Article

Rotifers in Heated Konin Lakes—A Review of Long-Term Observations

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Abstract: The Konin lakes, heated by power stations and invaded by alien organisms, are a natural laboratory in which we can study the impact of climate change on the native communities of aquatic organisms. The aim of our study was to assess the impact of water heating and the occupation of the littoral zone of the lake by invasive species Vallisneria spiralis on changes in the species structure of rotifer communities of plankton, epiphyton and psammon. The archival material was used from the years: 1970–1975, 1978 and 1983, and compared with the results of studies conducted in Licheń and Ślesin Lakes in the years 2010–2011 and 2017–2018. It has been shown that the heating of waters of the studied lakes, combined with the shortening of their retention time, as well as the invasions of alien species, have caused significant changes in the taxonomic and trophic structure of plankton rotifers. In inhabiting Vallisneria bed epiphytic rotifer communities, the share of alien species did not increase, but relatively high densities of uncommon sessile species still persist. Psammon communities in the lakes are dominated by monogonont species relatively common in this habitat in nonheated lakes, but they are nearly devoid of bdelloids, which are abundant in psammon of Masurian lakes.

Keywords: Rotifera; plankton; epiphyton; psammon; invasive macrophyte

1. Introduction

Global warming and biological invasions are among the most important processes affecting ecosystems now and in the future [1]. The opening of new exotic trade routes, as well as the movement of people and materials across continents, and the changed use of land promote the process of globalization [2]. One of the most striking consequences of the process is the increase in the number of alien, often invasive, species [3]. Biological invasions, and so the phenomenon of “homogenization of biocoenoses”, i.e., simplifying of the structure of communities, are widely expected to be among the greatest problems in the world’s future [4]. Although the appearance of alien species often increases the diversity of flora and fauna [5,6], the process is treated as a negative phenomenon, since it might disturb the functioning of ecosystems and threaten the existence of the species particularly susceptible to such interference, especially rare and protected species. Furthermore, vice versa, the disruption of ecosystems due to human activities favors the invasion of alien species, whereas providing relatively undisturbed habitats and preventing further habitat degradation and fragmentation can effectively defend against invasions [7].
The so-called Konin Lakes have been subjected to such interference since the late 1960s, when the lakes became the collectors of waters heated by two power plants, Ślesin and Pątnów. As a result, the temperature of surface waters of the most heated Lake Licheńskie increased by approximately 5 °C [8]. The temperature increase has allowed the invasion of at least 41 thermophilic species of plants and animals to the system, of which 18 were new for fauna of Poland [9]. Among them, Vallisneria spiralis had a particularly strong impact on the functioning of the littoral zone of the Konin lakes. The species appeared in the Konin lakes in the mid-1990s [10–12] and built the submerged monospecies or strongly dominated water meadows, which made the native submerged macrophytes move to the deeper parts of the lakes [13]. Up to now, the impact of those changes on invertebrates has been unexpected. Babko et al. [14] found that despite the simple architecture of Vallisneria, Ciliata communities were relatively rich in species, thus they concluded that V. spiralis in the Konin lakes did not impoverish the ciliate diversity.

The same observations were made for rotifers [15]. The research conducted in 2004–2006 on the occurrence of rotifers among single-species beds of Vallisneria showed that the hypothesis regarding the taxonomic poverty of communities inhabiting such architecturally simple habitats in this case was untrue. During the research, 167 species of Monogononta were indicated, including 6 species new to Polish fauna [16]. However, these eurythermal or thermophilic species accounted for no more than 2% of the total density of Rotifera. The comparison of rotifer communities inhabiting both single species Vallisneria beds, as well as multispecies groups of native aquatic vegetation, showed that these two habitats are inhabited by communities of Rotifera similar in regard to their taxonomic richness. The average number of species of Rotifera met at Vallisneria was similar to that quoted earlier in the mixed macrophyte assemblages from lakes of different morphometry and trophy [15]. Thus, it has been shown that invasive species can create habitats easily colonized by native species.

According to Shurin [17], natural communities of organisms are completely filled with species, thus, biotic interactions exclude potentially invasive species from such communities. Perhaps this explains why, although present among Vallisneria, the alien species of rotifers did not dominate the community of Rotifera [16]. It remains, however, to be clarified whether the heating of water was not a disturbing factor for natural zooplankton communities. The Konin lakes, being subjected to various types of human pressure (including water heating, fisheries and tourism) have become a natural laboratory where we can study the impact of these most dangerous (now and in the future) phenomena on the natural and alien communities of aquatic organisms. It is believed that global warming will allow the invasion of thermophilic species, including those which have not yet found favorable conditions for their development in Polish waters.

Macrophytes provide both a habitat and a refuge for littoral zooplankton [18]. However, the presence of macroinvertebrate predators may turn macrophytes into areas risky for zooplankton [19]. The question is: how does the change of native macrophytes to become invasive influence the structure of rotifer communities?

Diversity, density and production rate of rotifer species may indicate changes in ecosystem productivity [20]. Rotifers respond very quickly to environmental alterations caused by rapid changes in the structure of their communities. Therefore, tracking the variation in this community can also clearly illustrate changes that affect the entire ecosystem. According to Bonecker et al. [21], the diversity of rotifers is more affected than of the other groups of zooplankton, and as such, they may constitute a useful indicator for monitoring programs.

The general objective of this research was to assess the impact of water heating and the occupation of the littoral zone of the lake by the invasive macrophyte Vallisneria spiralis on changes in the species structure of rotifer communities of plankton, epiphyton, and psammon. We test the following hypotheses:

**Hypothesis 1 (H1).** The heating of waters of the studied lakes, combined with the shortening of their retention time, have caused significant and long lasting changes in the abundance, production and taxonomic and trophic structure of the lakes' rotifer fauna.
Hypothesis 2 (H2). The invasion by *Vallisneria spiralis* is accompanied by the appearance of alien species in rotifer communities of plankton, periphyton, and psammon, which changes the species structure of rotifer communities.

