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Diversity of Rotifers in Small Rivers Affected by Human Activity

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Abstract: The rivers flowing through Upper Silesia and the adjacent areas (Southern Poland) are affected by various anthropogenic pressures including urbanisation, agriculture and animal husbandry, as well as industry (e.g., mining), which are reflected in the measured physical and chemical water parameters. The species composition of rotifers relative to a variety of microhabitats was studied in eight small rivers of this region in 2017. Our research is a comprehensive and up-to-date analysis that focuses on the rotifers in small rivers and shows the diversity of rotifers relative to the microhabitats and environmental variables. The diversity of rotifers ranged from 0 to 23 taxa in individual samples. In the studied rivers, 129 taxa of rotifers were found. *Notommata groenlandica*, a species that has not been recorded in the country for 100 years, was found in two rivers. The Kruskal–Wallis one-way ANOVA and Dunn's multiple comparison post hoc tests revealed statistically significant differences in the median number of rotifer taxa between the abiotic types of rivers, rivers, sampling sites, microhabitats and seasons. A multiple regression analysis revealed a significant relationship (correlation) between the number of rotifer taxa, and the concentration of nitrites, total dissolved solids and dissolved oxygen in the water.

Keywords: anthropogenic pressure; human disturbance; salinisation; running waters; habitat; Rotifera

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1. Introduction

To date, more than 2030 species that belong to the Phylum Rotifera are known, which are classified into three main groups: the exclusively parthenogenetic subdivision Bdelloidea (about 461 clonal species), the largest subdivision Monogononta (about 1570 species), and the marine subdivision Seisonida (4 species) [1]. However, studies regarding their integration approaches indicate that the diversity of rotifers is much higher than is currently estimated [2,3]. Rotifers are considered to be a valuable tool in environmental assessments, mainly because they are quite abundant, and thus, are an important part of most non-marine food webs [4,5]. In addition, rotifers are generally cosmopolitan, and their distribution is generally limited by environmental conditions, but may also be limited by biogeographic barriers [6,7]. It is also known that because of their evolutionary adaptations, rotifers segregate according to the specificity of habitats [8,9]. For example, planktonic rotifers are used to monitor the water of dam reservoirs and lakes [10–12]. Surprisingly, despite the great diversity of rotifers and their habitat preferences, little is known about the habitat preferences of the periphytic rotifers [13]. Macrophytes can shape the diversity of rotifers by providing a food source and a suitable habitat for their life. On the other hand, periphytic rotifers can also cause the growth of macrophytes, and thus provide food for other animals [13–15]. Therefore, research that takes into account the approach to the habitat selectivity of rotifers is important and can be used to monitor aquatic ecosystems [16].

According to Limnofauna Europaea [17], five zoogeographical regions converge in Poland. Four of them (the Central Highlands, the Carpathians, the Central Plains and the Eastern Plains) converge in Upper Silesia, which is one of the largest coal basins in the world. Mining activity causes the discharge of saline mine waters into rivers (even after mines are closed for economic reasons), mainly through the smaller rivers that carry their waters to the Odra River and the Vistula River [18,19]. In addition, rivers flowing through agricultural areas are characterised by high concentrations of nutrients in the water [20,21]. Other threats to the stability of river ecosystems include changes in land use, toxic and domestic waste and climate change [22,23]. These individual changes in aquatic ecosystems could impair the natural functioning, and could also modify the structure and function of biotic communities [24,25]. The decline in biodiversity is also caused by overexploitation, urban development, invasion and disease, system modification, human disturbance, transport and energy production [26]. To summarise, the rivers of the Upper Silesia region and adjacent areas are affected by most of these "big killers". The territory of Southern Poland includes both areas with significant anthropogenic transformations as a result of strong industrialisation and urbanisation, as well as less transformed and legally protected areas. Therefore, the rivers flowing through Southern Poland that have different land uses in their catchment areas differ in terms of the degree of anthropogenic pressure. Consequently, this region is an excellent area for ecological research into various aquatic ecosystems, especially in rivers.

The data on rotifers that was found in the scientific literature using the term "rotifer" via a bibliometric search in the popular scientific databases include over 22 000 documents. Using the same method, it was found that the term "rotifer" and the term "river" reveal six times fewer documents related to this type of water body. Meanwhile, when a term related to stagnant waters was used, four times as many documents were found than for the term "river". This finding is in opposition to the trend of scientific interest in rivers as opposed to other types of inland waters [27]. This simple method revealed disproportions in the interest in the research on rotifers in lotic and lentic environments. Therefore, this reflects the insufficient state of study concerning the diversity of rotifers in small rivers. This issue perfectly fits in our research, in which we attempted to determine the habitat preferences of the rotifers that occur in small rivers subjected to different kinds of anthropogenic pressure.

The objectives of the research were to determine the diversity of the rotifers in small rivers subjected to various types of anthropogenic pressure and to reveal the habitat (namely microhabitats and environmental conditions) preferences for the identified rotifer species. In addition, we indicate further directions for research on rotifers in future ecological studies.

2. Materials and Methods

The research was conducted in the rivers that flow through one of the highly industrialised and urbanised regions in Europe, i.e., Upper Silesia and adjacent areas (Southern Poland) from spring to autumn 2017. Eight rivers of four abiotic types in the catchments of the Vistula and Odra rivers within two ecoregions (the Central Plains and the Carpathians) were selected according to the European Union Water Framework Directive (EU WFD) [28]. Depending on the degree of anthropogenic pressure, two sampling sites for each river were selected, i.e., one reference site and the other under significant anthropogenic pressure (Figures 1 and S1). The general characteristics of the study sites and the main anthropogenic pressures are presented in Table 1.

Table 1. General characteristics of the studied sampling sites. Abbreviations: BOL—the Bolina River, CEN—the Centuria River, MIT—the Mitręga River, MLE—the Mleczna River, DZI—the Dziechcinka River, VIS—the Vistula River, KOR—the Korzenica River, WIE—the Wiercica River.

River	Sampling Site	Geographical Coordinates	Ecoregion	Type of River/Geology	Catchment Land Use	Main Anthropogenic Pressure	Bottom Sediments
BOL	Upper	N: 50°13.793; E: 19°05.142	Ecoregion 14—Central Plains	Type 5/mid-altitude siliceous streams with a fine particulate substratum	Industrial and urban, grassland	Salinisation (coal mine), industrial and communal sewage, regulation of the riverbed	Silty
	Lower	N: 50°14.742; E: 19°06.078					Silty-sandy
CEN	Upper	N: 50°24.879; E: 19°29.190			Natural monument and Natura 2000; Woodland	None	Sandy-silty
	Lower	N: 50°21.920; E: 19°29.682			Natura 2000; Woodland and grassland	Organic pollution (agriculture, animal grazing), fishponds	Sandy-stony
MIT	Upper	N: 50°24.797; E: 19°22.779	Ecoregion 14—Central Plains	Type 6/mid-altitude calcareous streams with a fine particulate substratum on loess	Built-up area and grassland	Dam reservoir, communal sewage	Sandy-silty
	Lower	N: 50°26.070; E: 19°17.956				Dam reservoir, communal sewage, regulation of the riverbed	Sandy-silty
MLE	Upper	N: 52°09.754; E: 19°00.213			Industrial and urban, grassland	Industrial and communal sewage, regulation of the riverbed	Sandy-silty
	Lower	N: 50°07.018; E: 19°04.487				Salinisation (coal mine), industrial and communal sewage, regulation of the riverbed	Silty-sandy
DZI	Upper	N: 49°38.021; E: 18°50.828	Ecoregion 10—Carpathians	Type 12/flysch streams	Woodland, road	None	Stony-gravel
	Lower	N: 49°38.789; E: 18°52.025			Built-up area, woodland	Regulation of the riverbed	Stony-concrete
VIS	Upper	N: 49°37.190; E: 18°59.160			Nature reserve and Natura 2000, woodlands, built-up area	None	Stony-gravel
	Lower	N: 49°38.728; E: 18°51.167			Built-up area, woodland	Dam reservoir, communal sewage, regulation of the riverbed	Stony-gravel

