Biodiversity of Zooplankton in Polish Small Water Bodies

Natalia Kuczyńska-Kippen

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Abstract Although ponds located in a low-transformed landscape harbour higher biodiversity than ponds in areas with a large impact of anthropopression, both types of water bodies can contribute to the enrichment of fauna on local and regional scales. This review presents aspects of pond zooplankton diversity with reference to the occurrence of species, common and rare, and significant drivers of their distribution. The results of various studies carried out on small water bodies in Poland revealed a great level of zooplankton diversity, which points directly to a high variation of the origin of types of ponds. Land use within the direct catchment area influences the creation of zooplankton diversity, although a greater impact is connected with various habitats, particularly the open water zone and macrophyte-dominated areas. The complex architecture of elodeids is responsible for the highest zooplankton diversity with many rare species, offering a great number of available

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ecological niches for littoral animals and profitable anti-predator conditions for planktonic species. Therefore, one should strive to maintain or even increase the complexity of aquatic vegetation within even small-surfaced ponds. The generally high share of rare species found in ponds underlines their high ecological value but, at the same time, a lack of thorough studies. The most common rotifers found in Polish ponds were *Keratella cochlearis*, *Anuraeopsis fissa*, *Polyarthra vulgaris* and *Keratella quadrata* as well as *Chydorus sphaericus*, *Bosmina longirostris*, *Ceriodaphnia quadrangula* and *Eubosmina coregoni* among crustaceans. This reflects the wide ecological valence of these species and suggests that most ponds are eutrophic.

Keywords Aquatic diversity · Catchment type · Human impact · Macrophytes · Microcrustaceans · Origin type · Ponds · Rotifers

1 Introduction

1.1 Ponds as a Valuable Habitat for Maintaining Biodiversity

Small water bodies are among freshwater ecosystems which are critical for maintaining high biodiversity. Their large abundance in many parts of the world and greater total area than lakes contribute to an extremely high level of global diversity [1]. However, due to their small size and depth, they can be exposed to severe human disturbances [2, 3], and freshwater biodiversity may decline in response to human land use, eutrophication and habitat destruction while increasing in the presence of natural drivers such as area and habitat heterogeneity [4]. Despite being prone to human-originated stressors in the direct catchment area (e.g. agricultural or urban areas), they often remain undamaged and thus create a refuge for diverse organisms, including zooplankton, which may have disappeared from more polluted aquatic systems [3]. From the point of view of ecology, ponds play a very important ecotone role, being a transitional system between various biocoenoses and aquatic ecosystems and also creating an interface between terrestrial and aquatic environments. In this way they build a bridge that connects various wetlands, favouring the migration of many species. Small water bodies, along with boughs, mid-field woodlots and also ditches, small streams, oxbows or wetlands, are an element important for the preservation and enrichment of biodiversity, both in the biological, habitat and landscape aspects of a certain area.

Despite having a multiplicity of extremely useful functions, small water bodies have never been a central object of interest for the scientific community and have not been included in proper and long-term monitoring studies for centuries [3, 5]. Neither has their proper classification been developed even though many recent studies have shown that distinct differences in their functioning, compared to lake ecosystems, exist (e.g. [6]). The same concerns the lack of information on their functioning and inhabiting organisms, including zooplankton. Most organisms found in ponds are generally common species of a wide range of tolerance to environmental factors and can be found also in other types of freshwaters. However, due to the occurrence of more specialised species, the communities of plankton organisms can be quite specific and are called heleoplankton. Characteristics of biocoenoses of small water bodies require taking into account a number of different environmental factors, such as origin, pond morphology, specificity of the location in a diverse landscape, hydrological relations, abiotic parameters of their waters as well as various types of habitats. These diverse habitat elements will be responsible for the development of diverse but also specific plankton communities.

2 Zooplankton Diversity in Ponds

2.1 Taxonomic Diversity of Zooplankton

Small water bodies contribute greatly to preserving but also enriching the biodiversity both on a local and regional scale, making up an optimal habitat for many groups of organisms. Natural ponds in various landscapes are usually expected to host higher species diversity than nutrient-rich degraded ponds, such as fishponds, urban ponds or those located within an agricultural landscape. However, if the biodiversity of such an individual pond remains rather low, it can contribute to much higher diversity at the regional level [7]. This is why to ensure the maximum possible biodiversity, conservation practices should consider the landscape-scale organisation of ecological communities [8].

The diversity of zooplankton communities greatly depends on a number of environmental factors. However, the potential diversity reflects study regularity and the amount of studied water bodies and/or sites. Recognition of the taxonomic structure of zooplankton also refers to the recognition of their diverse habitats. According to [9], as a result of thorough seasonal analysis of zooplankton, each temperate water body will contain ca. 150 rotifer species. Looking at the examination intensity as well as the number of studied ponds, the same pattern of species richness was obtained for ponds in central-western Poland (Table 1). The highest diversity was attributed to the greatest amount of water bodies taken into account, where almost 300 ponds were examined in the Wielkopolska province. A similar species number was obtained for a group of only six ponds, studied on regular basis, 13 times in 1 year, compared to a much larger group of ponds (55), examined on only one occasion.

