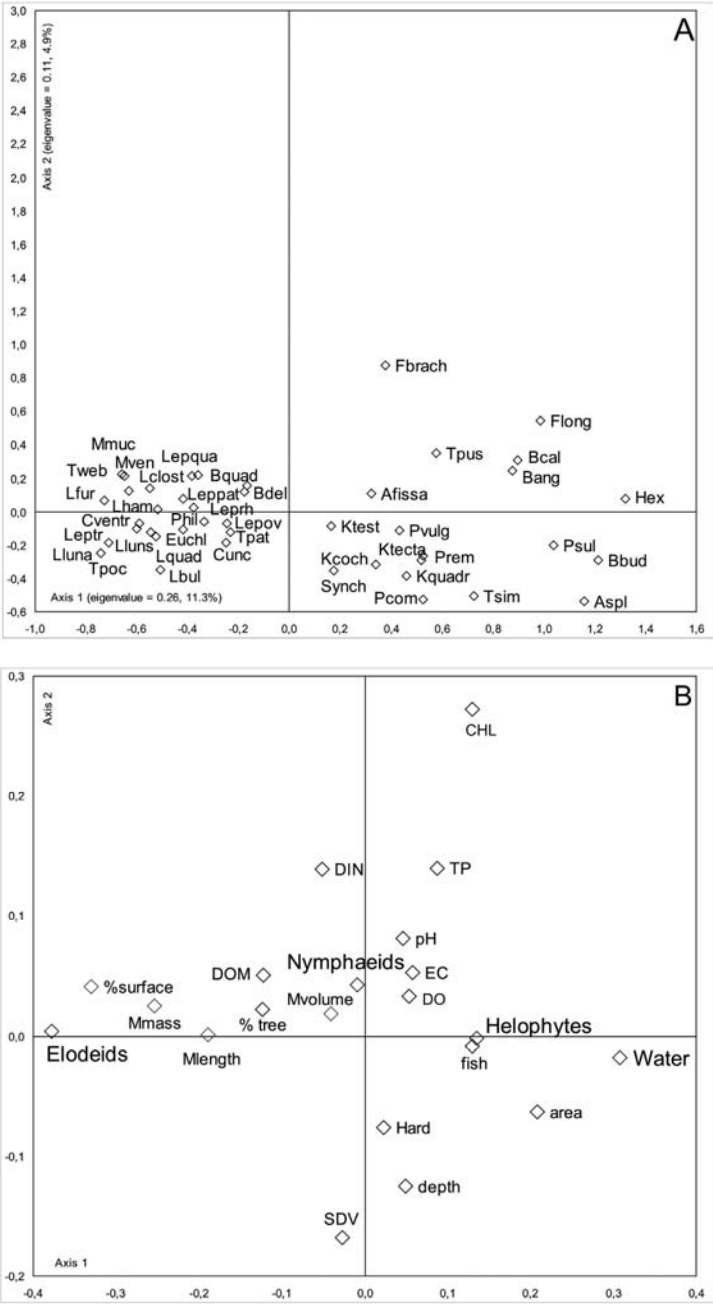

Fig. 1. Canonical correspondence analysis (CCA) of rotifer species (ind·l^{-1}) – A, and environmental parameters – B.
Habitat: the open water – water, elodeids, helophytes, and nymphaeids; biometric parameters: Mlength – macrophyte length, Mmass – macrophyte biomass, Mvolume – macrophyte volume; remaining variables: (morphometric features: area and depth; % of the surface overshaded by surrounding trees – % tree, % of the surface overshaded by pleustophytes – % surface, fish presence, water hardness – Hard, pH, conductivity – EC, dissolved oxygen – DO, total phosphorus concentration – TP, dissolved inorganic nitrogen – DIN, dissolved organic matter – DOM, chlorophyll *a* concentration – CHL, water transparency – SDV). Only species with the highest numbers are displayed.
Abbreviations of rotifer species included: Afissa – *Anuraeopsis fissa* (Gosse), Aspl – *Asplanchna priodonta* Gosse, Bdel – *Bdelloidae*, Bang – *Brachionus angularis* Gosse, Bbud – *Brachionus budapestinensis* Daday, Bcal – *Brachionus calyciflorus* Pallas, Bquad – *Brachionus quadridentatus* Hermann, Cventr – *Cephalodella ventripes* (Dixon-Nuttall), Cunc – *Colurella uncinata* (O.F. Müller), Euchl – *Euchlanis dilatata* Ehrenberg, Fbrach – *Filinia brachiata* (Rousselet), Flong – *Filinia longiseta* (Ehrenberg), Hex – *Hexarthra mira* (Hudson), Kcoch – *Keratella cochlearis* (Gosse), Ktecta – *Keratella cochlearis* f. *tecta* (Lauterborn), Kqudr – *Keratella quadrata* (O.F. Müller), Ktest – *Keratella testudo* (Ehrenberg), Lbul – *Lecane bulla* (Gosse), Lclost – *L. closterocerca* (Schmarda), Lfur – *Lecane furcata* (Murray), Lham – *Lecane hamata* (Stokes), Lluna – *Lecane luna* (O.F. Müller), Lluns – *Lecane lunaris* (Ehrenberg), Lquad – *Lecane quadridentata* (Ehrenberg), Lepov – *Lepadella ovalis* (O.F. Müller), Leppat – *Lepadella patella* (O.F. Müller), Lepqua – *Lepadella quadricarinata* (Stenroos), Leprh – *Lepadella rhomboides* (Gosse), Leptr – *Lepadella triptera* Ehrenberg, Mmuc – *Mytilina mucronata* (O.F. Müller), Mven – *Mytilina ventralis* (Ehrenberg), Pcom – *Pompholyx complanata* Gosse, Psul – *Pompholyx sulcata* Hudson, Phil – *Philodina* sp., Prem – *Polyarthra remata* (Skorikov), Pvulg – *Polyarthra vulgaris* Carlin, Synch – *Synchaeta pectinata* Ehrenberg, Tpat – *Testudinella patina* (Hermann), Tpus – *Trichocerca pusilla* (Lauterborn), Tsim – *Trichocerca similis* (Wierzejski), Tweb – *Trichocerca weberi* (Jennings), Tpoc – *Trichotria pocillum* (O.F. Müller).

erating the level of overall overshading. It was also found [32] that in small water bodies situated within the agricultural landscape of different levels of anthropogenic transformation in the near catchment area (meadows, villages, fields), concentrations of macro- and microelements were lowest in those water bodies characterized by the occurrence of a tree band around them. In such conditions rotifers of littoral origin dominated. The CCA analysis extracted small and shallow water bodies, with a high level of