Table 1. *Cont.*

River	Sampling Site	Geographical Coordinates	Ecoregion	Type of River/Geology	Catchment Land Use	Main Anthropogenic Pressure	Bottom Sediments
KOR	Upper	N: 50°03.509; E:18°56.804	Ecoregion 14—Central Plains	Type 17/lowland sandy streams	Built-up area and grassland	Fishponds and agriculture, communal sewage	Silty-sandy
	Lower	N: 50°01.850; E: 19°05.839			Built-up area and grassland, protected areas: Natura 2000	Fishponds and agriculture	Sandy-stony
WIE	Upper	N: 50°41.117; E: 19°24.472			Nature reserve and Natura 2000, woodlands and grassland	None	Sandy-stony
	Lower	N: 50°52.471; E: 19°26.133			Woodlands, grassland and built-up area	Agriculture, animal grazing, dam reservoirs	Sandy-silty

Figure 1. Photos of the sampling sites. (**a**) upper course of the Bolina River, (**b**) lower course of the Bolina River, (**c**) upper course of the Centuria River, (**d**) lower course of the Centuria River, (**e**) upper course of the Mitręga River, (**f**) lower course of the Mitręga River, (**g**) upper course of the Mleczna River, (**h**) lower course of the Mleczna River, (**i**) upper course of the Dziechcinka River, (**j**) lower course of the Dziechcinka River, (**k**) upper course of the Vistula River, (**l**) lower course of the Vistula River, (**m**) upper course of the Korzenica River, (**n**) lower course of the Korzenica River, (**o**) upper course of the Wiercica River, (**p**) lower course of the Wiercica River.

Water samples for the physical and chemical analyses were collected before the biological sampling. The electrical conductivity (EC), total dissolved solids (TDS), temperature and dissolved oxygen were measured in the field using a Multi 3410 WTW meter. The salinity was measured in the field as the EC and then converted, according to Piscart et al. [29]. The concentrations of selected ions, total hardness and alkalinity were analysed in the laboratory according to Hermanowicz et al. [30].

The samples of rotifers were collected from various microhabitats: open water, stones, bottom sediments, macrophytes and diatom aggregations. The planktonic samples of rotifers were collected using the standard methods by pouring 20 dm^3 of water through a plankton net with a mesh size of 50 μm. The periphytic samples of rotifers were collected from different substrata (macrophytes and diatom aggregations) by cutting different fragments (a total of 25 cm^2 for each surface) of each macrophyte and diatom using a soft toothbrush [31,32]. The rotifer samples from the stones were collected from the same surface using a soft toothbrush. Biological samples from bottom sediments were collected using a sharp-edged cylinder with a surface area of 20 cm^3, according to Bielańska-Grajner et al. [33].

Rotifer species were classified according to Segers [1] and identified according to citing publications [33–38].

The significance of the differences in the median values of the environmental variables between the abiotic types of rivers, the rivers and the sampling sites, as well as in the median values of the number of rotifer taxa between the sampling sites, rivers, abiotic types of rivers and different microhabitats [different substratum, types of plant growth and leaf morpha groups including diatoms, which were grouped (cumulated) according to study seasons] and different seasons were calculated using the Kruskal–Wallis one-way ANOVA and Dunn's multiple comparison post hoc tests. Multiple regression techniques (including multilinearity checking) were used to elucidate the relationship between the species richness (number of rotifer taxa) and selected environmental variables, and then to assess the influence of an anthropogenic transformation on the rotifers in the studied rivers. Therefore, the data were first log-transformed to approximately conform to normality. The statistical analyses were performed using Statistica version 13.1.

3. Results

The conducted research indicated a large amount of diversity among the abiotic types of rivers (also the rivers and sampling sites) relative to the abiotic parameters. The physical and chemical parameters of the water in most sampling sites were influenced by the geological substratum of the catchment area of the rivers (calcareous, flysch, siliceous). However, the impact of anthropogenic pressure was also reflected, e.g., in the relatively high concentrations of nitrates (up to 79.74 mg dm^{-3}), nitrites (up to 9.96 mg dm^{-3}) and phosphates (up to 19.20 mg dm^{-3}) in the water and in modifications of the riverbed at the sampling sites. In addition, very high values of EC (up to 46 600 μS cm^{-1}), TDS (23 300 mg dm^{-3}), total hardness (4857.92 mg $CaCO_3$ dm^{-3}), the concentrations of chlorides (up to 17 028 mg dm^{-3}) and temperature (up to 29.1°C), were recorded in the lower course of the Bolina River (abiotic type 5) (Table 2, Tables S1 and S2).

During the entire study period, 129 taxa (including 104 species and one subspecies) of rotifers were identified in all of the sampling sites (Table 3). The halophilic rotifer species *Brachionus plicatilis* was found in the Bolina River (only in the planktonic samples). In contrast, *Notommata groenlandica* was found in the upper course of the Centuria River and the lower course of the Wiercica River. *N. groenlandica* was rediscovered after more than 100 years in the inland waters of the territory of Poland. This species was only found in the periphytic samples that had been collected from *Glyceria nemoralis* (upper course of the Centuria River) and *Sparganium erectum* (lower course of the Wiercica River). Species diversity was the highest in the lowland sandy streams (79 taxa, including 69 species), while the lowest in the flysch streams (21 taxa, including 18 species). However, the lowest number of taxa was recorded in the most degraded river (the most anthropogenically salinised), i.e., in the Bolina River (ten taxa, including eight species) (Figure 2). For most of the samples, the number of Monogononta taxa dominated. The reverse trend was observed only in the sampling sites of flysch streams in which Bdelloidea taxa dominated. When the seasons were considered, a higher number of rotifer taxa were recorded in autumn. In contrast, a higher number of taxa were found in summer in the upper course of the Korzenica River (Tables 3 and 4). The highest number of rotifer taxa was recorded in autumn in the periphyton samples, while the lowest was recorded in the bottom sediment samples. Among the periphyton samples, the highest number of taxa was recorded in the samples taken from the elodeids and the lowest from the nymphaeids. When analysing the leaf morph groups, the highest number of taxa was recorded on emergent reeds, sedges, while the lowest was recorded on the filamentous algae and floating-leaves (rooted) (Figure 2).

Table 2. The physical and chemical parameters of the waters of the abiotic type of rivers (ranges) and the results of the Kruskal–Wallis one-way ANOVA and Dunn's multiple comparison post hoc tests (superscript a, b, c, d denote significant differences between the rivers).

