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Soil conditions under great cormorant and grey heron colonies in a wetland: Effect on soil nematode abundance and trophic structure

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Abstract: This study aimed to investigate how great cormorants and grey herons affect the density and trophic diversity of soil nematodes under breeding colonies located in Stawy Raszyńskie Nature Reserve (central Poland). Soil samples from the colonies were compared to control samples from adjacent areas unaffected by birds. Samples were taken at each site (two colonies and two relevant control sites) to a depth of 20 cm, and the soil cores were split into topsoil (0–10 cm) and subsoil (10–20 cm). A modified Baermann method was used to extract nematodes from the soil.

The soil under nests supported more abundant nematode communities, but with a lower trophic diversity compared to the control sites. The cormorants had a greater impact on nematodes than the herons. We found that the external nitrogen input, the higher organic matter content and abundance of ammonifying bacteria, as well as the lower soil pH under the colonies than in the control sites, affected the nematode trophic groups in different ways. Compared to the control sites, there were significantly more bacterivorous nematodes but fewer herbivorous nematodes under the colonies. No predatory nematodes were found under the bird colonies and, in the case of the cormorant colony, no omnivorous nematodes.

No significant differences in the abundance of fungivorous nematodes between the impact and the control plots were noticed. The results indicate that allochthonous input under bird colonies promotes microbial activity and the most opportunistic trophic group of nematodes, which may at least temporarily enhance decomposition and mineralisation processes and consequently affect nutrient cycling in the wetland soil.

Keywords: bird excreta, great cormorant, grey heron, nematodes, nitrogen

INTRODUCTION

The populations of the great cormorant (*Phalacrocorax carbo* L.) and the grey heron (*Ardea cinerea* L.) in Poland, as in the rest of Europe, have increased significantly in recent years (Eerden van, 1995; Tomiałojć and Stawarczyk, 2003; Eerden van *et al.*, 2012). To date, the role of these piscivorous wetland birds in ecosystems has most often been considered in terms of losses to fish stocks (Walczuk and Romanowski, 2013; Manikowska-Ślepowrońska, Szydzik and Jakubas, 2016) and forestry (Grochalski and Bednarz, 2019). However, these two species, as colonial birds, spend most of their time living in colonies and roosting sites, where they drop excreta directly onto the surface of the soil and plants (Ligęza and Smal, 2003). The piscivorous birds can also carry out secondary dispersal of seeds and invertebrates via predation on fish (Leeuwen van *et al.*, 2017). The bird droppings contain, in addition to undigested food residues, products of protein metabolism in the form of uric acid, urea and creatine (Ligęza and Misztal, 2000). A consequence of increased input of organic matter in colony areas may be an over-enrichment of soils and groundwater with various forms of nitrogen (Mulder *et al.*, 2011; Young, Hurrey and Kolb, 2011;

Klimaszyk, Piotrowicz and Rzymski, 2014; Irick *et al*., 2015; Gwiazda *et al*., 2015).

A number of works have focused on the physical and chemical parameters of soil in bird colony areas (Hobara *et al*., 2005; Harrow, Hawke and Holdaway, 2006; Ligęza, 2009; Ziółek and Melke, 2014; Klimaszyk and Rzymski, 2016). Some studies on the impact of birds on soil microorganisms (Osono *et al*., 2002; Domínguez *et al*., 2017), lichens (Żółkoś, Kukwa and Afranowicz-Cieślak, 2013) and plants (Kolb *et al*., 2012) can also be found, but only a few studies deal with the impact of bird colonies on soil invertebrates, including earthworms (Callaham, Butt and Lowe, 2012), mites (Ilieva-Makulec, Kozacki and Makulec, 2016; Oszust and Klimaszyk, 2022) and nematodes (Andriuzzi *et al*., 2013; Ilieva-Makulec, Bjarnadottir and Sigurdsson, 2015; Ilieva-Makulec, Kozacki and Makulec, 2018; Pen-Mouratov and Dayan, 2019).

Nematodes are one of the most relevant invertebrate groups in soil. They constitute taxonomically and functionally diverse communities influenced by soil conditions (Wasilewska, 1974; Wasilewska, 1997; Yeates, 2003; Dmowska and Ilieva-Makulec, 2004). Nematode communities include taxa with different feeding preferences, life strategies and sensitivity to changes in soil abiotic and microbiological parameters (Paoletti *et al*., 1991; Wasilewska, 1995; Wasilewska, 1997; Yeates, 2003; Trett, Urbano and Forster, 2009; Wilson and Kakouli-Duarte (eds.), 2009). Nematodes are closely interrelated with plants, microorganisms and other groups of soil fauna. They participate in nutrient cycling and affect primary production (Freckman, 1988; Hunt and Wall, 2002).