2. Materials and Methods

2.1. Study Sites

The Konin lakes’ system (Wielkopolsko-Kujawskie lake district) consists of five lakes connected by two different circulation circuits used to cool the heated waters discharged from two power plants. The shorter circulation circuit, used in winter, is created by lakes Gosławskie, Pątnowskie, Licheński and the southern part of Lake Mikorzyńskie (Figure 1). The longer circulation circuit operates during the summer season and includes Lake Ślesińskie and the northern part of Lake Wąsowsko-Mikorzyńskie. This closed cooling system increases the mean annual surface water temperature in Lake Licheński by about 5 °C, and in Lake Ślesiński by about 3 °C [8].

**Figure 1.** Scheme of the cooling system of the Konin Lakes. Explanation: colours mark intake to (blue) and discharge from (green) power stations.

Lakes Licheński and Pątnowskie (Table 1) have been connected to the cooling system since 1958 and were the primary recipients of the heated waters [22]. Both Lake Licheński and Mikorzyński receive heated waters from two power plants (Konin and Pątnów PP) year round. Lake Ślesiński has been connected to the cooling system in 1970 and is used to increase the effectiveness of the system from May to September, i.e., during the warmest period [23]. Lake Gosławskie is included in the cooling cycle of power plant Pątnów, which has been functioning since 1969 in full operation. The whole lake is heated, and its average temperature is 3–5 °C higher than natural temperatures (Table 2).
Our work is based on the results of extensive research conducted from 1970 to 2017. Some of the data have been already published in numerous papers, e.g., [25–27]. Summer temperatures were measured monthly from 1965 to 2018.

In summer, among the studied lakes, Lake Licheński had the highest water temperature in the epilimnion, which significantly differed from the remaining lakes—its average temperature in 1965–2018 was 26.3 °C. In the least heated lake, Lake Ślesiński, the long-term average was 3.4 °C lower, while in the remaining three lakes it was by 1.0–1.6 °C higher than in Lake Ślesiński (Figure 2). However, the water temperature in particular lakes considerably varied. The lowest temperatures when unheated were in Lake Ślesiński in 1965–1969 (20.8 °C). Outliers were noted in two lakes, i.e., those located above and below the first and third quartiles. One outlier was identified in Lake Ślesiński, and two in Lake Mikorzyński (Figure 2).

### 2.2. Sampling and Laboratory Methods

Our work is based on the results of extensive research conducted from 1970 to 2017. Some of the data have been already published in numerous papers, e.g., [25–27]. Summer temperatures were measured monthly from 1965 to 2018.

In all cases, the same sampling methods used were adapted to the habitat from which they were taken. Pelagic zooplankton was collected with a 5-litre sampler at 1-metre intervals, and was pooled.
together and separately for epi-, meta- and hypo-limnion. The samples were condensed by filtering them through a 50-μm mesh net, and fixed immediately with Lugol’s solution, and then (in a laboratory) in 2% formalin.

Figure 2. Comparison of water temperature in the epilimnion of the Konin lakes in the summer (1965–2018).

Littoral zooplankton was sampled from open water sites among macrophytes with a 1-litre sampler concentrated on a 30-μm mesh net. Sessile and epiphytic rotifers were collected together with their plant substratum by submerging a 1-litre glass in a weedy station and arranging a few aquatic plants (or their fragments) loosely in it. Fragments of leaves were examined under the microscope. The plant material was then dried and weighed. The remaining fragments of macrophytes were fixed with 2% formalin and washed on a plankton net of 30-μm mesh size. Animals collected on the net were transferred into bottles and counted.

To sample psammon, a 2-cm thick sand layer was cut out by means of a sharp-edged cylinder with an area of 28 cm² from three zones: hydroarenal (submerged sand), hygroarenal (sand wetted by lake waves), and euarenal (emergent sand). The samples were transferred to glass containers and rinsed 6 times with tap water. After sedimentation of sand grains (ca. 10 s), supernatant water was filtered through a 30 μm mesh-size plankton net. All rotifers were identified and counted.

Biomass of rotifers was established following Ejsmont-Karabin [28]. The production of rotifer communities was established from the number of eggs counted in samples collected every three days from 21 July to 31 July 2010. A curvilinear logarithmic generalized relationship between the rate of egg development and temperature [29] was used.

Species structures of psammon communities of Rotifera from the Konin lakes were compared with those from lakes of northeastern Poland [30] using the index of percentage similarity of community (PSC) [31]: PSC = 100–0.5 \( \sum (a-b) = \sum \min (a, b) \), where \( a \) and \( b \) are percentages of individuals of each species in total numbers of the communities of lakes A and B, compared in pairs. The index takes into account the quantitative relations between different pairs of species.

An estimate of total species richness—the bias-corrected Chao2 [32–34], which calculates the estimated true species diversity of a sample—was also applied as to find out the possibly closest amount of species that can be identified from Vallisneria beds in Lake Licheński and L. Ślesiński.

Statistical analyses were conducted with the application of STATISTICA version 9.0 (StatSoft Inc 2009, Tulsa, OK, USA). They included regression analyses, which were performed to determine whether the number of rotifer species was related to the number of samples analyzed. Probability levels ≤0.05 were considered significant. Basic descriptive statistics were presented as boxplots (Figure 2). The lower and upper limits of the boxes are the first and third quartiles, respectively. The
crosses correspond to the means. Points above or below are outliers and the min and max are represented by whiskers. Analysis of variance (ANOVA) and post hoc Tukey’s test were used in order to identify water temperature differences in the Konin lakes. For the classification of average five-year water temperatures in epilimnion, the algorithm of Macnaughton-Smith was used to improve the variance criterion [35]. Redundancy analysis (RDA) (CANOCO soft. version 4.52, Biometris, Wageningen, The Netherlands [36,37]) was performed to find the relations of density of dominant species of Rotifera in Lakes Licheńskie and Ślesińskie with temperature in summer 1970–2011. Species data were log-transformed. Species richness of the rotifer species in waters of different temperatures was determined by the rarefaction species richness in package vegan (R) [38], based on data from Lakes Licheńskie and Ślesińskie for the years 1970–2010.