Parameter	Type 5	Type 6	Type 12	Type 17	*H* Value	*p* Value
Altitude [m a.s.l.]	257–343 ^{c,d}	236–317 ^{c}	415–748 ^{a,b,d}	215–309 ^{a,c}	44.007	<0.001
Width of the riverbed [m]	3.30–7.78	2.87–9.36	3.47–19.80	1.85–12.05	0.500	0.919
Depth of the riverbed [cm]	9.75–58.60 ^{b}	36.80–109.17 ^{a,c}	19.30–57.60 ^{b}	6.70–98.33	18.904	<0.001
Flow velocity [m s^{-1}]	0.060–0.790 ^{b}	0.007–0.384 ^{a,c}	0.107–0.939 ^{b,d}	0.057–0.706 ^{c}	22.633	<0.001
Dissolved oxygen [mg dm^{-3}]	4.24–9.69 ^{b}	0.69–6.78 ^{a,c}	4.88–5.90 ^{b}	2.98–6.49	11.609	0.009
Temperature [°C]	7.5–29.1	9.4–25.1	9.1–23.8	9.7–23.5	7.797	0.050
Salinity [PSU]	0.19–33.55	0.28–5.16	0.02–0.06	0.17–0.28	45.479	<0.001
EC [µS cm^{-1}]	250–46 600 ^{c}	360–7160 ^{c,d}	30–90 ^{a,c,d}	220–370 ^{b,c}	45.479	<0.001
TDS [mg dm^{-3}]	110–23 300 ^{c}	170–3570 ^{c,d}	10–30 ^{a,b,d}	100–170 ^{b,c}	45.881	<0.001
Chlorides [mg dm^{-3}]	8–17 028 ^{c}	15–1970 ^{c}	4–9 ^{a,b,d}	4–25 ^{c}	36.478	<0.001
Sulphates [mg dm^{-3}]	35–770 ^{c,d}	22–272 ^{c,d}	8–18 ^{a,b}	10–64 ^{a,b}	39.919	<0.001
Total hardness [mg $CaCO_3$ dm^{-3}]	160.00–4857.92 ^{c,d}	160.00–560.00 ^{c,d}	28.00–68.00 ^{a,b,d}	110–320 ^{a,b,c}	47.971	<0.001
Magnesium [mg dm^{-3}]	1.94–670.00 ^{c,d}	0.06–62.53 ^{c}	0.04–5.14 ^{a,b}	0.00–13.80 ^{a}	32.260	<0.001
Calcium [mg dm^{-3}]	55–1310 ^{c,d}	40–158 ^{c}	10–21 ^{a,b,d}	24–82 ^{a,c}	45.340	<0.001
Alkalinity [mg $CaCO_3$ dm^{-3}]	75.0–380.0 ^{c}	125.0–275.0 ^{c}	2.5–50.0 ^{a,b,d}	20.0–180.0 ^{c}	39.516	<0.001
pH	7.2–7.9	6.8–8.1	6.5–8.4	6.2–8.2	2.006	0.571
Nitrates [mg dm^{-3}]	0.00–79.74	0.89–15.95 ^{c}	0.00–9.30 ^{b,d}	0.44–18.61 ^{c}	13.726	<0.001
Nitrites [mg dm^{-3}]	0.00–9.96 ^{c}	0.03–093 ^{c}	0.00–0.01 ^{a,b}	0.00–0.59	30.897	<0.001
Ammonium [mg dm^{-3}]	0.00–12.12 ^{c}	0.23–1.42 ^{c}	0.13–0.45 ^{a,b}	0.00–0.63	18.045	<0.001
Phosphates [mg dm^{-3}]	0.00–0.14 ^{b,d}	0.08–19.20 ^{a,c}	0.00–1.52 ^{b}	0.00–0.87 ^{a}	39.919	<0.001
Iron [mg dm^{-3}]	0.03–0.88 ^{b}	0.25–1.46 ^{a,c}	0.03–0.34 ^{b,d}	0.03–3.11 ^{c}	27.324	<0.001

[a] Type 5, [b] Type 6, [c] Type 12, [d] Type 17.

Table 3. Summary of the identified rotifers relative to the various microhabitats and seasons. Abbreviations: BOLU—upper course of the Bolina River, BOLL—lower course of the Bolina River, CENU—upper course of the Centuria River, CENL—lower course of the Centuria River, MITU—upper course of the Mitręga River, MITL—lower course of the Mitręga River, MLEU—upper course of the Mleczna River, MLEL—lower course of the Mleczna River, DZIU—upper course of the Dziechcinka River, DZIL—lower course of the Dziechcinka River, VISU—upper course of the Vistula River, VISL—lower course of the Vistula River, KORU—upper course of the Korzenica River, KORL—lower course of the Korzenica River, WIEU—upper course of the Wiercica River, WIEL—lower course of the Wiercica River, SP—Spring, SU—Summer, AU—Autumn, s.l.—sensu lato.

Taxon	Sampling Site	Microhabitat	Season
Adineta gracilis Janson, 1893	DZIL, VISU	*Chiloscyphus polyanthos*, *Fontinalis antipyretica*, *Platyhypnidium riparioides*, *Scapania undulata*	SP, AU
Adineta vaga (Davis, 1873)	VISU	*Hygrohypnum luridum*, *Scapania undulata*	SU
Adineta vaga major Bryce, 1893	WIEL	*Phalaris arundinacea*	SU
Anuraeopsis fissa Gosse, 1851	MITU	open water	SU
Asplanchna priodonta Gosse, 1850	MITU	open water	SU
Bdelloidea non determinata	CENL, DZIL, DZIL, DZIU, KORL, KORU, MITL, MITU, MLEU, WIEL, WIEU, VISU	open water, stones, bottom sediments, diatom aggregation, *Berula erecta*, *Callitriche* sp., *Chiloscyphus polyanthos*, *Elodea canadensis*, *Fontinalis antipyretica*, *Glyceria maxima*, *Myosotis palustris*, *Phalaris arundinacea*, *Platyhypnidium riparioides*, *Potamogeton crispus*, *P. natans*, *Ranunculus aquatile*, *R. circinatum*, *Sagittaria sagittifolia*, *Scrophularia umbrosa*, *Sparganium erectum*, *Thamnobryum alopecurum*, *Veronica beccabunga*	SP, SU, AU

Table 3. *Cont.*

Taxon	Sampling Site	Microhabitat	Season
Brachionus angularis Gosse, 1851	BOLL, MITU	open water	SU
Brachionus plicatilis s.l. Müller, 1786	BOLL, BOLU	open water	SU, AU
Brachionus quadridentatus Hermann, 1783	MITL	diatom aggregation	SU
Brachionus rubens (Ehrenberg, 1838)	BOLL, BOLU	open water, *Phragmites australis*	SP
Brachionus species non determinata	BOLL	diatom aggregation	AU
Cephalodella auriculata (Müller, 1773)	CENU, KORL, KORU, MITL, MITU, MLEU, WIEL, VISL	open water, stones, bottom sediments, diatom aggregation, *Berula erecta*, *Glyceria nemoralis*, *Phalaris arundinacea*, *Polygoum hydropiper*, *Potamogeton crispus*, *P. pectinatus*, *Rorippa amphibia*, *Sagittaria sagittifolia*	SP, SU, AU
Cephalodella catellina (Müller, 1786)	KORU, MITL	open water, diatom aggregation, *Callitriche* sp., *Potamogeton crispus*	SP, SU, AU
Cephalodella delicata Wulfert, 1937	CENU	*Carex rostrata*	SU
Cephalodella eva (Gosse, 1887)	KORL, KORU, MITU, WIEL, VISL	*Callitriche* sp., *Elodea canadensis*, *Potamogeton crispus*, *Rorippa amphibia*, *Spraganium erectum*	SU, AU
Cephalodella forficula (Ehrenberg, 1830)	KORL, MITU	*Berula erecta*, *Fontinalis antipyretica*	SU, AU
Cephalodella gibba (Ehrenberg, 1830)	KORL, KORU, MITL, MITU, MLEU, WIEL, WIEU, VISL	open water, stones, bottom sediments, diatom aggregation, *Callitriche* sp., *Fontinalis antipyretica*, *Glyceria maxima*, *Lemna minor*, *Phalaris arundinacea*, *Polygonum hydropiper*, *Potamogeton crispus*, *Sparganium emersum*, *S. erectum*	SP, SU, AU
Cephalodella globata (Gosse, 1887)	MITL, WIEU	open water, bottom sediments	SU, AU
Cephalodella gracilis (Ehrenberg, 1830)	CENL, CENU, KORU, MITU, MLEL, MLEU, WIEL	open water, *Berula erecta*, *Carex rostrata*, *Phalaris arundinacea*, *Potamogeton natans*, *P. pectinatus*, *Rorippa amphibia*, *Sparganium erectum*	SP, SU, AU
Cephalodella hoodii (Gosse, 1886)	MLEU	stones	AU
Cephalodella megalocephala (Glascott, 1893)	VISL	*Elodea canadensis*	AU
Cephalodella megalotrocha Wiszniewski, 1934	CENU	*Carex rostrata*	SU
Cephalodella misgurnus Wulfert, 1937	KORL	*Sparganium erectum*	AU
Cephalodella nana Myers, 1924	KORL	open water	AU
Cephalodella species non determinata	KOLR, WIEL	open water, *Potamogeton natans*	SP, SU
Cephalodella stenroosi Wulfert, 1937	MITU	*Spraganium erectum*	SU
Cephalodella ventripes (Dixon-Nuttall, 1901)	KORU	open water	SP