The research on 54 ponds, with 28 pastoral and 26 forest ponds, revealed a high richness with 265 zooplankton species in total [10]. The most diverse genus was *Lecane* (Fig. 1) with 26 species, which constitutes almost half of the lecanid structure in Poland. This genus is very diverse, inhabiting predominately benthic and littoral environments, both dominated by floating-leaved plants, submerged macrophytes or helophytes [11]. The greatest diversity occurs in the standing or slowly flowing waters of tropical and subtropical climatic zones, where up to 40 species can be found in one water body. Some *Lecane* species (e.g. *Lecane bulla, Lecane luna*,

Table 1 The total number of species with the mean number of species and SD as well as minimum (min) and maximum (max) values of Rotifera, Cladocera and Copepoda in the open water area of small water bodies in four provinces in Poland

No of study	N samples	N species Rotifera		N species Cladocera		N species Copepoda	
		Total (mean ± SD)	Min–max	Total (mean ± SD)	Min–max	Total (mean ± SD)	Min–max
1.	278	258 (21 ± 10)	0–57	63 (5 ± 3)	0–18	34 (2 ± 2)	0–9
2.	74	122 (20 ± 5)	7–35	30 (4 ± 3)	0–14	19 (2 1 1)	1–5
3.	55	132 (18 ± 7)	5–41	32 (5 ± 4)	0–14	22 (2 ± 2)	0–6
4.	42	66 (18 ± 6)	5–29	24 (7 ± 3)	1–13	10 (2 ± 2)	0–6
5.	27	93 (19 ± 8)	4–36	24 (5 ± 3)	1–10	13 (2 ± 2)	0–5
6.	15	61 (15 ± 3)	7–20	22 (4 ± 3)	1–10	5 (1 ± 1)	0–3

Total number of samples in each study is given
1. 278 ponds; sampled once (2006–2015); region: Wielkopolskie province
2. 6 ponds; sampled 13 times in 1 year (2009); region: Kujawsko-Pomorskie province
3. 55 ponds; sampled once (2006–2013); region: Kujawsko-Pomorskie province
4. 6 ponds; sampled 7 times in 1 year (2009); region: Poznań agglomeration, Wielkopolskie province
5. 27 ponds; sampled once (2010); region: Dolnośląskie province
6. 15 ponds; sampled once (2010); region: Lubuskie province

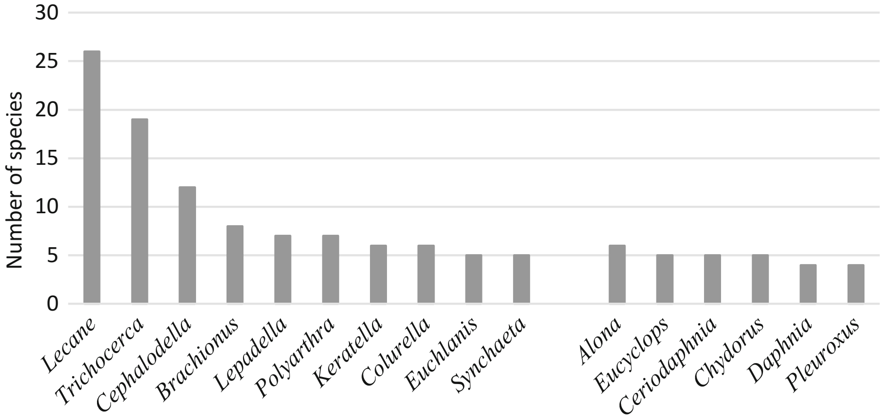

Fig. 1 The number of zooplankton species representing certain genus in small water bodies

Lecane closterocerca or *Lecane lunaris*) are considered to be eurytopic, frequently occurring in Polish ponds (Table 2). *Trichocerca*, the second rich genus in terms of the number of species, is mainly characteristic of vegetated zones. Its presence in the pelagic zone is usually accidental, a result of being washed away from among macrophytes. Thus, only some species, e.g. *Trichocerca capucina* or *Trichocerca pusilla*, occur in the open water. Altogether 19 species were identified, out of 37 trichocercids in Poland [11], with *Trichocerca similis*, *Trichocerca pusilla* and *Trichocerca rattus* being most frequent in ponds. The third genus of significant importance for Rotifera species richness was *Cephalodella*, which has 41 species in

Table 2 The most frequent species (with the level of frequency in %) – ≥5%, representing Rotifera, Cladocera and Copepoda in the open water area of a set of 410 small water bodies located within the central-western part of Poland

Rotifera	%
Keratella cochlearis (Gosse)	76
Lecane closterocerca (Schmarda)	65
Bdelloidea	65
Anuraeopsis fissa (Gosse)	59
Polyarthra vulgaris Carlin	57
Keratella quadrata (O.F. Müller)	50
Lepadella patella (O.F. Müller)	47
Brachionus angularis Gosse	46
Colurella uncinata (O.F. Müller)	45
Keratella cochlearis f. *tecta* (Lauterborn)	44
Polyarthra remata (Skorikov)	39
Trichocerca similis (Wierzejski)	38
Filinia longiseta (Ehrenberg)	38
Lepadella ovalis (O.F. Müller)	35
Testudinella patina (Hermann)	34
Brachionus quadridentatus (Hermann)	32
Mytilina ventralis (Ehrenberg)	29
Mytilina mucronata (O.F. Müller)	27
Trichocerca pusilla Lauterborn	27
Colurella adriatica Ehrenberg	26
Lepadella quadricarinata (Stenroos)	26
Lecane hamata (Stoces)	26
Synchaeta pectinata Ehrenberg	26
Lecane bulla (Gosse)	25
Euchlanis dilatata Ehrenberg	24
Asplanchna priodonta Gosse	23
Lecane luna (O.F. Müller)	23
Cephalodella catellina (O.F. Müller)	21
Trichocerca rattus (O.F. Müller)	21
Cephalodella gibba (Ehrenberg)	20
Keratella testudo (Ehrenberg)	20
Lecane lunaris (Ehrenberg)	20
Brachionus calyciflorus Pallas	20
Colurella obtusa (Gosse)	16
Pompholyx complanata Gosse	16
Lepadella rhomboides (Gosse)	19
Pompholyx sulcata (Hudson)	15
Cephalodella ventripes Dixon-Nuttall	14
Trichocerca weberi (Jennings)	14
Ascomorpha ecaudis (Perty)	13
Cephalodella auriculata (O.F. Müller)	12