3. Results and Discussion

3.1. Plankton Communities of Rotifera

3.1.1. Long-Term Changes in Abundance of Plankton Communities of Rotifera

The extensive research on rotifer fauna conducted in the years 1970–1974 covered all five lakes (Figure 3). Later on, the study was carried out on several occasions on only two lakes, L. Licheńskie and L. Ślesińskie. The general observation is, that rotifer abundance, i.e., the pattern which may indicate trophic status of the lakes [39], remains on a level close to that observed in the 1970s and is typical for meso-eutrophy or low eutrophy. Pyka et al. [40] studying changes in Lakes Licheńskie and Ślesińskie, have shown that the short retention time of waters restricted phytoplankton blooms, thus, phosphorus precipitation on calcite prevented eutrophication of the lakes. As a result, both lakes seemed to maintain meso-eutrophic status. Similar and low density of rotifers in Lakes Licheńskie and Ślesińskie was also observed in summer 1999 [41]. Similarly, 13-year studies of power plant lakes situated in the midwestern US [42] showed that rotifer zooplankton were less abundant in treatment lakes.

![Figure 3. Results of long-term extensive observations of rotifer density in water column in the Konin lakes. Data for 1999 are derived from [41]. Grey lines indicate gaps in research for the years 1985–1998 and 2000–2009.](image)
An impact of the heating of waters on seasonal changes in rotifer abundance was studied in one of the Konin lakes—Lake Gosławskie [27]. It was shown that higher temperatures caused small seasonal variation in rotifer abundance, which was relatively low when compared to similar morphologically, but not heated lakes.

3.1.2. Long-Term Changes in Species Structure of Plankton Communities of Rotifera

The studies conducted in Lake Licheńskie and Lake Ślesińskie in 2010–2011 and compared with results of earlier research, revealed some changes in occurrence of rotifer species, common in both the lakes (Figure 4). Although Keratella cochlearis and Pompholyx sulcata remained most abundant, the communities were enriched with Polyarthra species (P. vulgaris and P. remata). It slightly changed the importance of the role of herbivorous species of Rotifera in the food web. At the same time, some species disappeared. These were Trichocerca porcellus, Trichocerca pusilla and Brachionus angularis. Filinia terminalis, a species typical for cold waters and occurring in meta- and hypolimnion of both studied lakes in the years 1970–1974, was absent in the layers in the years 2010–2011.

![Figure 4. The percentage of dominant rotifer species in the total rotifer density in water column in Lake Licheńska and Lake Ślesińska in summer.](image)

In general, an input of energy to ecosystems increases species diversity [43], which was confirmed for Norwegian lakes [44]. Nevertheless, the authors pointed out that lake-specific properties such as catchment influence, lake productivity, food-web structure, immigration and some stochastic events may disguise the effect of temperature.

In Hillbricht-Ilkowska et al. [26], studies it has been suggested that changes in zooplankton structure were determined by abiotic factors like temperature and water movements rather than by biotic ones. The change in abiotic factors may have a serious impact on seasonality of rotifer occurrence and their spatial distribution (especially in colder part of the season) if warm stenotherms and eurytherms appear earlier and mostly close to inflows of heated waters, such as in the case of Lake Mälaren [45]. Part of the research data achieved for the years 1970–1973 was compared by Hillbricht-Ilkowska et al. [25] with data from 1966. The comparison indicated serious differences in rotifer domination in Lake Licheńska and Mikorzyńska. Pompholyx sulcata, which was absent in 1966, was abundant in 1973. At the same time, some species (i.e., Anuraeopsis fissa, Ascomorpha ovalis, Asplanchna priodonta) disappeared from plankton of the lakes, whereas density of Keratella cochlearis decreased several dozen times.

However, should we expect serious impact of temperature on species structure of pelagic rotifers taking into account that, in general, most rotifers have a very wide tolerance range [46]? It seems that the most serious changes in rotifer communities happened between 1966 and 1973 [25]. Later on, even if studies conducted in Lake Licheńska and Lake Ślesińska in 2010–2011 revealed some changes in
occurrence of rotifer species, common for both the lakes (Figure 4), dominants like Keratella cochlearis and Pompholyx sulcata remained most abundant.

The results of the redundancy analysis (significance confirmed by Monte Carlo permutation test for the significance test, F-ratio = 3.195; p-value = 0.0100; number of permutation—499) seem to confirm the thesis on the dependence of at least some of the species dominating in summer on the temperature in Lake Licheńskie and L. Ślesińskie (Figure 5). The first two canonical axes explain 53% (axis 1—16.6% and axis 2—36.4%) of total variability in the Rotifera data. Syncheta kitina, Brachionus angularis, Trichocerca pusilla, Pompholyx sulcata and Keratella cochlearis show a clear negative correlation with summer temperature. Filinia terminalis, Brachionus calyciflorus, Trichocerca porcellus and two species of the genus Polyarthra do not react or react positively to temperature rise. However, some of these relationships may depend on water temperature indirectly through changes in water chemistry and, as a result, the abundance of bacterio- and phyto-plankton. This may concern species such as Pompholyx sulcata, which is very common in meso-eutrophic and eutrophic nonheated lakes in summer and is probably warm-stenothermic.

![Figure 5. The redundancy analysis (RDA) map of major group of dominant rotifers and temperature mean for summer—ToC-Summ. Labels of rotifer species: K. quadra—Keratella quadrata; K. cochle—K. cochlearis; T. pusill—Trichocerca pusilla; T. porcel—T. porcellus; S.kitina—Synchaeta kitina; F. termin—Filinia terminalis; P. sulcat—Pompholyx sulcata; B. calyci—Brachionus calyciflorus; B. angula—B. angularis; P. remata—Polyarthra remata; P. vulgar—P. vulgaris.](image)

The heating of waters may drastically change seasonal succession in rotifer communities, as it has been shown in Lake Gosławskie [27]. The observed absence of seasonal succession and disappearance of cold-water species from spring community of Rotifera were attributed mostly to higher temperatures. The disappearance of Filinia terminalis from hypolimnion, probably resulting from higher temperatures, may be phenomenon of the same kind.