Table 3. *Cont.*

Taxon	Sampling Site	Microhabitat	Season
Collotheca species non determinata	KORL, MITU, VISL	*Elodea canadensis*, *Fontinalis antipyretica*, *Phalaris arundinacea*	SP, SU, AU
Colurella adriatica Ehrenberg, 1831	BOLL, BOLU, CENL, CENU, DZIL, DZIU, KORL, MITL, MLEL, MLEU, WIEU, VISL, VISU	open water, stones, bottom sediments, diatom aggregation, *Carex rostrata*, *Elodea canadensis*, *Enteromorpha* sp., *Fontinalis antipyretica*, *Glyceria nemoralis*, *Mougeotia* sp., *Phalaris arundinacea*, *Phragmites australis*, *Platyhypnidium riparioides*, *Veronica beccabunga*	SP, SU, AU
Colurella colurus (Ehrenberg, 1830)	BOLL, CENU, DZIL, KORL, KORU, MLEL, WIEL, VISL, VISU	open water, *Callitriche* sp., *Elodea canadensis*, *Enteromorpha* sp., *Glyceria maxima*, *G. nemoralis*, *Nuphar lutea*, *Phalaris arundinacea*, *Scirpus sylvaticus*	SU, AU
Colurella species non determinata	CENL	open water	SU
Colurella uncinata (Müller, 1773)	KORL, KORU, MITL, MITU, MLEL, MLEU	open water, diatom aggregation, *Fontinalis antipyretica*, *Phalaris arundinacea*, *Potamogeton pectinatus*, *Ranunculus aquatile*, *Sparganium emersum*, *S. erectum*	SP, SU, AU
Dicranophorus forcipatus (Müller, 1786)	MITU, WIEL, WIEU	stones, *Elodea canadensis*, *Rorippa amphibia*, *Thamnobryum alopecurum*	AU
Dicranophorus grandis (Ehrenberg, 1832)	KORU	*Potamogeton crispus*	SU
Dicranophorus hercules Wiszniewski, 1932	DZIU, KORU, MITU, WIEU	open water, stones, bottom sediments, *Sparganium erectum*	SP, SU, AU
Dicranophorus rostratus (Dixon-Nuttall & Freeman, 1902)	DZIU	bottom sediments	SU
Dicranophorus secretus Donner, 1951	MITU	*Spraganium erectum*	SU
Dicranophorus species non determinata	KORU, MITU	open water, *Berula erecta*, *Sparganium erectum*	SU
Dissotrocha macrostyla (Ehrenberg, 1838)	KORL, MLEU	stones, *Callitriche* sp.	AU
Dissotrocha species non determinata	CENU	bottom sediments	AU
Encentrum diglandula (Zawadovsky, 1926)	BOLU	*Enteromorpha* sp.	AU
Encentrum lupus Wulfert, 1936	MITL	*Fontinalis antipyretica*	AU
Encentrum marinum (Dujardin, 1841)	BOLL, BOLU, DZIU, KORL, KORU, MLEL	open water, stones, bottom sediments, diatom aggregation, *Enteromorpha* sp., *Phragmites australis*	SP, SU, AU
Encentrum mustela (Milne, 1885)	WIEL	*Glyceria maxima*	SP
Encentrum saundersiae (Hudson, 1885)	KORU	open water	SP
Encentrum species non determinata	CENL	*Berula erecta*	SU
Encentrum tyrphos Wulfert, 1936	KORL, WIEL	open water, *Phalaris arundinacea*	SU, AU
Erignatha clastopis (Gosse, 1886)	KORL	*Fontinalis antipyretica*	SU

Table 3. *Cont.*

Taxon	Sampling Site	Microhabitat	Season
Erignatha species non determinata	KORL	open water	SU
Euchlanis deflexa (Gosse, 1851)	CENU, MITL, MLEU	*Glyceria nemoralis*, *Phalaris arundinacea*, *Polygonum hydropiper*	AU
Euchlanis dilatata Ehrenberg, 1832	KORL, KORU, MITL, MLEU, WIEL	open water, stones, diatom aggregation, *Callitriche* sp., *Glyceria maxima*, *Mougeotia* sp., *Phalaris arundinacea*, *Potamogeton crispus*, *P. natans*, *Ranunculus aquatile*, *Sparganium erectum*	SP, SU, AU
Euchlanis species non determinata	KORL, KORU, WIEL, WIEU, VISL	open water, stones, *Callitriche* sp., *Fontinalis antipyretica*, *Nuphar lutea*, *Phalaris arundinacea*, *Potamogeton crispus*, *Ranunculus aquatile*, *Thamnobryum alopecurum*	SP, SU, AU
Filinia longiseta (Ehrenberg, 1834)	MITU, WIEL	open water	SU, AU
Floscularia ringens (Linnaeus, 1758)	MLEU	*Callitriche* sp.	AU
Habrotrocha roeperi (Milne, 1889)	DZIL, MITL	*Fontinalis antipyretica*, *Platyhypnidium riparioides*, *Scrophularia umbrosa*	SU, AU
Habrotrocha species non determinata	CENL, CENU, DZIL, DZIU, KORL, MITL, MLEU, WIEL, WIEU, VISL, VISU	stones, bottom sediments, *Berula erecta*, *Callitriche* sp., *Carex rostrata*, *Fontinalis antipyretica*, *Hygrohypnum luridum*, *Nuphar lutea*, *Phalaris arundinacea*, *Platyhypnidium riparioides*, *Ranunculus aquatile*, *Sparganium erectum*, *Thamnobryum alopecurum*	SP, SU, AU
Itura aurita (Ehrenberg, 1830)	KORU	open water	SU
Keratella cochlearis (Gosse, 1851)	CENL, KORU, MITL, MITU	open water	SP, SU, AU
Keratella quadrata (Müller, 1786)	CENL	open water	SP
Keratella tecta (Gosse, 1851)	CENL, MITL	open water	SP, SU
Lecane bulla (Gosse, 1851)	MLEU	open water	SU
Lecane closterocerca (Schmarda, 1859)	CENU, KORL, KORU, MITL, MITU, MLEL, MLEU, WIEL	open water, stones, diatom aggregation, *Callitriche* sp., *Carex rostrata*, *Fontinalis antipyretica*, *Glyceria maxima*, *Mougeotia* sp., *Potamogeton crispus*, *P. natans*, *P. pectinatus*, *Ranunculus aquatile*, *Rorippa amphibia*, *Sparganium erectum*	SP, SU, AU
Lecane hamata (Stokes, 1896)	WIEU	*Thamnobryum alopecurum*	AU
Lecane inermis (Bryce, 1892)	KORU, MITU, MLEL, MLEU, VISL	open water, stones, *Potamogeton crispus*, *Spraganium erectum*	SU, AU
Lecane luna (Müller, 1776)	KORL, MITL	open water, *Callitriche* sp., *Phalaris arundinacea*	SP, SU, AU
Lecane lunaris (Ehrenberg, 1832)	MITL, MLEL, MLEU	open water, bottom sediments, *Fontinalis antipyretica*, *Phragmites australis*, *Polygonum hydropiper*	SU, AU
Lecane scutata (Harring & Myers, 1926)	KORL	diatom aggregation	SU

