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Differences of water chemistry, bird assemblages and nutrient loads introduced by waterbirds into morphologically similar waterbodies

by

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Abstract

The number and structure of waterbirds is affected by the size of the waterbody, the presence of islands and macrophytes, but also by their trophy status. The aims of the study were to compare nutrients in water, numbers of waterbird assemblages, and the loading of nitrogen and phosphorus introduced by waterbirds in two similar waterbodies with different rates of water discharge. This study was conducted in two eutrophic shallow waterbodies, P1 and P2 in 2016 and 2017. The median concentrations of NO_2^-, NO_3^- and NH_4^+ were 4.0 times, 3.2 times, and 1.7 times greater in the P1 than in the P2 location, respectively. Similar proportions of organic matter in sediments were statistically greater in P1. The number of birds was also significantly greater in P1 than in P2. The waterbirds (*Anas platyrhynchos, Aythya fuligula, Fulica atra, Phalacrocorax carbo* and *Chroicocephalus ridibundus*) excreted 5.2 times more total phosphorous and 3.3 times more total nitrogen in P1 than in P2. Significant negative correlations were also found between the concentrations of NO_3^- and the number of waterbirds in P1.

Key words: bird assemblages, nitrogen and phosphorus concentration, reservoirs, seasonal numbers, water parameters

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1. Introduction

The key factors affecting the richness and numbers of waterbirds assemblages were the size of the area and whether the shoreline was covered by macrophytes or the presence of islands (Dobrowolski 1995). Kalivodová & Feriancová-Masárová (1999) reported that water quality and shore vegetation had a determining role for bird communities in reservoirs. Bird assemblages were greater in eutrophic waterbodies than in oligotrophic ones (Dobrowolski et al. 1976, Stawarczyk & Karnaś 1992). This was connected with a richer food base and better nesting conditions. On the other hand, fecally derived nutrients have the potential to enrich waterbodies and thus contribute to the process of eutrophication. A greater number of waterbirds in eutrophic reservoirs will increase the quantity of phosphorus and nitrogen in water or at least accelerate the circulation of these elements in the environment (Gwiazda et al. 2014).

The loads of phosphorus and nitrogen contributed by waterbirds to the environment have previously been studied in lakes (Dobrowolski et al. 1976; Gere & Andrikovics 1992; Manny et al. 1994; Marion et al. 1994; Rönicke et al. 2008), dam reservoirs (Gwiazda 1996; Gwiazda et al. 2014), and in other waterbodies (Ganning & Wulff 1969; Portnoy 1990; Post et al. 1998). Numerous studies have shown the impact of birds on the concentrations of nutrients (Leentvaar 1967; Ganning & Wulff 1969; Manny et al. 1994; Marion et al. 1994; Kitchell et al. 1999) in their habitat. The loading of nitrogen and phosphorus by birds to ecosystems can be an important source of nutrients there. Waterbirds significantly increased the phosphorus and nitrogen resources in small waterbodies (Kitchell et al. 1999; Manny et al. 1994; Scherer et al. 1995; Post et al. 1998). Greater amounts of nitrogen and phosphorus from birds' droppings are notably deposited in sediments (Gwiazda et al. 2010; Gwiazda et al. 2014).

The aims of study were to determine the water chemistry, birds' assemblages, and the influence of waterbirds on nutrients in two small waterbodies of similar size.

2. Materials and methods

2.1. Study area

This study was conducted in two artificial waterbodies, Podkamycze 1 and Podkamycze 2 (Cracow, southern Poland) (Fig. 1). Podkamycze 1 (50°05'11"N, 19°50'01.6"E) and Podkamycze 2 (50°04'59.6"N, 19°50'05.4"E) are located next to each other and are separated by a dam. The studied waterbodies are relatively small, covering 16.8 – 17.3 ha, with a maximum depth from 2.5 to 3.0 m. The waterbodies were filled by water from the Rudawa River independently. Water retention time was 6.6 days in Podkamycze 1 and 6.0 days in Podkamycze 2 in 1999-2009 (Pawełek & Grenda 2010). They are both classified as being eutrophic with algal blooms from May to November. Cyanobacteria blooms have also been shown to occur in both studied reservoirs (Krztoń et al. 2019). The mean Cyanobacteria biomass was 1.20 mg l^{-1} in Podkamycze 1 and 29.27 mg l^{-1} in Podkamycze 2 (Kosiba & Krztoń 2022). The shoreline in some places was covered by a narrow belt of aquatic macrophytes. However, the vegetation cover is similar on both waterbodies. The function of these waterbodies is to supply drinking water for residents of the Cracow conurbation.