3.1.3. Long-Term Changes in Productivity of Plankton Communities of Rotifera

In the two heated lakes (Table 3) the mean summer daily production to biomass coefficients (P:B) increased in 1983 for both nonpredatory and predatory rotifers when compared to the values from 1966 and 1973. In 2010 P:B values for nonpredatory rotifers remained at a relatively high level (but lower than in 1983), however, predatory rotifers (mostly Asplanchna priodonta) disappeared from the community. In 2010 the mean production of the rotifer community was 0.043 mg WW L⁻¹ 24 h⁻¹ in Lake Licheńskie and markedly higher, 0.060 mg WW L⁻¹ 24 h⁻¹, in Lake Ślesińskie. The main source
of energy for the production was in both lakes detritus with bacteria, because rotifer community was dominated by detritivorous species, *Keratella cochlearis* and *Pompholyx sulcata* (Figure 4).

Among the results of thermal-stressing of ecosystems, there are shown changes in zooplankton composition that favor small-bodied over large-bodied species [47,48]. This shift in zooplankton body size may have a strong impact on the community metabolic rates [49], and so, zooplankton production. Rotifers, similarly to other ectotherms, achieve smaller size at maturity at higher temperature through phenotypic plasticity [50], which is described as temperature-size-rule [51]. Because generation times of ectotherms generally increase with body size, and decrease with increasing temperature for a given body size [52], we may expect that rotifer production should be higher in heated-lakes. Thus, the observed changes in the P:B coefficient (Table 3) were in accordance with the expectations. Earlier studies [53] have shown that production rate of phytoplankton in continually heated and mixed lakes is high despite a low biomass of small algae. Fecundity (and production) of rotifers dominated by small species depends to a larger extent on detritus and bacteria. It seems that those previously observed trends were also valid for the years 2010–2011.

Table 3. Mean summer daily P:B coefficient (daily production to biomass in units of wet weight) for nonpredatory and predatory rotifers in the Konin lakes in different years of study. Data for 1966 are derived from [54], for 1973 according to [25], and for 1978 and 1983 according to [54]. LP—lack of predatory rotifers.

| Years | Lake Licheńskie | Lake Ślesińskie |
|-------|-----------------|-----------------|
|       | Nonpredatory    | Predatory       | Non-Predatory | Predatory |
| 1966  | 0.29            | 0.15            | 0.41          | 0.73      |
| 1973  | 0.39            | LP              | 0.36          | 1.07      |
| 1978  | 0.54            | LP              | 0.87          | 1.75      |
| 1983  | 0.89            | 1.92            | 0.70          | LP        |
| 2010  | 0.66            | LP              | 0.70          | LP        |

3.2. Epiphytic Communities of Rotifera Accompanying Invasion of *Vallisneria spiralis* L.

*Vallisneria spiralis*, a plant commonly kept in aquaria, was probably introduced into the Konin lakes from this source. A role of aquaria in the establishment of different plants and animals (also rotifers) has been documented by Duggan [55]. The invasion of the littoral zone of the heated Konin lakes by this alien macrophyte of a very simple architecture was expected to reduce habitat quality for rotifer fauna, because submerged macrophytes with more complex architecture are known to create richer food resources and higher habitat diversity than plants of simple architecture [56–59]. The replacement of native macrophytes by an invasive one, even if its architecture is similar, may have an indirect effect on aquatic food webs. This has been shown for macroinvertebrate communities inhabiting milfoils (*Myriophyllum*) in eastern North America [60]. The invasion of the littoral zone of Lake Wanaka (New Zealand) by two macrophyte species creating dense beds caused more significant changes in lake productivity, species composition, and food-web dynamics [61].

A full list of rotifer species recorded from *Vallisneria* beds in 2004–2005 contained 141 species (Chao number = 165) in Lake Licheńskie and 94 (after Chao nonparametric estimator = 163) in Lake Ślesińskie. Among Monogononta prevailed the species of the genera *Lecane* (23 species with *L. arcula*, *L. bulla*, *L. closterocerca*, *L. hamata* being the most abundant) and *Trichocerca* (18 species with *T. porcellus*, *T. rattus* and *T. bidens* dominating). This habitat was characterized by the presence of species new to fauna of Poland, i.e., *Asplanchnopus hyalinus* Harring, *Beauchampia crucigera* (Dutrochet), *Lecane inopinata* (Harring and Myers), *Lecane shieli* (Segers and Sanoamuang), *Lecane undulata* (Hauer) and *Lepadella apsida* (Harring) [16].

The epiphyton of the three Konin lakes was strongly dominated by bdelloids (Figure 6), which were most abundant in summer in Lake Mikorzyńskie. Sessile species on *Vallisneria* from single-species beds contributed 0.4% to the total rotifer density in Lake Ślesińskie and up to 26.5% in Lake Licheńskie. Thus, they were markedly more abundant in the warmer lake, Lake Licheńskie (Figure 6). Similarly, thermal pollution of the river Loire resulted in very high densities of thermophyle and
sessile rotifer *Sinantherina socialis* [62]. However, although present in the Konin lakes, *S. socialis* was less abundant there than the two species of the genus *Limnias* (*L. melicerta* and *L. ceratophyllum*) (Figure 7). The community of sessile Rotifera was relatively rich in species and contained as many as 12 species.

**Figure 6.** Density of three taxonomic and functional groups of Rotifera epiphytic on *Vallisneria* in the three Konin lakes in the years 2004 and 2005.

**Figure 7.** Percentage share of different species in the community of sessile Rotifera epiphytic on *Vallisneria* in the three Konin lakes.