Table 3. *Cont.*

Taxon	Sampling Site	Microhabitat	Season
Lecane species non detereminata	KORL	*Sparganium emersum*	SU
Lepadella (Lepadella) acuminata (Ehrenberg, 1834)	MITU, MLEU, WIEL	open water, *Sparganium erectum*	SU, AU
Lepadella (Lepadella) elliptica Wulfert, 1939	WIEL	*Glyceria maxima*	SU
Lepadella (Lepadella) ovalis (Müller, 1786)	CENL, DZIL, KORU, MITU, MLEU	open water, *Platyhypnidium riparioides*, *Ranunculus aquatile*, *R. circinatum*	SP, SU
Lepadella (Lepadella) patella (Müller, 1773)	CENL, KORL, KORU, MITL, MITU, MLEL, MLEU, WIEL, WIEU	open water, diatom aggregation, *Berula erecta*, *Elodea canadensis*, *Glyceria maxima*, *Myosotis palustris*, *Phalaris arundinacea*, *Potamogeton pectinatus*, *Ranunculus aquatile*, *Rorippa amphibia*, *Sparganium emersum*, *Sparganium erectum*, *Thamnobryum alopecurum*	SP, SU, AU
Lepadella species non determinata	CENL, MITU	*Berula erecta*	SU
Limnias melicerta Weisse, 1848	MLU	*Callitriche* sp.	AU
Lindia species non determinata	KORL, MITU, WIEL	*Phalaris arundinacea*, *Sagittaria sagittifolia*, *Sparganium erectum*	SU
Lindia (Lindia) torulosa Dujardin, 1841	KORL, MLEU	open water	SP, AU
Lindia (Lindia) truncata (Jennings, 1894)	CENU	*Glyceria nemoralis*	SU
Macrotrachela species non determinata	KORL	*Phalaris arundinacea*	AU
Monogononta species non determinata	BOLU, CENU, KORU, MITL, WIEL	open water, bottom sediments, *Glyceria nemoralis*, *Phragmites australis*, *Potamogeton crispus*	SU
Monommata species non determinata	KORU, MITL	open water, *Potamogeton crispus*	SP, SU
Mytilina mucronata (Müller, 1773)	MITL	*Fontinalis antipyretica*	AU
Mytilina species non determinata	WIEL	*Rorippa amphibia*	SU
Mytilina ventralis (Ehrenberg, 1830)	WIEL	*Phalaris arundinacea*	SU, AU
Notommata cerberus (Gosse, 1886)	MLEU	*Phalaris arundinacea*	SU
Notommata cyrtopus Gosse, 1886	CENL, MITL, MITU, WIEL	stones, diatom aggregation, *Phalaris arundinacea*, *Ranunculus circinatus*, *Sparganium erectum*	SU, AU
Notommata glyphura Wulfert, 1935	BOLU, MITU, MELU	open water, stones, *Sparganium erectum*	SU, AU
Notommata groenlandica Bergendal, 1892	CENU, WIEL	*Glyceria nemoralis*, *Sparganium erectum*	AU
Notommata species non determinata	MITL	open water, *Sparganium erectum*	SU
Otostephanos donneri Bartoš, 1959	MLEU	stones	SU

Table 3. *Cont.*

Taxon	Sampling Site	Microhabitat	Season
Philodina acuticornis Murray, 1902	CENL, CENU, DZIL, DZIU, KORL, KORU, MITL, MITU, MLEU, WIEL, WIEU, VISD, VISU	stones, diatom aggregation, *Berula erecta*, *Cllitriche* sp., *Chiloscyphus polyanthos*, *Elodea canadensis*, *Fontinalis antipyretica*, *Glyceria maxima*, *Hygrohypnum luridum*, *Myosotis palustris*, *Phalaris arundinacea*, *Platyhypnidium riparioides*, *Polygonum hydropiper*, *Potamogeton crispus*, *P. natans*, *Ranunculus aquatile*, *R. circinatus*, *Rorippa amphibia*, *Scirpus sylvaticus*, *Sparganium emersum*, *S. erectum*, *Thamnobyryum alopecurum*, *Veronica anagalis-aquatica*, *V. beccabunga*	SP, SU, AU
Philodina citrina Ehrenberg, 1832	MITL	diatom aggregation	AU
Philodina flaviceps Bryce, 1906	WIEU	*Veronica beccabunga*	SU
Philodina species non determinata	KORU	*Phalaris arundinacea*	SU
Philodinavus paradoxus (Murray, 1905)	KORL	stones	AU
Pleurotrocha petromyzon (Ehrenberg, 1830)	CENU, KORU, MITL	open water, *Fontinalis antipyretica*, *Glyceria nemoralis*, *Phalaris arundinacea*	SU, AU
Polyarthra species non determinata	MITU	open water	SU
Polyarthra vulgaris Carlin, 1943	MITU, WIEL	open water	AU
Pompholyx sulcata Hudson, 1885	KORU, MITU	open water	SU, AU
Proales daphnicola Thompson, 1892	KORU, WIEL	open water, *Rorippa amphibia*	SP, AU
Proales sordida Gosse, 1886	MITL, MITU, MLEU, VISL	bottom sediments, diatom aggregation, *Berula erecta*, *Callitriche* sp., *Sparganium erectum*	SU, AU
Proales species non determinata	WIEL	*Glyceria maxima*	SU
Proales theodora (Gosse, 1887)	KORU, WIEL	open water, stones, *Glyceria maxima*, *Sparganium erectum*	SP, SU, AU
Proalinopsis squamipes Hauer, 1935	KORL	open water	AU
Rotaria citrina (Ehrenberg, 1838)	WIEL	stones, *Potamogeton natans*	SU
Rotaria macrura (Ehrenberg, 1832)	KORU	stones, *Batrachium aquatice*	SU
Rotaria magnacalcarata (Parsons, 1892)	KORL, MITU	*Berula erecta*, *Fontinalis antipyretica*	SP, SU
Rotaria rotatoria (Pallas, 1766)	BOLU, CENL, KORL, KORU, MITL, MITU, MLEL, MLEU, WIEU,	open water, stones, bottom sediments, diatom aggregation, *Berula erecta*, *Callitriche* sp., *Elodea canadensis*, *Myosotis palustris*, *Phalaris arundinacea*, *Phragmites australis*, *Potamogeton pectinatus*, *Ranunculus circinatus*, *Sparganium erectum*	SP, SU, AU
Rotaria species non determinata	KORL, MITU	*Callitriche* sp., *Elodea canadensis*	SP, SU
Rotaria tardigrada (Ehrenberg, 1830)	CENL, MLEL, WIEU	bottom sediments, *Elodea canadensis*, *Phragmites australis*, *Veronica beccabunga*	SP, SU, AU
Squatinella rostrum (Schmarda, 1846)	MITL	open water	SU

Table 3. *Cont.*

Taxon	Sampling Site	Microhabitat	Season
Synchaeta oblonga Ehrenberg, 1832	VISL	open water	SU
Synchaeta stylata Wierzejski, 1893	CENL	open water	SU
Synchaeta tremula (Müller, 1786)	KORU	open water	SP
Taphrocampa selenura Gosse, 1887	MITL	*Fontinalis antipyretica*	SU
Testudinella clypeata (Müller, 1786)	MLEL, MLEU	open water, stones, bottom sediments, *Phragmites australis*, *Potamogeton pectinatus*	SU, AU
Testudinella patina (Hermann, 1783)	KORL, KORU, MLEU	open water, *Callitriche* sp., *Fontinalis antipyretica*	SU, AU
Trichocerca collaris (Rousselet, 1896)	CENU	bottom sediments	SU
Trichocerca cylindrica (Imhof, 1891)	MITU	open water	SU
Trichocerca intermedia (Stenroos, 1898)	WIEU	*Veronica beccabunga*	AU
Trichocerca rattus (Müller, 1776)	MITL	open water	SU
Trichocerca similis (Wierzejski, 1893)	CENL, KORU, MTIU	open water *Potamogeton crispus*	SP, SU, AU
Trichocerca species non determinata	CENL, KORL, MITL, WIEU	open water, bottom sediments, *Sparganium erectum*	SU, AU
Trichocerca taurocephala (Hauer, 1931)	MITU	bottom sediments	SU
Trichocerca tenuior (Gosse, 1886)	KORU	open water	SU
Trichocerca weberi (Jennings, 1903)	KORU	open water	SU
Trichotria pocillum (Müller, 1776)	WIEL	open water, *Rorippa amphibia*	AU
Trichotria tetractis (Ehrenberg, 1830)	MITL	diatom aggregation	SU
Wierzejskiella velox (Wiszniewski, 1932)	DZIU	bottom sediments	AU
Wulfertia ornata Donner, 1943	VISL	*Elodea canadensis*	AU