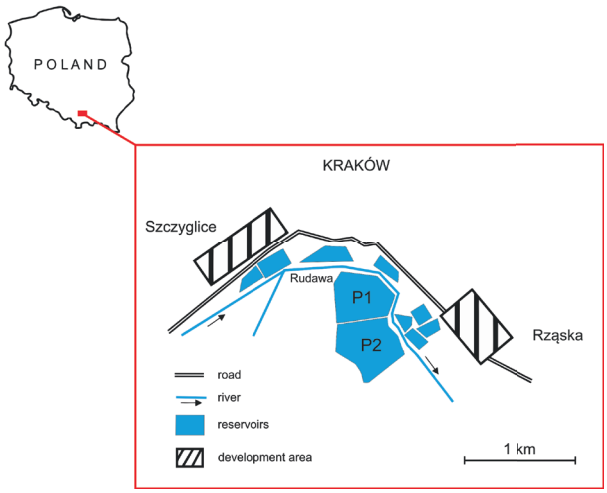

Figure 1
Location of the study area

2.2. Material and analyses

The counting of birds on the studied waterbodies was conducted once a month from June to October 2016 and from April to October 2017. The number of waterbirds was counted at both sites from a dike between them in the morning and in clear weather conditions. A binocular 10 × 42 and scope 10-60 × 82 was used during the field study.

Water samples were taken once a month from one site in each waterbody with a 5l sampler and from a depth of approx. 1 m from April to October in 2017. The sediment samples were collected using a sediment core sampler once at each reservoir.

Specific forms of nutrients (NO_2^-, NO_3^-, NH_4^+, PO_4^{3-}) were determined in the water samples. Laboratory

analyses included ion chromatography (DIONEX ICS 1000). The sediment samples were dried at 105°C for 24 hours to establish their dry matter contents, followed by roasting at 550°C for 5 hours. The residue was then weighed. The amounts of organic matter were measured as a percentage weight loss after roasting (loss-on-ignition).

The total nitrogen (TN) and total phosphorus (TP) loads delivered by the birds to the studied waterbodies were determined on the basis of the number of selected species in a month, the number of days in a given month, and the amount of TN and TP in the faeces excreted by the selected species daily. These amounts were obtained from research literature: Mallard *Anas platyrhynchos* - 2.6 g TN, 0.4 g TP (Gwiazda 1996), Tufted Duck *Aythya fuligula* - 0.6 g TN, 0.2 g TP (Manny et al. 1994), Coot *Fulica atra* - 0.6 g TN, 0.2 g TP (Boros 2021), Black-headed Gull *Chroicocephalus ridibundus* - 0.9 g TN, 1.0 g TP (Gwiazda 1996), Great Cormorant *Phalacrocorax carbo* - 3.3 g TN, 2.5 g TP (Gwiazda et al. 2010).

The differences in the amounts of nutrients in the waters of the two waterbodies were tested using the Wilcoxon test. Correlations between the water parameters and waterbird numbers were calculated. All calculations were made using StatSoft, Inc. STATISTICA (data analysis software system), version 10 software (www.statsoft.com).