(continued)

Table 2 (continued)

Polyarthra major Burckhardt	11
Squatinella rostrum (Schmarda)	11
Brachionus rubens Ehrenberg	10
Lepadella acuminata (Ehrenberg)	10
Lepadella triptera Ehrenberg	10
Lophocharis oxysternon (Gosse)	10
Platyias quadricornis (Ehrenberg)	10
Lecane quadridentata (Ehrenberg)	9
Trichotria pocillum (O.F. Müller)	9
Trichocerca dixon-nuttalli (Jennings)	9
Keratella ticinensis (Callerio)	8
Dissotrocha aculeata (Ehrenberg)	8
Lecane furcata (Murray)	8
Polyarthra dolichoptera Idelson	17
Brachionus budapestinensis (Daday)	7
Ascomorpha saltans Bartsch	7
Filinia brachiata (Rousselet)	7
Brachionus diversicornis (Daday)	6
Lophocharis salpina Ehrenberg	6
Trichocerca brachyura (Gosse)	6
Gastropus hyptopns (Ehrenberg)	6
Testudinella mucronata (Gosse)	6
Trichocerca capucina Wierzejski & Zacharias	6
Colurella colurus (Ehrenberg)	5
Scaridium longicaudum (O.F. Müller)	5
Kellicottia longispina (Kellicott)	5
Lecane elsa Hauer	5
Beauchampiella eudactylota (Gosse)	5
Lecane flexilis (Gosse)	5
Cephalodella tenuior (Gosse)	5
Trichocerca vernalis Hauer	5
Filinia terminalis (Plate)	5
Hexarthra mira (Hudson)	5
Lecane nana (Murray)	5
Trichocerca musculus (Hauer)	5
Cladocera	%
Chydorus sphaericus (O.F. Müller)	59
Bosmina longirostris (O.F. Müller)	45
Ceriodaphnia quadrangula (O.F. Müller)	28
Eubosmina coregoni Baird	26
Scapholeberis mucronata (O.F. Müller)	20
Simocephalus exspinosus(Koch)	16
Ceriodaphnia pulchella Sars	16

(continued)

Table 2 (continued)

Alonella excisa (Fischer)	15
Pleuroxus aduncus (Jurine)	15
Daphnia pulex (De Geer)	14
Alona rectangula Sars	13
Daphnia cucullata Sars	11
Diaphanosoma brachyurum (Lievin)	10
Daphnia longispina O.F. Müller	10
Acroperus harpae (Baird)	10
Ceriodaphnia reticulata (Jurine)	10
Daphnia galeata Sars	8
Alonella exigua (Lilljeborg)	8
Graptoleberis testudinaria (Fischer)	6
Simocephalus vetulus (O.F. Müller)	6
Peracantha truncata (O.F. Müller)	6
Ceriodaphnia laticaudata P.E. Müller	5
Tretocephala ambigua (Lilljeborg)	5
Copepoda	%
Thermocyclops oithonoides (Sars)	21
Mesocyclops leuckarti (Claus)	15
Megacyclops viridis (Jurine)	13
Harpacticoidae	11
Eudiaptomus gracilis (Sars)	10
Eucyclops serrulatus (Fischer)	8
Cyclops vicinus (Sars)	7
Acanthocyclops vernalis (Fischer)	6
Eucyclops macruroides (Lilljeborg)	5
Eudiaptomus graciloides (Lilljeborg)	5

Poland [11]. In the analysed ponds, 12 species were found, mainly inhabitants of periphytic environments with *Cephalodella catellina*, *Cephalodella gibba* and *Cephalodella ventripes* occurring as the most common. In turn, the *Brachionus* genus is considered to favour environments with large areas of open water. In macrophytes, brachionids, such as *Brachionus quadridentatus*, choose loosely arranged habitats where they can freely swim between individual plants. In the analysed ponds, as many as eight *Brachionus* species were found, which constitutes half of the *Brachionus* fauna in Poland. Among them *Brachionus angularis*, *Brachionus quadridentatus* and *Brachionus calyciflorus* were most frequent. The majority of brachionids are indicators of high trophic state of water [12]. Two more genera, *Lepadella* and *Polyarthra*, were represented by seven species each, constituting 30% and 100% of species identified from Poland. *Lepadella* is a typically littoral-associated genus, while *Polyarthra* prefers open water environments. *Polyarthra major* prefers low-trophy waters, while *Polyarthra longiremis* is associated with eutrophic waters [11]. Generally *Polyarthra vulgaris*, *Polyarthra remata* and *Polyarthra major* as well as *Lepadella patella*, *Lepadella ovalis* and *Lepadella quadricarinata* were common in Polish ponds. Moreover, six species were found among the *Colurella* and *Keratella* genera. All colurellids are periphytic organisms, while *Keratella* is a limnetic genus. One of the most frequently occurring species was *Keratella cochlearis*. *Keratella cochlearis* f. *tecta* and *Keratella quadrata*, both frequently occurring in the analysed material, are indicators of eutrophic waters [12], so their mass appearance corresponds to a high trophy of ponds. Among colurellids, *Colurella uncinata*, *Colurella adriatica* and *Colurella obtusa* were most frequent. Other genera were represented by five or less species (Table 2).