In Lake Licheński, the mean rotifer densities in both studied years were relatively unchanged (Table 4). There were, however, marked differences between the stations. In the year 2005, epiphytic communities were similarly abundant at all stations, whereas in 2017, we observed a 4-fold difference between the highest (st. 1) and the lowest (st. 2) values.

**Table 4.** Quantitative and qualitative characteristics of epiphytic rotifer communities in Lakes Licheński and Ślesiński in the years 2005 and 2017 (mean ± SD).

| Year       | Lake Licheński | Lake Ślesiński |
|------------|----------------|----------------|
|            | 2005           | 2017           | 2005        | 2017       |
| Mean rotifer density (ind. gDW⁻¹) | 2411 ± 295     | 2612 ± 1676    | 631 ± 659   | 134 ± 74   |
| Mean number of species       | 18 ± 8         | 40 ± 6         | 20 ± 5      | 17 ± 6     |
| Shannon’s diversity index   | 1.44 ± 0.74    | 2.62 ± 0.35    | 2.53 ± 0.14 | 2.29 ± 0.29 |
| Dominant species             | *Cupelopagis vorax*   | *Limnias ceratophyllum* | *Colurella adriatica* | *Euchlanis dilatata* |

In Lake Ślesiński rotifer densities decreased, but there were large, nearly 5-fold, differences between the stations in 2005. In 2017 the difference between the studied two stations was 2-fold and rotifer densities were relatively low (Table 4).

In Lake Licheński the number of rotifer species increased nearly twice, i.e., from 9–23 species in 2005 to 34–45 in 2017. Consequently, the species diversity also increased from 0.86–2.31 in 2005 to
2.36–3.04 in 2017. We also noted the differences in domination of epiphytic species. In 2005 a predatory and large species, *Cupelopagis vorax* (55% of total rotifer density), dominated, whereas in 2017 a sessile *Limnias ceratophyllum* accounted for 19% of rotifer numbers.

In Lake Ślesińskie, the number of species slightly decreased and the dominating species also changed. In both years these were free-flowing littoral species, i.e., *Colurella adriatica* (25% of mean rotifer density in 2005) and *Euchlanis dilatata* (39% in 2017) (Table 4).

### 3.3. Psammon Communities of Rotifera in the Konin Lakes

The rotifer communities in all three lakes and arenal zones were dominated by species of the genus *Lecane*, but there were differences in particular species domination. In Lakes Licheńskie and Ślesińskie, a psammon community was most abundant in the higroarenal zone (Figure 8). In Lake Licheńskie, the community was dominated by *Lecane bulla*, whereas in Lake Ślesińskie, *Lecane closterocerca* dominated. In Lake Gosławskie, the highest abundance of psammon rotifers was noted in the hydroarenal zone, and the community was dominated by a relatively large species—*Lecane luna*. Very low density was observed in the euarenal zone, and it was markedly lower than in the remaining arenal zones in all three lakes (Figure 8). The species structure of psammon communities was to some extent similar to that observed in Masurian Lakes, however, with an exception of psammon in Lake Licheńskie (Figure 9). The rotifer communities in all three arenal zones of the lake were the least similar to the mean values observed in Masurian Lakes. The highest percentage similarity was observed in all arenal zones of Lake Ślesińskie, i.e., the lake less heated than the remaining ones.

![Figure 8. Densities (ind. 100 cm^-2) of rotifer species dominating in psammon communities in three zones of lake arenal in the Konin lakes.](image)

### 3.4. Biodiversity of Rotifer Fauna

The appearance of alien species may both increase [5,6] and decrease [63,64] diversity of flora and fauna, since it might disturb the functioning of ecosystems and threaten the existence of the native species. To compare species richness of rotifer communities from the Konin lakes with those from the lakes in northeastern Poland, we used data published by Ejsmont-Karabin [65].
The number of species recorded in the pelagic zone of the three heated Konin lakes is close to the average of nonheated lakes (Figure 10). Species richness of Rotifera in open waters seems to be, as a rule, much lower and rather limited when compared to littoral and psammon habitats [34]. On the contrary, the rotifer species inhabiting macrophytes were much more numerous in the three studied Konin lakes than in nonheated lakes, and the difference increased with the increasing number of samples analyzed (Figure 10). These results seem to contradict those given in the literature [66,67], which show that there is a positive relationship between species diversity and a level of complexity of macrophyte architecture versus species richness of invertebrates inhabiting the macrophytes. However, in the Konin lakes, single species or macrophyte beds dominated by one species (Vallisneria spiralis) are the habitat of a much larger number of Rotifera species than species-rich natural macrophyte assemblages. An explanation may be the significant abundance of periphyton on Vallisneria (A. Hutorowicz—personal information).

**Figure 9.** Percentage of psammon communities (PSC) of Rotifera from the 3 Konin Lakes compared to mean values calculated for rotifers from 17 Masurian Lakes (after [30]).

**Figure 10.** Numbers of rotifer species in the three habitats of Konin lakes compared to different lakes in northeastern Poland and their relation to the number of analyzed samples; p-value in all cases < 0.0001. Black circles show number of species found in the studied Konin Lakes; open circles and regression lines - data for the remaining lakes. Explanations: 1 - Lake Gosławskie; 2 - Lake Licheriskie; 3 - Lake Ślesiński.
The psammon communities of Rotifera in the Konin lakes seem to be richer in species than those in nonheated lakes (Figure 10). However, the result of the comparison may involve an error due to the relatively low number of observations.

4. Conclusions

The heating of pelagic waters of the studied lakes, combined with the shortening of their retention time, have not caused significant and long-lasting changes in the abundance of Rotifera, although the production to biomass coefficient increased twice since 1966.

The taxonomic and trophic structure of the lakes’ rotifer fauna changed during 45 years of observations. Although most of rotifer species met at the beginning of the research remained, the abundance of algivorous species of the genus Polyarthra seems to have increased recently. Changes in water temperature may have an impact on some species dominating in the Konin lakes, however, it is not certain whether this is a direct relationship.