The differences in the median values of most of the physical and chemical parameters of the waters and the morphological features between the sampling sites were significant ($p < 0.01$) (the Kruskal–Wallis one-way ANOVA and the Dunn's multiple comparison post hoc tests) (Table 2, Tables S1 and S2). The Kruskal–Wallis one-way ANOVA and the Dunn's multiple comparison post hoc tests revealed statistically significant differences ($p < 0.05$) in the median number of rotifer taxa between the sampling sites, rivers, various microhabitats and seasons (Figures 2 and 3, Table 4).

Table 4. The number of rotifer taxa (ranges) in specific seasons of the year (superscript $^{a, b, c}$ denotes significant differences between the seasons).

Variable	Spring	Summer	Autumn	*H* Value	*p* Value
Number of taxa (ranges)	0–15 ^{b,c}	1–20 ^{a,c}	2–23 ^{a,b}	12.408	0.002

^{a} Spring, ^{b} Summer, ^{c} Autumn.

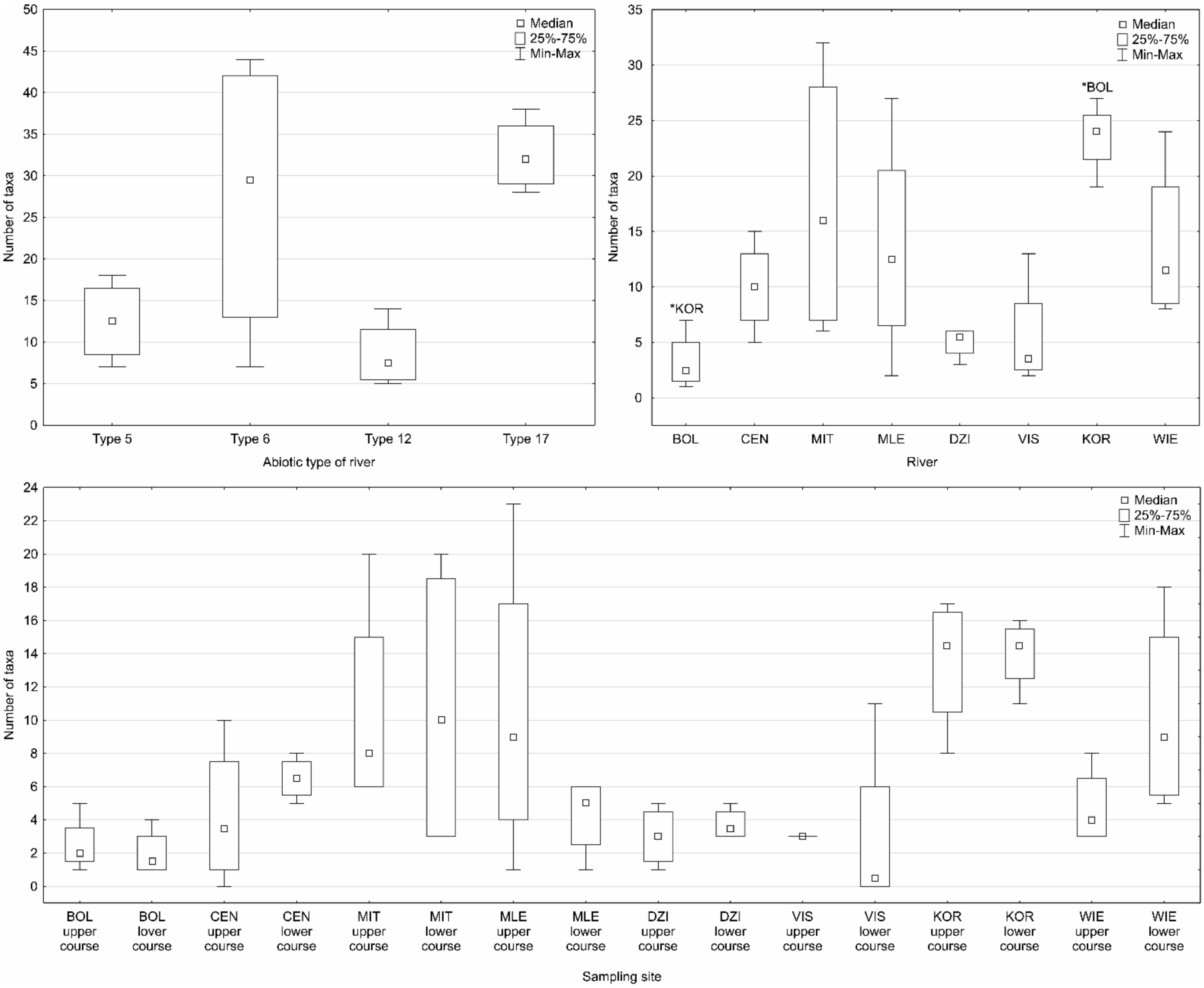

Figure 2. Box-and-whisker plot showing the number of rotifer taxa in the abiotic types of rivers, in the rivers and at the sampling sites (asterisks above a whisker denote significant differences between the rivers, $p < 0.05$). Abbreviations as in Table 1.

A multiple regression analysis revealed a significant relationship between the dependent variable, the species richness and at least three of the studied environmental variables. Table 5 presents the results of this analysis and includes information about the β-coefficients, indicating that species richness was significantly correlated with the concentration of nitrites, TDS and dissolved oxygen in the water. A regression analysis showed that 12.2% of the variance in species richness was explained by these variables ($R^2 = 0.548$, $p < 0.001$, SE = 0.287). Significant relationships existed between the species richness and the following environmental variables: the concentration of nitrites, TDS and dissolved oxygen in the water. The species richness increased with an increase in the concentration of nitrites, whereas species richness decreased with an increase in the concentration TDS and dissolved oxygen in the water (Table 5).