From among crustaceans, the *Alona* genus, a typical macrophyte-rich inhabitant [13], was the most diverse with five species, *Alona affinis*, *Alona costata*, *Alona guttata*, *Alona rectangula* and *Alona rustica*, out of ten recorded from the Polish fauna. Three genera, *Eucyclops*, *Ceriodaphnia* and *Chydorus*, were represented by five species each. The genus *Eucyclops*, usually described as epibenthic, is represented in the Polish fauna by five species [13], and all of them were also found in the studied ponds. Ceriodaphnids are encountered in both pelagic and littoral environments [14]. Out of eight Polish species, five – *Ceriodaphnia laticaudata*, *Ceriodaphnia megops*, *Ceriodaphnia pulchella*, *Ceriodaphnia quadrangula* and *Ceriodaphnia reticulata* – were found in the studied ponds. The first two species preferably inhabit ponds, while the three remaining are typical of various types of water bodies. *Ceriodaphnia quadrangula* belonged to the most frequent ceriodaphnids (Table 2). *Chydorus*, with five species found in ponds, is known to inhabit a variety of freshwater environments, often preferring macrophyte-dominated habitats.

2.2 Most Frequent Zooplankton Species

There were 48 rotifer species found in more than 10% of over 400 studied ponds from central-western Poland. Despite analysing only the open water, the most frequent species were both of pelagic and littoral origin. However, limnetic species, such as *Keratella cochlearis*, *Anuraeopsis fissa*, *Polyarthra vulgaris* and *Keratella quadrata*, were of the highest frequency (Table 2).

Keratella cochlearis, a representative of the family Brachionidae, is known for being widely distributed, also in diverse Polish waters [15–17]. In ponds, *Keratella cochlearis* was recorded in 216 sites out of 254 investigated sites (85%), which confirms its cosmopolitan range. Its size and spine length are smaller in eutrophic and hypertrophic waters than in mesotrophic and oligotrophic [18]. Moreover, its morphology may also be associated with the presence of fish. Therefore, this common species *Keratella cochlearis* also plays an indicative role. *Lecane closterocerca*, recorded from 65% of ponds, is a periphytic species. Its common presence might result from a generally littoral character of ponds which are often overgrown by macrophytes. However, it is also very common in the open water patches of ponds, often being a dominating species [16, 19]. Moreover, bdelloids as a group reached a high frequency. This reflects the high variability of conditions prevailing in ponds as bdelloids inhabit specific freshwater environments among which are moist soils, mosses, bogs [20], psammic habitats [21] or extremely cold habitats [22]. But they are also typical for lakes, streams and springs [23] as well as for small water bodies [24] which can be prone to serious changes in abiotic parameters, specifically changes in the water level [7]. Another three species, which reached a very high frequency in Polish ponds, *Anuraeopsis fissa*, *Polyarthra vulgaris* and *Keratella quadrata* (Table 2), are typically limnetic species, commonly occurring in various types of water bodies all over the world.

From among crustaceans, 16 cladoceran and 5 copepod species occurred with $\geq$10% frequency (Table 2). *Chydorus sphaericus*, *Bosmina longirostris*, *Ceriodaphnia quadrangula* and *Eubosmina coregoni* were the most common cladocerans in the central-western part of Poland. The first two species are indicators of eutrophy in lakes, suggesting the generally high trophic state of the majority of ponds [25]. *Chydorus* sphaericus is one of the most widespread species from among freshwater crustaceans [14, 26], often belonging to dominating species [27, 28]. It inhabits a range of plant-associated habitats but is also known for its adaptation to lead a pelagic lifestyle due to the fact that it uses filamentous algae as both a substrate and a food source [29]. *Bosmina longirostris*, with a high adaptive ability to changing conditions, is also a worldwide distributed species [30], often occurring in Polish ponds [31].

2.3 Rare Zooplankton

Ponds in Poland are often a source of species of a high conservation value, including zooplankton [27]. A comparison made between five types of water bodies (lakes, ponds, ditches, rivers, streams) within an agricultural area in lowland England proved that ponds supported the highest biodiversity in respect to the number of species and the highest index of species rarity across the studied area [32]. The occurrence of rare species in freshwaters depends on many factors, where the degree of recognition of a particular type of ecosystem is very important. Many faunistic studies, usually carried out in the previous century, contributed valuable information on the occurrence of such species (e.g. [33–35]). Ponds located within a natural landscape of low anthropogenic transformation may have a high ecological value, being a rich source of rare or threatened species, but ponds located in agricultural areas also contribute to the enrichment of regional diversity due to the presence of their own unique species. Therefore, even if it is presumed that intensified anthropopressure will reduce the chance of rare species occurring, the maintenance of habitat complexity referring to various macrophyte cover increases overall biodiversity and that of species that are infrequent in the national fauna.