3. Results

3.1. The chemistry of water and sediments

Some chemical parameters of the water were much greater at Podkamycze 1 than Podkamycze 2. Notably, the concentrations of NO_2^-, NO_3^-, and NH_4^+ ($Z = 3.233$, $p = 0.001$, $n = 14$; $Z = 3.296$, $p = 0.001$, $n = 14$, $Z = 2.166$, $p = 0.03$, $n = 14$, respectively) were statistically greater but the PO_4^{3-} concentrations were not ($Z = 1.161$, $p = 0.25$, $n = 14$) (Fig. 2). The median concentrations of NO_2^-, NO_3^-, and NH_4^+ were respectively 4.0 times, 3.2 times,

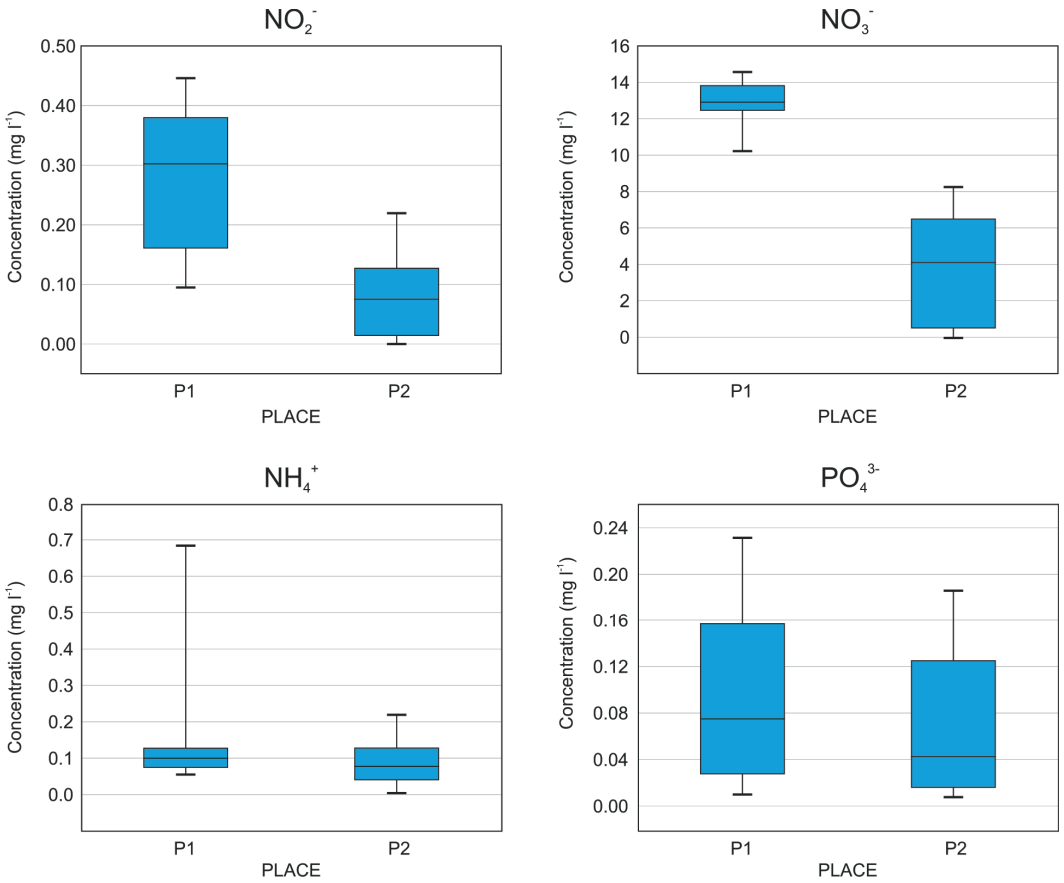

Figure 2

Values of NO_2^-, NO_3^-, NH_4^+, and PO_4^{3-} in the Podkamycze 1 (P1) and Podkamycze 2 (P2) waterbodies from April to October 2017. The dark horizontal lines represent median values; the boxes enclose the 1st and 3rd quartiles; the whiskers represent the the 5th and 95th percentiles.

and 1.7 times greater at the Podkamycze 1 site than at Podkamycze 2. The proportion of organic matter in sediments revealed statistically greater values at Site 1 than Site 2 (Z = 2.802, p = 0.005) (Fig. 3).