The invasion by Vallisneria spiralis was accompanied by the appearance of alien species in rotifer communities of periphyton which subsequently changed their species structure. Such appearance of alien species was not observed in plankton and psammon Rotifera.

The species richness of rotifer fauna in the Konin lakes remains at a level similar to that of nonheated lakes in regard to plankton, and it seems to be markedly higher when it comes to psammon and epiphyton communities.

The results of our initial research on the impact of climate change (temperature rise and invasion of an alien species) on Rotifera from the three lake habitats show that communities inhabiting these habitats may differ in their response to the changes. Therefore, further research should include not only pelagic organisms, but also those inhabiting littoral microhabitats, i.e., epiphyton, psammon, and not yet studied epizoon.

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References

1. Walther, G.-R.; Roques, A.; Hulme, P.E.; Sykes, M.T.; Pyšek, P.; Kühn, I.; Zobel, M.; Bacher, S.; Botta-Dukát, Z.; Bugmann, H.; et al. Alien species in a warmer world: Risks and opportunities. Trends Ecol. Evol. 2009, 24, 686–693, doi:10.1016/j.tree.2009.06.008.
2. Mayfroidt, P.; Flamin, E.F.; Erb, K.-H.; Hertel, T.W. Globalization of land use: Distant drivers of land change and geographic displacement of land use. Curr. Opin. Env. Sust. 2013, 5, 438–444, doi:10.1016/j.cosust.2013.04.003.
3. Hulme, P.E. Trade, transport and trouble: Managing invasive species pathways in an era of globalization. J. Appl. Ecol. 2009, 46, 10–18, doi:10.1111/j.1365-2664.2008.01600.x.
4. Sutherland, W.J.; Bailey, M.J.; Bainbridge, I.P.; Brereton, T.; Dick, J.T.A.; Drewitt, J.; Dulvy, N.K.; Dusic, N.R.; Freckleton, R.P.; Gaston, K.J.; et al. Future novel threats and opportunities facing UK biodiversity identified by horizon scanning. J. Appl. Ecol. 2008, 45, 821–833, doi:10.1111/j.1365-2664.2008.01474.x.
5. Rosenzweig, M.L. The four questions: What does the introduction of exotic species do to diversity? Evol. Ecol. Res. 2001, 3, 361–367.
6. Strayer, D.L. Alien species in fresh waters: Ecological effects, interactions with other stressors, and prospects for the future. *Freshw. Biol.* 2010, 55, 152–174, doi:10.1111/j.1365-2427.2009.02380.x.

7. Marvier, M.; Kareiva, P.; Neubert, M.G. Habitat destruction, fragmentation, and disturbance promote invasion by habitat generalists in a multispecies metapopulation. *Risk Anal.* 2004, 24, 869–878, doi:10.1111/j.0272-4332.2004.00485.x.

8. Socha, D.; Zdanowski, B. *Ekosystemy Wodne Okolice Konina*; Biblioteka Monitoringu Środowiska: Poznań, Poland, 2001; pp. 1–72.

9. Najberek, K.; Solarz, W. Jeziora konińskie jako ognisko inwazji gatunków obcych w Polsce. In *Gatunki Obce w Faunie Polski*; Głowacinski, Z., Okarma, H., Pawłowski, J., Solarz, W., Eds.; Instytut Ochrony Przyrody PAN: Kraków, Poland, 2011; pp. 614–623.

10. Gąbka, M. *Vallisneria spiralis* (Hydrocharitaceae)—Nowy gatunek we florze Polski. *Fragm. Florist. Geobot. Pol.* 2002, 9, 67–73.

11. Hutorowicz, A.; Dziedzic, J.; Kapusta, A. Nowe stanowiska *Vallisneria spiralis* (Hydrocharitaceae) w jeziorach konińskich (Pojezierze Kujawskie). *Fragm. Florist. Geobot. Pol.* 2006, 13, 89–94.

12. Protasov, A.A.; Afanasiev, S.A.; Sinicyna, O.O.; Zdanowski, B. Composition and functioning of benthic communities. *Fish. Aquat. Life* 1994, 2, 257–284.

13. Hutorowicz, A. *Vallisneria spiralis* in lakes in the vicinity of Konin (Pojezierze Kujawskie). *Biodivers. Res. Conserv.* 2006, 1, 154–158.

14. Babko, R.; Fyda, J.; Kuzmina, T.; Hutorowicz, A. Ciliates on the macrophytes in industrially heated lakes (Kujawy Lakeland, Poland). *Vest. Zool.* 2010, 44, e1–e11.

15. Ejsmont-Karabin, J.; Hutorowicz, A. Rotifera communities associated with invasive *Vallisneria spiralis* L. (Hydrocharitaceae) versus native macrophytes in the lakes heated by power stations (Konin Lakes, W. Poland). *Pol. J. Ecol.* 2011, 59, 569–576.

16. Ejsmont-Karabin, J. Does invasion of *Vallisneria spiralis* L. promote appearance of rare and new rotifer (Rotifera) species in littoral of the lakes heated by power station (Konin Lakes, W. Poland). *Pol. J. Ecol.* 2011, 59, 201–207.

17. Shurin, J.B. Dispersal limitation, invasion resistance, and the structure of pond zooplankton communities. *Ecology* 2000, 81, 3074–3086, doi:10.1890/0012-9658(2000)081[3074:DLIRAT]2.0.CO;2.

18. Montiel-Martinez, A.; Ciroz-Perez, J.C.; Corkidi, G. Littoral zooplankton-water hyacinth interactions: Habitat or refuge? *Hydrobiologia* 2015, 755, 173–182, doi:10.1007/s10750-015-2231-7.

19. Sagrario, G.; de los Angeles, M.; Balseiro, E.; Ituarte, R.; Spivak, E. Macrophytes as refuge or risky area for zooplankton: A balance set by littoral predaceous macroinvertebrates. *Freshw. Biol.* 2009, 54, 1042–1053, doi:10.1111/j.1365-2427.2008.02152.x.