A detailed analysis of 54 ponds [10] revealed the presence of 39 species of zooplankton that are rare or are described as infrequently occurring in the Polish fauna [11, 14], mainly from among rotifers – 29 species representing 15 genera.

Among cladocerans, nine such species from among seven genera were found and only one copepod species (Table 3). Contrary to expectation, field ponds had more rare species (31) than forest ponds (23). Most of these species were littoral-associated, which is a signal for the need to conduct research not only in the open water but also in vegetated zones, despite the small area of ponds. Finding such a large number of rare species also likely resulted from the lack of interest in conducting basic research and thus a small degree of recognition of this ecosystem. In most cases, a positive relationship between the number of rare species with the Shannon-Weaver diversity index and zooplankton richness was found, while a negative relation existed with abundance. Among rare species from Wielkopolska, *Brachionus polyacanthus* deserves special attention as this is the second report regarding this species from Poland [10]. In another study carried out on 65 ponds differing in regard to catchment type, origin, depth, size, macrophyte cover, the presence of fish and level of shading, out of 197 taxa identified, 32 were classified as rare, endangered or new to Polish fauna [36]. The comprehensive study, conducted over 5 years, on microcrustaceans within different types of aquatic environments in the Upper Narew Valley presented 74 species in 559 samples, with a new species for the Polish fauna (*Metacyclops planus*) from oxbows [37]. This indicates a necessity for conducting detailed analyses encompassing various ecosystems. Moreover, a study of 53 ponds in south-eastern Poland (the Central Roztocze Upland) revealed the presence of 54 cladoceran species with several rare species: *Ceriodaphnia dubia*, *C. rotunda*, *C. setosa*, *Bunops serricaudatus*, *Ilyocryptus agilis*, *Lathonura rectirostris*, *Macrothrix laticornis*, *M. rosea*, *Streblocerus serricaudatus*, *Chydorus ovalis* and *Rhynchotalona falcata* [38]. The author suggests that most of these species belonged to the Macrothricidae family, mainly consisting of benthic organisms. This is why they are often overlooked during typical studies, such as in the open water area. Therefore their rarity may be misleading.

Furthermore, some rare species may be found in small water bodies of unique type, such as mining subsidence pools. A study in the Silesian Uplands (southern part of Poland) revealed the presence of a rare halophilous species *Notholca salina*, observed in hypo- and mesosaline ponds [39]. It was underlined that identification of rare species is often restricted due to the low frequency of conducted studies. *Notholca salina*, like other *Notholca* species, occurs in cold seasons. This is why in studies carried out in the optimum summer season, such species do not appear, and the overall biodiversity may be underestimated. Another type, meteor craters, a very rare type of pond worldwide, can also be a source of rare species. A study conducted on a group of such ponds, located in the forest near the city of Poznań, revealed rare zooplankton species such as *Keratella paludosa*, *Lecane elsa* and *Tretocephala ambigua* [40, 41]. However, the origin of ponds was not decisive; rather the specificity of environmental conditions favoured the occurrence of diverse communities along with rare species. Other specific habitats are artificial ponds located in botanical gardens or palm houses, such as the Poznań Palm House where the presence of rare species for Poland, *Asplanchna herricki*, *Colurella sulcata* and *Gastropus minor*, were detected [42]. It is not only in specific types of pond that rare species can be found; they can also be found in ponds used for fish

Table 3 The frequency (in %) of rare species in a group of 54 ponds, located in field (28) and forest (26) ponds[a]

Rotifera	%
Asplanchna sieboldi (Leydig)	2
Brachionus polyacanthus (Ehrenberg)	2
Cephalodella gibboides Wulf	11
Cephalodella gigantea Remane	2
Cephalodella mus Wulfert	21
Cephalodella tenuiseta Burn	2
Colurella sulcata (Stenroos)	15
Colurella tesselata (Glascott)	2
Euchlanis triquetra Ehrenberg	8
Lecane aculeata (Jakubski)	11
Lecane bifurca (Bryce)	2
Lecane clara (Bryce)	2
Lecane inermis (Bryce)	4
Lecane nana (Murray)	13
Lecane pyriformis (Daday)	12
Lecane stenroosi (Meissner)	2
Lepadella cristata (Rousselet)	2
Lepadella elliptica Wulfert	2
Lepadella triba Myers	2
Microcodon clavus Ehrenberg	2
Mytilina trigona (Gosse)	2
Notommata glyphura Wulfert	8
Plationus patulus (O.F. Müller)	4
Ptygura furcillata (Kellicott)	2
Resticula gelida Herring et Myers	2
Testudinella incisa (Ternetz)	2
Trichocerca bidens (Lucks)	2
Trichocerca iernis (Gosse)	6
Trichocerca vernalis Hauer	6
Cladocera	%
Alona karelica Stenroos	10
Alona rustica Scott	24
Chydorus gibbus Sars	2
Chydorus ovalis Kurz	4
Dunhevedia crassa King	6
Leydigia acanthocercoides (Fischer)	4
Moina brachiata (Jurine)	2
Scapholeberis kingi Sars	2
Tretocephala ambigua (Lilljeborg)	4
Copepoda	%
Paracyclops affinis (Sars)	2

[a]Material taken from [10], changed

farming, such as the rotifer *Filinia opoliensis* recorded by [43]. The occurrence of rare species for the Polish fauna is also connected with climate change. This supports the arrival of new tropical or subtropical species [44], which can be primarily found in heated lakes [45, 46] and then start their march into other aquatic ecosystems, including ponds. The determination of the optimum conditions for the occurrence of rare species will help to provide a basis of helpful knowledge for the management of small water bodies and thereby assist in promoting their rank on the landscape scale.