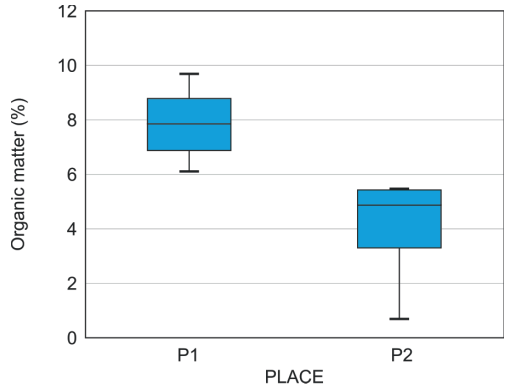

Figure 3

Percentage of organic matter in the Podkamycze 1 (P1) and Podkamycze 2 (P2) waterbodies from April to October 2017. The dark horizontal lines represent median values; the boxes enclose the 1st and 3rd quartiles; the whiskers represent the 5th and 95th percentiles.

3.2. Waterbird numbers

The number of waterbirds was significantly greater in Podkamycze 1 than Podkamycze 2 each month (Z = 2.981, p = 0.003, n = 14) (Fig. 4). The phytophages (Mallard, Coot, Swan *Cygnus olor*), benthophages (Tufted Duck, Pochard *Aythis ferina*), and ichthyophages (Great Crested Grebe *Podiceps cristatus*, Great Cormorant, Black-headed Gull, Common Tern *Sterna hirundo*) (Z = 2.667, p = 0.008, n = 14; Z = 2.589, p = 0.009, n = 14; Z = 2.158, p = 0.03, n = 14, respectively) numbers were statistically greater at Podkamycze 1 (Fig. 4). The median abundance of birds was five times higher in Podkamycze 1 than in Podkamycze 2.

3.3. Nutrient loading by waterbirds

The amounts of nitrogen defecated by the waterbirds (Mallard, Coot, Tufted Duck, Black-headed Gull, and Great Cormorant) into the Podkamycze 1 and the Podkamycze 2 sites were estimated as 107.0 kg (6.3 kg ha^{-1}) TN and 32.6 kg (1.9 kg ha^{-1}) TN, respectively. The loads of phosphorus excreted by waterbirds into these reservoirs were 37.4 kg (2.2 kg ha^{-1}) TP and 6.1 kg (0.4