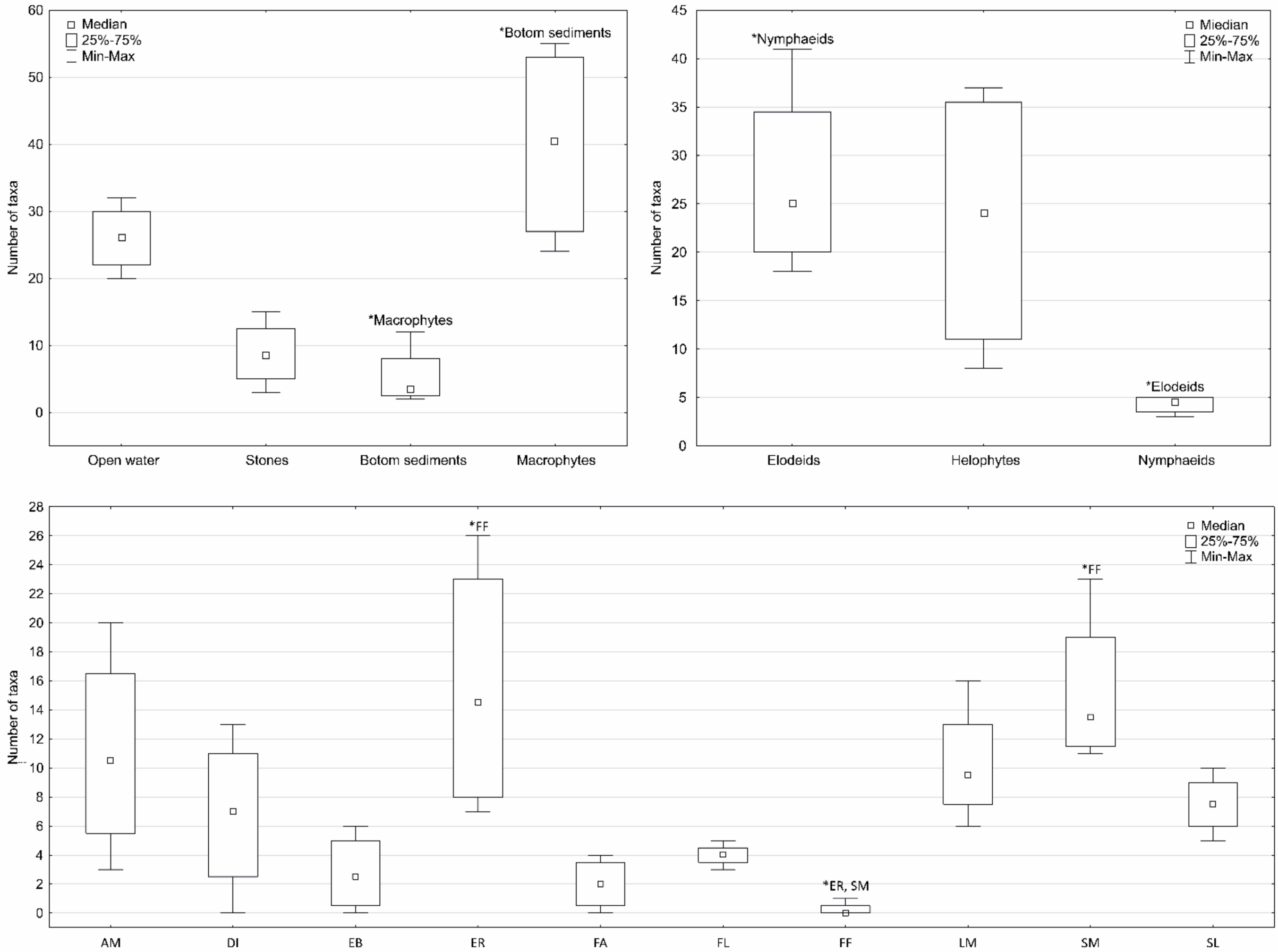

Figure 3. Box-and-whisker plot showing species richness in the different microhabitats (asterisks above a whisker denote significant differences among the rivers, $p < 0.05$). Abbreviations: AM—Amphibious; DI—Diatoms; EB—Emergent broad-leaved; ER—Emergent reeds, sedges; FA—Filamentous algae; FL—Floating-leaved (rooted); FF—Free-floating; LM—Liverworts and mosses; SM—Submerged broad-leaved; SL—Submerged linear-leave.

Table 5. The results of multiple linear regression analysis of the influence of the selected variables on species richness. Abbreviations: β—regression coefficient, SE—standard error of β.

Variable	β	SE	*t* Value	*p* Value
Width of the riverbed	0.1397	0.1820	0.7675	0.4506
Flow velocity	−0.1104	0.1552	−0.7111	0.4842
Dissolved oxygen	−0.3332	0.1487	−2.2408	0.0345
Temperature	−0.0981	0.1594	−0.6155	0.5443
TDS	−0.9488	0.4505	−2.1063	0.0463
Calcium	−0.2322	0.5140	−0.4520	0.6555
pH	−0.0774	0.1358	−0.5698	0.5743
Nitrates	0.0087	0.1286	0.0675	0.9468
Nitrites	0.6085	0.2652	2.2940	0.0313
Ammonium	−0.0855	0.1862	−0.4592	0.6504
Phosphates	−0.2075	0.1797	−1.1550	0.2600
Iron	−0.0293	0.1717	−0.1709	0.8658

4. Discussion

It is well documented that the number of aquatic invertebrate taxa increases with a river's course, which is consistent with the River Continuum Concept (RCC) [39]. However, our results indicate otherwise. The more human-induced disturbances and the degree of their intensity, the more likely it is that this trend will be reversed [40,41]. For example, Afanasyev et al. [42] found a higher diversity of rotifers in flowing water bodies than in the waters of the Vita River (estuarine region of the Vita River). We especially observed this phenomenon in the anthropogenically salinised rivers, i.e., in the Bolina and Mleczna rivers in which we recorded a lower number of rotifer taxa in the lower courses compared to the upper courses of these rivers. A broader analysis of the impact of anthropogenic salinity on rotifer communities in one of the most anthropogenically salinised rivers was presented in our previous studies [43,44]. However, the impact of the anthropogenic salinisation of flowing waters on rotifer communities is still insufficiently documented. Thus, in this work, we add another contribution to this topic. In addition, we found rare halophilic rotifers in the anthropogenically salinised rivers, namely *Brachionus plicatilis* in the Bolina River and *Testudinella clypeata* in the Mleczna River. On the other hand, we also observed a decrease in the number of rotifer taxa along with an increase in the concentration of dissolved oxygen in the water in the reference sampling sites. These sampling sites were characterised by a relatively high concentration of dissolved oxygen and a low concentration of nutrients. Therefore, they provided favourable conditions for the occurrence of only a few oligotrophic species. Another regularity that is observed in natural river ecosystems is that the nutrient concentrations increase with the course of the river [31]. We observed a statistically significant positive correlation between the species richness and the concentration of nitrites in the water. It is known that the availability of nutrients, e.g., phosphates, is crucial for the development of rotifers [43,45]. Moreover, the different species of rotifers can consume different sources of food, namely, the diet of rotifers can consist of detritus, diatoms, algae or protozoans [46,47]. The importance of phosphates is reflected in the fact that in water, they occur in the dissolved form as orthophosphates (PO_4^{3-}), which are attached to suspended inorganic particles and dissolved organic particles, mainly in bacteria and detrital particles. Other forms of phosphorus must be transformed into orthophosphates, which can only then be directly absorbed by algae and used by other organisms [40]. Hence, a higher nutrient concentration in the water promotes a greater diversity of rotifers. Therefore, our results indicate (especially in the Korzenica, Mleczna and Centuria rivers) that a greater diversity of rotifers was observed in the sampling sites richer in nutrients (contaminated by agriculture and fishponds, domestic sewage or even at reference ones with a higher concentration of nutrients) than in the sampling sites characterised by a greater depth and width of the riverbed.

Our observations are consistent with the focus on local conditions when analysing microinvertebrates, especially in small rivers [48,49]. When the local pollution is strong, it can significantly affect the shaping of rotifer communities. Therefore, this indicates that the rotifer communities in small rivers are a valuable tool that can be used in assessing human pressure on the aquatic environment. Therefore, further studies are needed, including, in particular, a quantitative analysis of the rotifer communities in different types of rivers under varying anthropogenic pressures (and including reference sites).