overshading and lack of fish in the studied reservoirs, as preferable for this ecological group of rotifers. Littoral species also selectively chose elodeids, which due to the highest level of spatial complexity, create a large number of available ecological niches, thus various species may co-occur. The type of macrophyte habitat, together with biometric features responsible for the creation of complex habitat, were very strong predictors of rotifer species distribution, accounting for 23% of rotifer variability. Moreover, taking into consideration other factors not included in the present study, it was found that littoral rotifers will build more numerous communities in ponds of low level of anthropogenic transformation in the direct catchment area [33], where larger variation and especially an abundance of elodeids, potentially occur. In these water bodies much higher water transparency also was recorded.

The second group of rotifers – pelagic species, distinguished by CCA analysis, was affected by other parameters. They preferred larger and deeper ponds with fish predation present. Moreover, high concentrations of TP, high electric conductivity, and lower water transparency were noted here. Such environmental conditions, typical for eutrophic waters, also were reflected in the occurrence of many species that are indicators of high trophy conditions [34, 35]. Pelagic species also were found to be associated with the open water area and helophytes. There were two reasons for the habitat selectivity of these rotifers. Some pelagic species (e.g. representatives of *Keratella*, *Filinia*, *Hexarthra*, *Polyarthra*, or some brachionids) are known for the evolution of anti-predator strategies, such as e.g. spine production that makes them more likely to be rejected after capture or help them to quickly escape by making rapid jumps [36]. Another reason for choosing helophytes, out of all available macrophyte-dominated habitats, may lay in the competition between rotifers and crustaceans. In water bodies with fish the larger fraction of zooplankton – cladocerans and copepods – will most often choose the heterogenic habitat – elodeids. The most complex habitat offers the best concealment conditions for cladocerans [37], hence rotifers, which are weaker competitors than crustaceans, are forced to inhabit less complex habitats such as helophyte beds during the daytime.

Conclusions

A strict division of rotifer species in relation to their ecological requirements was obtained in the CCA analysis. Different factors were responsible for pelagic and littoral species occurrence. The application of variance partitioning identified particular types of habitat: open water areas and macrophyte beds (explaining almost 11% of rotifer species variability), the degree of habitat complexity (12%), and finally the remaining parameters (27%) as very important predictors of the distribution of rotifer species in small water bodies located within an agricultural catchment area.

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