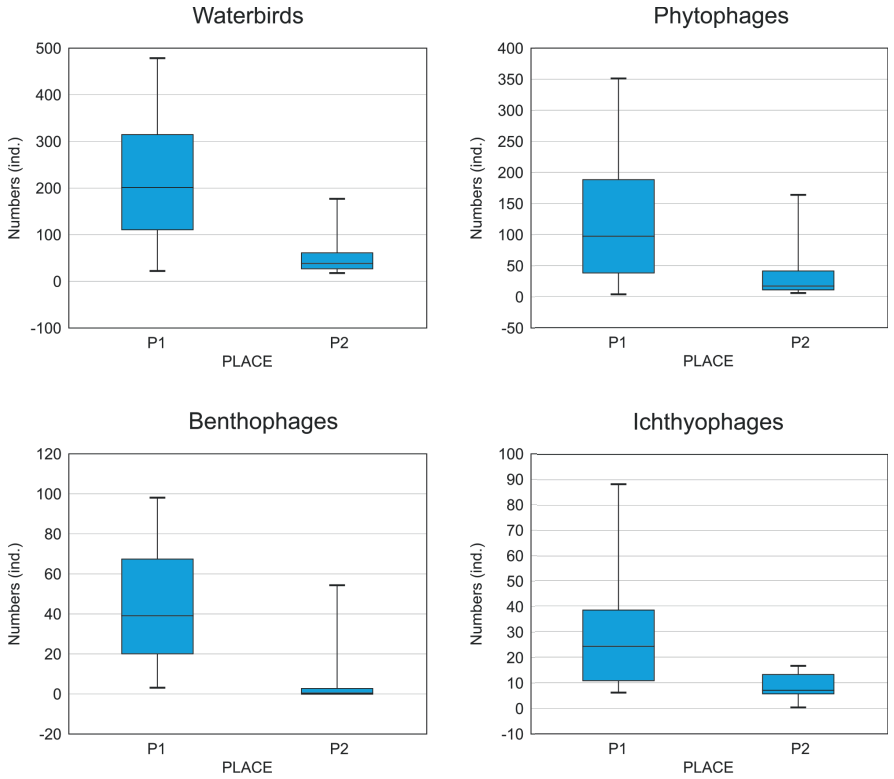

Figure 4

Numbers of all studied waterbirds, phytophages, benthophages, and ichthyophages in 2016 and 2017. The dark horizontal lines represent median values; the boxes enclose the 1st and 3rd quartiles; the whiskers show the minimum and maximum values.

kg ha^{-1}) TP, respectively. The birds contributed 3.3 × more TN and 5.2 × more TP to Podkamycze 1 than to Podkamycze 2.

3.4. Correlation between water parameters and waterbird numbers

Statistically significant negative correlations between the concentrations of NO_3^- and the number of waterbirds and between the NO_3^- concentrations and number of phytophages were found in Podkamycze 1 (Table 1). Moreover, the concentration of PO_4^{3-} and the number of ichthyophages at Podkamycze 2 were correlated (Table 1).

characterised by greater concentrations of nutrients in the water and greater proportions of organic matter in the associated sediments. Greater numbers of herbivorous birds, such as the Mallard, Swan and Coot, or benthivores birds, such as the Tufted Duck and Pochard, were found in the Podkamycze 1, characterised by a higher concentration of nitrogen in water and organic matter in sediment. This suggested better food conditions for bird species feeding on benthic plants and invertebrates there. Dobrowolski (1969) showed that eutrophic environments are preferred by Coot and Tufted Duck in the Mazurian Lakes. However, the Mallard, Great Crested Grebe, Swan, and Black-headed Gull did not reveal any

Table 1

Correlation statistics of water parameters and the numbers of waterbird groups at the Podkamycze 1 (P1) and Podkamycze 2 (P2). The probability values are shown in parentheses. Significant correlations are marked in bold.

Parameter	Site	All watebirds	Phytophages	Benthophages	Ichthyophages
NO_3^-	P1	**-0.885 (0.008)**	**-0.770 (0.04)**	-0.473 (0.28)	-0.425 (0.34)
	P2	0.322 (0.48)	-0.262 (0.57)	0.373 (0.41)	0.666 (0.10)
NO_2^-	P1	-0.248 (0.59)	-0.213 (0.65)	0.667 (0.10)	-0.235 (0.61)
	P2	-0.258 (0.58)	-0.540 (0.21)	-0.102 (0.83)	0.388 (0.39)
NH_4^+	P1	0.032 (0.94)	0.238 (0.61)	0.433 (0.33)	-0.250 (0.59)
	P2	0.698 (0.08)	0.680 (0.09)	0.129 (078)	0.004 (0.99)
PO_4^{3-}	P1	-0.322 (0.48)	-0.085 (0.86)	-0.186 (0.69)	0.069 (0.88)
	P2	-0.049 (0.92)	0.478 (0.28)	-0.280 (0.54)	**-0.790 (0.04)**

4. Discussion

Higher levels of nitrogen and phosphorus were found in the waters of the Podkamycze 1 which were more affected by waterbirds. Differences in nitrogen concentrations of the waters between the studied waterbodies may result from the water intake or processes that take place inside them. Pawełek & Grenda (2010) obtained different water outflow rates from both waterbodies during a study period covering 1999-2009. Pawełek & Grenda (2011b) reported the supply of nutrients to the studied waterbodies caused an increase in the number of organic substances in water.

Differences were found in the numbers of birds in these morphologically similar reservoirs. Numerous bird species prefer eutrophic habitats because these environments are associated with better food conditions and breeding places. In general, greater numbers of waterbirds were found in the waterbodies preferences in relation to more or less eutrophic parts of the Mazurian Lakes (Dobrowolski 1969).