The planktonic animal organisms that constitute part of zooplankton (Cladocera, Copepoda, Rotifera) are indicators of anthropogenic changes in running aquatic environments [42,50–59]. However, in both small lowland and highland rivers, the retention time that is required to develop planktonic organisms and to maintain a large abundance of planktonic organisms may be too short. As a result, in small rivers, the zooplankton can only be represented by tychoplankton. In addition, a slower flow velocity and less intense turbulence can help to reduce the diversity and abundance of planktonic organisms through the phenomena of sedimentation and fish predation [43,60,61]. This results in poor knowledge about the zooplankton communities in small lowland and upland rivers, particularly in mountain rivers [55]. For example, the first study recently showed spatial changes in the zooplankton composition in a small mountain river relative to environmental changes in the catchment area and riverbed transformations [62]. However, studies of the species richness of rotifers in small rivers in the Ukraine (tributaries of the Dnieper River) showed a high species richness of rotifers in natural rivers and in rivers with a periodic alteration of the direction and velocity of the flow. High numbers of rotifer taxa were related to the location of rivers in natural flood land because the species richness of rotifers in the rivers located in flood land that was partially or totally drained (regulated or canalised rivers) was visibly lower [53]. In some of the studied rivers, we identified rotifers typical for pelagic zooplankton, for example, *Asplanchna priodonta*, *Brachionus angularis*, *Filinia longiseta*, *Keratella cochlearis*, *K. quadrata*, *K tecta*, *Polyarthra vulgaris* and *Pompholyx sulcata*. However, their presence can be explained by the connectivity of these rivers with water reservoirs. Therefore, the planktonic samples from most of the rivers were mainly represented by tychoplankton. Thus, our research is a comprehensive analysis and up-to-date survey that focuses on rotifers in small lowland and upland rivers, showing the diversity of rotifers relative to various microhabitats and environmental variables. The methods we used were different because of the various types of microhabitats, such as open waters, stones, macrophytes and bottom sediments. A high level of the contamination of the samples of the bottom sediments and macrophytes (including diatoms) collected from some of the sampling sites, which was caused, among others, by the presence of coal silt in rivers under the influence of mine waters, made it necessary to analyse live samples. This situation meant that preserving the periphyton samples would make it impossible to identify the individuals of most species from the Bdelloidea subdivision because they were abundant in such samples. Due to the long duration of analysing such quantitative samples, this is impossible to realise in a small team. Therefore, we suggest that each microhabitat be analysed separately. This will enable a proper quantitative analysis of the periphyton samples despite the lack of a uniform sampling methodology, which makes it difficult to compare studies. The importance of this problem was indicated more than 20 years ago [13], and it has not been solved as yet.

Until recently, research on rotifers has focused almost entirely on their role in the environment in areas of zooplankton research [63,64]. However, recently increased attention has been paid to the functional role of rotifers with particular reference to the functional feeding groups [41,65]. It is known that macrophytes create extremely complicated habitats that determine the formation of many ecological niches, as well as the possibility for the coexistence of various organisms [16,66,67]. In addition, the role of habitat heterogeneity is assessing the diversity of other groups of organisms (rotifers in this case) as well as the potential of the sampling taken approach (especially rotifers) from a different habitat, which can not only be used in assessing the quality of the environment in large water bodies [16,68–70]. Studies concerning small water reservoirs have shown that the diversity of rotifers depends on the water reservoir zone and its characteristics. For example, a recently published study showed that a littoral zone with elodeids had a greater diversity of rotifers than the same zone with helophytes or the pelagic [16]. Our studies, which focused on both planktonic and periphytic samples, were compatible with these results. Moreover, we took it a step further and showed that the taxonomic diversity of rotifers depends on the leaf morpha groups, including diatoms. However, such an approach requires further detailed research that is mainly based on seasonal quantitative studies. This is important because it has been documented that, in shallow ecosystems, plant morphology can play a crucial role in the ecological assessment and protection of small water bodies [71,72]. Research that is based on rotifers in small rivers has not focused on this aspect. Future studies on rotifers in small rivers should not only include the analysis of planktonic, but also periphytic samples. This would offer more possibilities for analyses and could be the basis for their use in river monitoring. In addition to the arguments presented above, this is supported by the common occurrence of macrophytes in the aquatic environment, as well as the ease of collecting periphyton samples.

Detailed taxonomic studies of the rivers of Upper Silesia and adjacent areas revealed a large diversity of rotifers, which were represented by almost 130 taxa, including some rare species, mainly for Poland, in particular: *Brachionus plicatilis*, *Cephalodella delicata*, *C. globata*, *C. misgurnus*, *Dicranophorus rostratus*, *Encentrum marinum*, *E. lupus*, *E. tyrphos*, *Lepadella elliptica*, *Limnias melicerta*, *Lindia torulosa*, *L. truncata*, *Notommata groenlandica*, *Proales theodora*, *Proalinopsis squamipes* and *Testudinella clypeata*. One of these, namely *N. groenlandica*, is known from several countries in Europe and in this study, it was rediscovered in the present-day territory of Poland after more than 100 years. We found this species in the periphytic samples (on *Glyceria nemoralis* and *Sparganium erectum*) in two rivers (the Centuria and Wiercica rivers). Its current closest known place of occurrence is at a distance of at least 400 km [73,74]. Our results provide a great deal of new data on the ecology of many species of rotifers. For example, to date, *Notommata groenlandica* has been known to occur only in acidic environments such as peat bogs, ponds and has been found only in moss and acid silt samples [33,75]. These observations indicate that these species, which are considered to be rare, are likely to be spread more widely and that the habitat preferences of rotifers might be much broader than those that are currently known. Therefore, more research is required on the rotifers in small rivers.

5. Conclusions

The present study revealed that rotifers inhabit rivers subjected to various types of anthropogenic pressure that have a wide range of physical and chemical parameters of the water. They were found in extremely degraded rivers with a salinity of up to 33.55‰ (the Bolina and Mleczna rivers), which is comparable to that of the seas (e.g., the salinity of the North Sea ranges at about 35.0‰), as well as a relatively high conductivity, and the concentrations of nutrients, i.e., ammonium, nitrites, nitrates, phosphates. The maximum number of rotifer taxa was recorded in the mid-altitude calcareous streams, with a fine particulate substratum on loess (type 6) and very high concentrations of phosphates up to 19.20 mg dm^{-3}. Our study showed that the diversity of the rotifer communities in small rivers affected by various types of anthropogenic pressure is influenced by several (statistically important) environmental factors, including TDS, the concentration of dissolved oxygen in the water, nitrites, and also by the seasons. The research also revealed a large taxonomic diversity of rotifers relative to the different microhabitats. The highest taxonomic richness of rotifers was observed in the rivers characterised by a high concentration of nutrients in the water. At the same time, the highest number of rotifer taxa was recorded on macrophytes (elodeids) compared to the other microhabitats (open waters, stones, bottom sediments or other forms of plant growth). Periphytic rotifers and tychoplankton mainly represented the rotifer communities in these rivers. Among the identified species, the occurrence of *Notommata groenlandica* in Poland was rediscovered after more than 100 years. In addition, in this paper, new data on the ecology of some species of rotifers are provided. Therefore, small rivers, mainly those with a large diversity of aquatic vegetation, provide a suitable habitat for the development of rotifer communities. Since planktonic rotifers have successfully been used in monitoring stagnant waters, the presented results can be used as baseline study for the use of rotifers in monitoring small rivers. The finding related to the type of samples, i.e., bottom sediments, stones, should be considered since we proved that not all types of samples can be suitable for this kind of research. Finally, the research has shown that rotifers can be used as a valuable tool in assessing human pressure on small rivers, although more research is required, especially when comparing them to the reference sampling sites.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/d14020127/s1, Figure S1: Study area and sampling sites, Table S1: The physical and chemical parameters of the waters of the studied rivers (ranges) and the results of the Kruskal–Wallis one-way ANOVA and Dunn's multiple comparison post hoc tests (superscript $^{a, b, c, d, e, f, g, h}$ denote significant differences between the rivers), Table S2: The physical and chemical parameters of the waters of the sampling sites (ranges) and the results of the Kruskal–Wallis one-way ANOVA and Dunn's multiple comparison post hoc tests (superscript [a, b, c, d, e, f, g, h] denote significant differences among the rivers). Abbreviations: UC – upper course, LC – lower course.

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