20. Špoljar, M. Microaquatic communities as indicators of environmental changes in lake ecosystems. *J. Eng. Res.* 2013, 1, 29–42.

21. Bonecker, C.C.; Simões, N.R.; Minte-Vera, C.V.; Lansac-Tôha, F.A.; Velho, L.F.M.; Agostinho, A.A. Temporal changes in zooplankton species diversity in response to environmental changes in an alluvial valley. *Limnologica* 2013, 43, 114–121, doi:10.1016/j.limno.2012.07.007.

22. Staweecki, K.; Zdanowski, B.; Pyka, J.P. Long-term changes in post-cooling water loads from power plants and thermal and oxygen conditions in stratified lakes. *Arch. Pol. Fish.* 2013, 21, 331–342, doi:10.2478/apfp-2013-0034.

23. Staweecki, K.; Pyka, J.P.; Zdanowski, B. The thermal and oxygen relationship and water dynamics of the surface water layer in the Konin heated lakes ecosystem. *Arch. Pol. Fish.* 2007, 15, 247–258.

24. Brodzińska, B.; Jańczak, J.; Kowalik, A.; Szija, R. *Atlas Zajezor Polski*; Jańczak, J., Ed.; Instytut Meteorologii i Gospodarki Wodnej: Wydawnictwo Naukowe, S.C., Poznań, 1999, Volume 3, pp. 1–268 (in Polish).

25. Hillbricht-Ikowska, A.; Zdanowski, B.; Ejsmont-Karabin, J.; Karabin, A.; Węgleńska, T. Produkcja pierwotna i wtórna planktonu jezior podgrzanych. *Rocz. Nauk Rol.* 1976, H-97, 69–88.

26. Hillbricht-Ikowska, A.; Ejsmont-Karabin, J.; Węgleńska, T. Przydatność planktonowych wskaźników stanu trofii jezior do oceny zmian wieloletnich w systemie jezior podgrzanych. Monitoring ekosystemów jeziornych. *Osołonieczn* 1986, 71–81. ISBN 83-04-02234-6.

27. Ejsmont-Karabin, J.; Węgleńska, T. Disturbances in zooplankton seasonality in Lake Gosławskie (Poland) affected by permanent heating and heavy fish stocking. *Ekol. Pol.* 1988, 36, 245–260.

28. Ejsmont-Karabin, J. Empirical equations for biomass calculation of planktonic rotifers. *Polish Arch. Hydrobiol.* 1998, 45, 513–522.
29. Bottrell, H.H.; Duncan, A.; Gliwicz, Z.M.; Grygier, E.; Herzig, A.; Hillbricht-Iłkowska, A.; Kurasawa, H.; Larsson, P.; Węgleńska, T. A review of some problems in zooplankton production studies. *Norw. J. Zool.* 1976, 24, 419–456.

30. Ejsmont-Karabin, J. Rotifera of lake psammon: Community structure versus trophic state of lake waters. *Pol. J. Ecol.* 2003, 51, 5–35.

31. Whittaker, R.H.; Fairbanks, C.W. A study of plankton copepod communities in the Columbia Basin, Southeastern Washington. *Ecology* 1968, 39, 46–65.

32. Chao, A. Non-parametric estimation of the number of classes in a population. *Scam. J. Stat.* 1984, 11, 265–270.

33. Dumont, H.J.; Segers, H. Estimating lacustrine zooplankton species richness and complementarity. *Hydrobiologia* 1996, 341, 125–132.

34. Muirhead, J.R.; Ejsmont-Karabin, J.; Maclsaic, H.J. Quantifying rotifer species richness in temperate lakes, *Freshw. Biol.* 2006, 51, 1696–1709. doi:10.1111/j.1365-2427.2006.01614.x.

35. Henrion, R., Henrion, A., Henrion, G. BASIC-Programm DIVA zur divisiven Clusterung nach dem Varianzkriterium. *Acta Hydroch. Hydrobiol.* 1988, 16, 491–497.

36. Ter Braak, C.J.F.; Šmilauer, P. *Canoco for Windows Version 4.52, 1997–2003; Biometris—Plant Research International: Wageningen, The Netherlands, 2002.*

37. Lepš, J.; Šmilauer, P. *Multivariate Analysis of Ecological Data Using CANOCO; Cambridge University Press: Cambridge, UK, 2003; 282 p. ISBN 9780521811406.*

38. Oksanen, J.; Blanchet, F.G.; Kindt, R.; Legendre, P.; Minchin, P.R.; O’Hara, R.B.; Simpson, G.L.; Solymos, P.; Stevens, M.H.H.; Wagner, H. Vegan: Community Ecology Package. R Package Version 2.0-7. 2013. Available online: http://CRAN.R-project.org/package=vegan (accessed on 9 June 2014).

39. Ejsmont-Karabin, J. The usefulness of zooplankton as lake ecosystem indicators: Rotifer trophic state index. *Pol. J. Ecol.* 2012, 60, 339–350.

40. Pyka, J.P.; Stawecki, K.; Zdanowski, B. Variation in the contents of nitrogen and phosphorus in the heated water ecosystem of the Konin lakes. *Arch. Pol. Fish.* 2007, 15, 259–271.

41. Tunowski, J. Zooplankton structure in heated lakes with differing thermal regimes and water retention. *Arch. Pol. Fish.* 2009, 17, 291–303. DOI 10.2478/v10086-009-0021-0.

42. Mulhollem, J.J.; Colombo, R.E.; Wahl, D.H. Effects of heated effluent on Midwestern US lakes: Implications for future climate change. *Aquat. Sci.* 2016, 78, 743–753, doi:10.1007/s00027-016-0466-3.

43. Currie, D.J. Energy and large-scale patterns of animal species and plant-species richness. *Am. Nat.* 1991, 137, 27–49, doi:10.1086/285144.

44. Hessen, D.O.; Bakkestuen, V.; Walseng, B. Energy input and zooplankton species richness. *Ecography* 2007, 30, 749–758, doi:10.1111/j.2007.0906-7590.0529.x.