3 Drivers of Zooplankton Diversity in Ponds

There are variety of environmental factors that are responsible for structuring zooplankton and its diversity in small water bodies. Among them, biological predation from both planktivorous fish and invertebrates as well as competition among certain groups of zooplankton is some of the most important [47, 48]. In the case of abiotic factors, both physical and chemical variables impact zooplankton diversity [49]. Specifically, the water quality features have a pronounced effect on the evolution of distinct communities and particularly the diversity of both rotifers and microcrustaceans [25]. Moreover, the origin of ponds and the type of direct catchment are known to structure zooplankton assemblages in ponds, and finally the habitat type, belonging to the most significant predictors.

3.1 Zooplankton in Ponds of Various Trophic States

Zooplankton diversity can be used as a valuable tool for the assessment of water quality in ponds. Rotifers and cladocerans segregate with respect to water trophy. Eutrophic conditions are often associated with the highest diversity of rotifers, while mesotrophic conditions favour high diversity of crustaceans. This was demonstrated in the study conducted in various habitats (open water, helophytes, elodeids) of 274 pastoral ponds; in the central-western Poland, it was demonstrated that in each trophic state, the biomass of macrophytes was a key predictor of zooplankton diversity [25]. Specifically, a shift was recorded from the high preponderancy of elodeids (e.g. plant beds with *Myriophyllum* spp. or *Ceratophyllum demersum*) that were responsible for a rise in zooplankton diversity in mesotrophic waters to helophytes (*Typha angustifolia* or *Phragmites australis*) in hypereutrophic ponds. However, hypereutrophic conditions, caused by nutrient overloading, were unfavourable for zooplankton diversity.

Poor quality of water in ponds can also be detected by analysing the share of eutrophic species (e.g. *Anuraeopsis fissa*, *Brachionus angularis*, *Keratella cochlearis* f. *tecta*, *Keratella quadrata*, *Bosmina longirostris* and *Chydorus sphaericus*), which were among most frequent in Polish ponds. It was also noticed that the percentage of eutrophic species differed significantly between certain microhabitats. In forest ponds the open water area along with helophytes possessed the highest, while elodeids harboured the lowest share of eutrophic species [50].

3.2 Zooplankton in Ponds of Various Origins

Small water bodies represent different origin types, which in turn may have an impact on abiotic characteristics of water and also the life conditions for the inhabiting organisms. The basic division may refer to natural ponds such as kettle holes, oxbows and meteorite craters or to artificial ponds – man-made ponds, e.g. clay, gravel and sandpits – or mining subsidence reservoirs. Human activity contributes to the artificial creation of many ponds for industrial, agricultural or recreational purposes but also for fish production or fishing, or for purely aesthetic reasons, enriching the beauty of the landscape, such as park or ornamental ponds. Ponds can also be created for the needs of the ecosystem (e.g. fire protection, flood protection, depositing nutrients, etc.) but currently also as an educational tool and for experimental research.

Man-made small water bodies often contain a high diversity and can also host ecologically valuable species. A study conducted on peatbogs of the Łeczyńsko-Włodawskie Lakeland has shown that planktonic rotifer communities had high species diversity as well as the presence of rare species [51, 52]. Also, peatbog pools located in the western part of Poland (Wielkopolski National Park) created a valuable habitat for the occurrence of specific communities of zooplankton [53], where among 88 identified zooplankton species, taxa typical of astatic and/or acidic waters, e.g. *Lecane elsa*, *Lecane mira* or *Mytilina bisulcata*, occurred. A study carried out on two small peat pits near Turew in the Wielkopolska region showed that even though these ponds were neighbouring, out of 80 identified species, less than 50% were common for both water bodies [54]. This underlines the fact of the high value of ponds in maintaining various communities of organisms even in a restricted area.

Oxbows, which are old river beds, were defined by [55] as small water bodies located in river valleys, connected either permanently or only periodically or even completely separated from proper riverbeds. Detailed characteristics of oxbows in Poland were defined by [56], who gave evidence that this type of aquatic ecosystem creates ecological corridors and a refuge for various organisms. They also refer to the necessity for the restoration of the natural character of river valleys so as to conserve their natural ecological condition and biodiversity. The specificity of oxbows significantly contributes to the formation of high biodiversity. This is probably due to the generally low level of anthropogenic transformation in the surroundings of this type of small water body. Even though they can be found in pastoral landscape, oxbows are often located in protected areas with limited human activities, such as the studied ponds in the Rogalin Warta Valley or in the Nadwarciański Landscape Park [57]. The results of the study conducted on various types of aquatic ecosystems in the Upper Narew Valley over 5 years (almost 600 samples) showed that out of

74 microcrustacean species identified in total, more than 80% were attributed to oxbows, increasing the regional biodiversity of the whole floodplain [37]. In a study conducted on 55 ponds within the Wielkopolska region [58], a high distinction between rotifer communities inhabiting different origin types was detected with oxbows having the highest rotifer diversity compared to postglacial kettle holes and artificial ponds. Two types of rotifer assemblages were distinguished: (1) lower species diversity with relatively more pelagic species and a higher share of eutrophic fraction in anthropogenically modified postglacial kettle holes and (2) greater species diversity and a greater occurrence of littoral rotifers in oxbows and artificial ponds.