The Mallard, Coot, Tufted Duck, Great Cormorant and Black-headed Gull were found to put phosphorus and nitrogen into the ecosystems of both waterbodies. Waterbirds increased the nutrient pool in many shallow waterbodies. According to Scherer et al. (1995), waterbirds had put 159 – 167 kg of phosphorus (27% – 34% of the total) into a shallow Green Lake (Washington, USA, 105 ha) over three years. Kitchell et al. (1999) showed that birds (mostly *Anas caerulescens caerulescens*) increased the phosphorus and nitrogen loads (40% and 75%, respectively) of the wetlands of New Mexico (USA). The Canada Goose (*Branta canadensis*) and the Mallard were shown to have introduced substantial amounts of nitrogen (280 kg, 27% of the total) and phosphorus (88 kg, 70% of the total) into a small lake (15 ha) in Michigan (USA) (Manny et al. 1994). Gulls (*Larus argentatus, L. marinus*) also significantly increased the nitrogen and phosphorus

concentrations in the Gull Pond (Canada) (Portnoy 1990). Significantly increasing the nitrogen and phosphorus content of a shallow lake (Dołgie Wielkie Lake) in Poland, induced by the Great Cormorant roosting colony, has also been observed (Klimaszyk et al. 2015). Nutrients from bird populations contribute to the process of eutrophication in smaller waterbodies when greater assemblages of birds have populated an area, for example in Lake Hilversumse Wasmeer (The Netherlands) (Leentvaar 1967) and Lake Wintergreen, Michigan (USA) (Manny et al. 1994). However, the effect of birds on the water chemistry is not always recorded. The amounts of nitrogen and phosphorus introduced by waterbirds into the large reservoirs in southern Poland (Dobczyce Reservoir, Goczałkowice Reservoir) were low (Gwiazda 1996, Gwiazda et al. 2014). This could probably be explained by water exchange and intensive nitrification processes. Differences in the concentrations of NO_2^-, NO_3^-, NH_4^+, PO_4^{3-}, and TP in the waters of the areas near roosts of the Great Cormorant and the reference site of the Dobczyce Reservoir (Poland) were not found (Gwiazda et al. 2010).

A strong and significant relationship was found between the number of waterbirds and concentrations of NO_3^- in the water column. Our study also revealed a relationship between the amount of phytophages and NO_3^- concentrations in water. This observation was interesting because these relationships were negative, and this phenomenon may be difficult to explain. Birds excrete nitrogen compounds in the form of uric acid, which is poorly soluble in water. The concentration NO_3^- depends on other environmental factors, including the concentration of oxygen in water. According to unpublished data, peaks in the chlorophyll *a* concentration of the Podkamycze 1 and Podkamycze 2 were reported in September. This suggests a higher mass of algae and a high nutrient uptake from water in autumn. A high phytoplankton density and activity coincided with a substantial number of birds in September. No relationship was found between the number of waterbirds and the nutrient content in the waters of the Goczałkowice Reservoir (Gwiazda et al. 2014). In a similar way, Unckless & Makarewicz (2007) did not find that different quantities of geese faeces added to water samples had caused any differences in the concentrations of phosphorus and nitrogen or nitrate in the waters they studied. Probably, waterbirds did not directly increase the concentrations of nutrients in water. Phosphorus and nitrogen are mostly stored in bottom sediments. According to Scherer et al. (1995), phosphorus from droppings did not remain in the water but was deposited in sediments instead. Higher concentrations of nutrients in sediments can therefore lead to a long-term processes of nutrient enrichment and the accumulation of phosphorus and nitrogen in a specific habitat.

5. Conclusions

The results showed statistically higher concentrations of NO_2^-, NO_3^-, NH_4^+ and organic matter in sediments at the Podkamycze 1 site. We conclude that bird communities are likely to be greater in reservoirs with a higher trophy, likely associated with a greater food base. By excreting their faeces into water, waterbirds further increase the pool of nutrients in eutrophic habitats.

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