45. Lanner, M.; Pejler, B. The Effect of Cooling Water Discharges on Zooplankton in a Bay of Lake Mälaren; Report No 53, 31-33; Institute of Freshwater Research: Drottingholm, Sweden, 1973.

46. Berzins, B., Pejler, B. Rotifer occurrence in relation to temperature. *Hydrobiologia* 1989, 175, 223–231.

47. Moore, M.; Holt, C. Zooplankton body size and community structure: Effects of thermal and toxicant stress. *Trends Ecol. Evol.* 1993, 8, 178–183, doi:10.1016/0169-5347(93)90144-E.

48. Moore, M.V.; Holt, C.L.; Stemberger, R.S. Consequences of elevated temperatures for zooplankton assemblages in temperate lakes. *Arch. Hydrobiol.* 1996, 135, 289–319.

49. Ejsmont-Karabin, J. Phosphorus and nitrogen excretion by lake zooplankton (rotifers and crustaceans) in relationship to individual body weights of the animals, ambient temperature and presence or absence of food. *Ecol. Pol.* 1984, 32, 3–42.

50. Walczyńska, A.; Franch-Gras, L.; Serra, M. Empirical evidence for fast temperature-dependent body size evolution in rotifers. *Hydrobiologia* 2017, 796, 191–200, DOI 10.1007/s10750-017-3206-3.

51. Atkinson, D. Temperature and organism size—A biological law for ectotherms. *Adv. Ecol. Res.* 1994, 25, 1–58.

52. Gillooly, J.F. Effect of body size and temperature on generation time in zooplankton. *J. Plankton Res.* 2000, 22, 241–251, doi:10.1093/plankt/22.2.241.

53. Patalas, K. Primary and secondary production in a lake heated by thermal power plant. In *Proceedings of the 1970 Annual Technical Meeting of the Institute of Environmental Sciences, Boston, MA, USA, 12–16 April 1970*, pp. 267–271.
54. Hillbricht-Ilkowska, A.; Ejsmont-Karabin, J.; Węgleńska, T. Long-term changes in the composition, productivity and trophic efficiency in the zooplankton community of heated lakes near Konin (Poland). *Ekol. Pol.* 1988, 36, 115–144.

55. Duggan, I.C. The freshwater aquarium trade as a vector for incidental invertebrate fauna. *Biol. Invasions* 2010, 12, 3757–3770, doi:10.1007/s10530-010-9768-x.

56. Špoljar, M.; Dražina, T.; Habdija, I.; Meseljević, M.; Grčić, Z. Contrasting zooplankton assemblages in two oxbow lakes with low transparencies and narrow emergent macrophyte belts (Krapina River, Croatia). *Int. Rev. Hydrobiol.* 2011, 96, 175–190, doi:10.1002/iroh.20111257.

57. Špoljar, M.; Dražina, T.; Šargač, J.; Kralj Borojević, K.; Žutinić, P. Submerged macrophytes as a habitat for zooplankton development in two reservoirs of a flowthrough system (Papuk Nature Park, Croatia). *Ann. Limnol. Int. J. Lim.* 2012, 48, 161–175, doi:10.1051/limn/2012005.

58. Špoljar, M.; Dražina, T.; Lajtner, J.; Đurić, M.S.; Radanović, I.; Matuljić, D.; Tomljanović, T. Zooplankton assemblage in four temperate shallow waterbodies in association with habitat heterogeneity and alternative states. *Limnologica* 2018, 71, 51–61, doi:10.1016/j.limno.2018.05.004.

59. Compte, J.; Montenegro, M.; Ruhí, A.; Gascón, S.; Sala, J.; Boix, D. Microhabitat selection and diel patterns of zooplankton in a Mediterranean temporary pond. *Hydrobiologia* 2016, 766, 201–213, doi:10.1007/s10750-015-2455-2.

60. Wilson, S.; Ricciardi, A. Epiphytic Macroinvertebrate communities on Eurasian watermilfoil (*Myriophyllum spicatum*) and native milfoils *Myriophyllum sibiricum* and *Myriophyllum alterniflorum* in eastern North America. *Can. J. Fish. Aquat. Sci.* 2009, 66, 18–30, doi:10.1139/F08-187.

61. Kelly, D.J.; Hawes, I. Effects of invasive macrophytes on littoral-zone productivity and foodweb dynamics in a New Zealand high-country lake. *J. N. Am. Benthol. Soc.* 2004, 24, 300–320, doi:10.1899/03-097.1.

62. Champ, P. Dynamique d’une population d’un Rotifère épiphyte thermophile (*Sinantherina socialis*) en présence de pollution thermique. *Arch. Hydrobiol.* 1978, 83, 213–231.

63. Hejda, M.; Pysek, P.; Jarosik, V. Impact of invasive plants on the species richness, diversity and composition of invaded communities. *J. Ecol.* 2009, 97, 393–403, doi:10.1111/j.1365-2745.2009.01480.x.

64. Gallardo, B.; Clavero, M.; Sanchez, M.I.; Vila, M. Global Ecological impacts on invasive species in aquatic ecosystems. *Glob. Chang. Biol.* 2016, 22, 151–163, doi:10.1111/gcb.13004.

65. Ejsmont-Karabin, J. Does the world need faunists? Based on rotifer (Rotifera) occurrence reflections on the role of faunistic research in ecology. *Intern. Rev. Hydrobiol.* 2019, 104, 49–56, doi:10.1002/iroh.201901991.

66. Kuczynska-Kippen, N. Habitat choice in rotifer communities of three shallow lakes: Impact of macrophyte substratum and season. *Hydrobiologia* 2007, 593, 27–37, doi:10.1007/s10750-007-9073-6.

67. Lucena-Moya, P.; Duggan, I.C. Macrophyte architecture affects the abundance and diversity of littoral microfauna. *Aquat. Ecol.* 2011, 45, 279–287, doi:10.1007/s10452-011-9353-0.

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