Analyses on another origin type of ponds – the meteor craters – located in the Morasko Meteorite Nature Reserve near Poznań also gave an opportunity to find diverse zooplankton communities. Most of the identified species, with many rare for the Polish fauna, were characteristic of small temporary water bodies [40, 41]. The astatic character of these ecosystems, reflected by their fishless character and strong fluctuations in abiotic parameters, determined structure but also size of zooplankton.

3.3 Zooplankton in Permanent vs. Temporary Ponds

Due to the period of water filling, two types of ponds are distinguished: (1) astatic – seasonal ponds (e.g. vernal pools, puddles, rock pools) with irregular fluctuations in their water level, usually fishless, characterised by a huge variability of environmental conditions, which requires the development of specific adaptations of organisms to survive periods of pond disappearance and (2) permanent ponds, naturally filled with water at all times, regardless of the season or the variability of environmental conditions, and often have fish. Division into these two types of ponds is also reflected in the zooplankton community structure. As ascertained by [7], certain zooplankton species may be associated with gradients in hydroperiod and fish predation level. Temporary ponds support various zooplankton communities, both of littoral character (e.g. *Lepadella ovalis*, *Chydorus sphaericus*) and large-bodied pelagic taxa (e.g. *Eudiaptomus gracilis*), while permanent ponds with fish presence had lower diversity, with typically eutrophic taxa such as *Brachionus angularis*, *Keratella cochlearis* f. *tecta* or *Trichocerca pusilla* occurring with a high frequency. However, even though fish ponds are less diverse, they were found to be a source of rare species such as *Brachionus falcatus*, *Lecane tenuiseta* or *Ceriodaphnia dubia* that were exclusively found in these ponds compared to natural fish-free ponds. High biological diversity in ephemeral water bodies, including species important for conservation value, was also confirmed by [59, 60]. Moreover, [61] divided periodic ponds into two “faunistic types,” extracting (1) rich rotifer fauna in association with less muddy ponds, not surrounded by trees, and (2) poor rotifer fauna associated with ponds surrounded by bushes and trees, with a thick layer of sediments and decaying leaves.

3.4 Zooplankton in Ponds of Various Types of Catchment Area

The type of land use (forest, field or urban areas) and degree of anthropogenic transformation in the ponds' vicinity are known to be of great importance in influencing the water quality, and consequently it may determine the diversity of organisms, including zooplankton (e.g. [62]). In the case of small water bodies, which have a smaller catchment area compared to other types of aquatic ecosystems such as lakes, ditches, rivers and streams [32], only the direct surroundings can be taken into account. [63], who examined over 100 small water bodies in Belgium, showed that ponds within forested areas were characterised by significantly better water quality compared to ponds located in agricultural areas, which can be reflected in higher biodiversity.

In the study conducted in the Wielkopolska region [10], it was noticed that forest ponds were characterised by higher zooplankton diversity than field ponds. In both types of ponds, genera such as *Lecane*, *Trichocerca* and *Cephalodella* among rotifers and *Alona* and *Ceriodaphnia* among crustaceans were the most frequent. Most species of these genera are typically littoral organisms, although they were also frequently met in the open water areas, which is related to the specificity of ponds creating a mosaic of habitats.

The type of water body (forest vs. field) can be a significant predictor of zooplankton species distribution. In a study conducted on a group of 12 ponds, 6 each within field and forest surroundings, 2 groups of zooplankton species were distinguished: (1) forest-associated species (representatives of genera *Cephalodella*, *Lepadella*, *Lecane* or *Trichocerca*) and (2) field-associated species (representatives of genera *Keratella*, *Bosmina* or *Ceriodaphnia*) [49]. Moreover, even within one type of pond, a variation in the zooplankton structure can be observed. In a set of 21 urban ponds of different sizes and locations studied along the urbanisation gradient, it was found that the distance from the city centre, number of plant species and pH belonged to the most important parameters determining cladoceran fauna in urban ponds of the city of Łódź [64]. In another Polish city, Poznań, almost 20 various small water bodies (natural and artificial ponds, claypits and pools) were examined, and 114 species, representing ca. 25% of all rotifers from Poland, were recorded with *Brachionus angularis*, *Keratella cochlearis*, *Colurella uncinata*, *Lecane closterocerca* and *Lepadella patella* being the most common [65].

The impact of catchment conditions can also be reflected in the size of the animal's body. Cladoceran *Chydorus sphaericus* was slightly larger in fertile nutrient-rich field ponds [66]. In turn, the size of the rotifer *Filinia longiseta* was significantly lower in field ponds, which is explained by the stronger fish pressure in this type of water body [67].

3.5 Zooplankton in Various Habitats

Ponds, small and shallow ecosystems, were usually treated as a single landscape unit. Therefore, the open water was the only zone that was analysed. However, the small area of a pond can be divided into a number of microhabitats created by patches of macrophytes, creating different conditions for the inhabiting organisms. The distinctiveness of the microhabitats, related to the specific morphology and spatial structure of plants, called architecture, can be responsible for the formation of diverse groups of organisms [68]. This enables cohabitation of species representing different functional groups with different preferences for habitat or food. Macrophyte beds offer pelagic zooplankton a refuge from both planktivorous fish and invertebrate predation, but in the case of littoral species, they create a multiplicity of ecological niches enabling various organisms to co-occur and increase total biodiversity. In the study carried out on the impact of environmental factors that structured the zooplankton assemblages of 55 ponds in Wielkopolska, habitat type was the strongest predictor of rotifer distribution, regardless of any other parameter. Most rotifer species were associated with macrophyte-dominated ponds, thereby illustrating the high value of vegetated areas, even in small aquatic ecosystems [58]. Moreover, an extensive study, taking into account 65 ponds varying in, e.g. catchment type, pond morphology, the presence or lack of fish as well as overshading, proved that the type of habitat was the strongest driver of zooplankton species distribution. This indicates a prerequisite to examine ponds in relation to their microhabitats created by various macrophytes [36]. The results of other investigations, conducted on ponds differing in origin, anthropogenic transformation or morphology of a pond basin, indicated that biometric parameters of the habitat – dry biomass and stem length of plants in a unit of water volume [69] – belonged to the strongest predictors of zooplankton occurrence [25, 66, 70, 71]. Plant biometrics is not only an indicator of the degree of spatial complexity but also of the availability of ecological niches for animals. In most cases elodeids, the most complex habitat compared to architecturally simple helophytes and nymphaeids, hosted the most diverse communities of both rotifers and crustaceans [25, 27].

Zooplankton distribution is determined primarily by habitat type, defined by diverse ecological groups of aquatic and rush vegetation. The ecological significance of spatial heterogeneity for zooplankton is closely connected to a functional perspective relating distribution patterns to environmental processes [68]. The degree of heterogeneity of the plant substratum reflected by an increase in the diversity of littoral microhabitats, determined mainly by length of plant stems, significantly affects zooplankton communities, and their diversity is higher. While in the open water 10–20 species of zooplankton are usually encountered, in a complex plant habitat, the number of species will be much higher, accounting for 30–50 [10].

There is also a close and significant relationship between the body size of organisms and particular habitat types in ponds, which confirms the assumption that the size structure of rotifers, e.g. *Filinia longiseta* [67], and crustaceans, e.g. *Chydorus sphaericus* [66], may differ depending on the morphological type of plant. The obtained results showed that the littoral is an extremely complicated system of dependence between abiotic elements and the inhabiting organisms or those periodically living within macrophytes.

The analysis of the share of eutrophic species in particular zones (open water vs. macrophyte-dominated areas) showed that the open water zone had the highest share of such species, while the elodeids had the smallest [10]. This signifies the necessity to exclude plant zones of ponds from water quality assessments based on zooplankton indicator species. This is due to the fact that mesotrophic and eutrophic indicator species are typically pelagic forms, which find their optimum in the open water area.

4 Concluding Remarks

The results of studies conducted on small water bodies not only expand our knowledge on zooplankton diversity but also create a very rich source of understanding of the ecological state of these ecosystems. These should also be considered as effective arguments in support of measures that would lead to the protection and maintenance of those valuable ecosystems, particularly because there is a tendency for the number of ponds to decrease from year to year [10, 72–74]. Golus and Bajkiewicz-Grabowska [75] gave evidence that the hydrological functions of ponds are very variable throughout the year and highly depend on the level of water storage in the catchment of a water body. It is not only highly imperative that more attention should be paid to the creation of new ponds but also to recognise the need for revitalisation of existing ponds, which finally will contribute to the increase in overall biodiversity. A large part of Europe, especially southern and western, has already noted the need to renature small water bodies. Thus, many projects serve this purpose, aiming, i.e. to reverse the trend of decay and deterioration of their quality and creating new ponds that will be priority natural habitats of European importance in accordance with the EU Habitats Directive. Some initiatives of this type also appear in Poland; however, the approach of individuals who can contribute to the protection and restoration of a decent condition to the natural environment is also very important. Therefore, educational actions on the biodiversity associated with ponds should be continually developed. Even though water bodies subjected to less human impact create a refuge for various freshwater species [2], the diversity of organisms does not relate only to a low scale of anthropogenic transformation of the landscape [76]. It is therefore also important to preserve ponds within strongly transformed areas – intensively farmed arable lands or urban areas, where many species which are rare, endangered or have a very narrow ecological scale may exist [77, 78, 79]. This is why the basic duty of the ecologist is to recognise, monitor and then undertake activities in order to protect and maintain them for future generations. Thus, some researchers (e.g. [3]) have defined priorities that should be fulfilled, such as (1) application of reliable monitoring programmes for small aquatic ecosystems and (2) development of effective measures that will lead to protection of aquatic biodiversity. To protect biodiversity of small water bodies also requires their intense monitoring, and even though interest in ponds systematically increases, they still remain neglected by scientists and excluded from water management planning in many parts of Europe.

The examination of small water bodies fully confirms a thesis that great variation of zooplankton exists both in different ponds and in different habitats. This clearly shows the direction of future limnological research and heightens awareness of the need for the protection of the diversity of small freshwater ecosystems, since it is within them that the symptoms of global climatic changes will be soonest visible.

The assumption of [2] has been well demonstrated in the case of Polish ponds which support a very high richness of inhabiting species given their generally small size. This might be connected with the fact that individual ponds, even those situated in close vicinity, usually support distinct fauna, contributing to very high diversity on both regional and national scales [2]. Therefore, even if local alpha diversity referring to a single site and beta diversity calculated for spatial replacement of species between the sites of an area [80] is not very high, the regional diversity (gamma) of small water bodies can be great.

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