The aim of this study was to assess the effect of the breeding activity of two wetland bird species (great cormorant and grey heron) in the Stawy Raszyńskie Nature Reserve (Central Poland near Warsaw) on the abundance and trophic structure of soil nematodes. We hypothesised that the increased input of organic and inorganic substances into the soil that occur under the bird colonies would be reflected in the structure of the soil nematode communities. It was expected that the nematode density in the soil from the bird colony areas would be higher and the nematode trophic diversity would be lower than in the sites unaffected by birds.

STUDY MATERIALS AND METHODS

SITE DESCRIPTION

The research was carried out in 2015 in the Stawy Raszyńskie Nature Reserve, which covers an area of 110 ha consisting of ponds, islands in the ponds, dykes and adjacent areas comprising meadows and pastures. Approximately 130 species of both wetland and terrestrial birds have been found in the reserve (Bukaciński and Bukacińska, 1991).

Since 2007, the great cormorant and the grey heron have been establishing breeding colonies in the Stawy Raszyńskie Nature Reserve. The area of the great cormorant colony on the island on Falencki Pond covers 1 ha, while that of the grey heron colony is approximately 1.5 ha. The research sites within the great cormorant colony were established on the island on Falencki Pond (52°08'18.8" N; 20°54'54.9" E) and those within the grey heron colony in an alder forest near Spiski Pond (52°08'10.4" N; 20°54'38.6" E). The control sites (i.e. adjacent sites where the studied bird species did not form colonies) were located for the great cormorant on an island in the Górny Pond (52°08'28.4" N; 20°55'02.3" E), and for the grey heron in an alder forest near the Falencki Pond (52°08'09.5" N; 20°54'44.4" E).

At each colony, the study plots were located under the tree crowns, where visible traces were found on the ground indicating bird activity, such as large amounts of droppings, feathers and food residues (Photo 1).

NEMATODE SAMPLING AND PARAMETERS

The soil was sampled in spring, summer and autumn 2015. Ten samples were taken at each site (two colonies and two relevant control sites) to a depth of 20 cm, and the soil cores were split into two layers: topsoil (0–10 cm) and subsoil (10–20 cm).

A modified Baermann method was used to extract nematodes from the soil (Southey, 1986), and 4% formalin was used as a fixative (Bezooijen van, 2006).

Nematodes were counted using a stereo microscope at 25–40× magnification. In each sample, at least 50 randomly selected nematodes were identified to genus level based on their morphological characteristics using a light microscope at 100–600× magnification. Bongers and Andrássy keys were used for the identifications (Bongers, 1988; Andrássy, 2005; Andrássy, 2007; Andrássy, 2009). Nematodes were assigned to five trophic groups (bacterivorous, fungivorous, herbivorous, predatory and omnivorous) according to Yeates *et al.* (1993).

The analysed parameters of nematode communities were density (total and for trophic groups) and percentages of the different trophic groups. Two nematode functional indices were also calculated: the enrichment index (*EI*) and the channel index (*CI*) (Ferris, Bongers and Goede de, 2001). As these indices integrate the responses of nematode taxa from different trophic

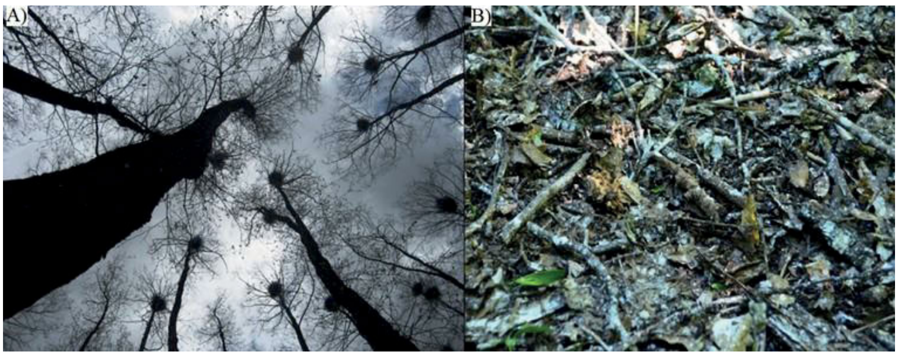

Photo 1. A part view of great cormorant breeding colony: A) nests in tree crowns, B) visible traces of bird activity on the ground (Photo: *D. Kozacki*)

groups and with different life strategies (r- and K-strategists) (Bongers, 1990; Bongers, 1999), they can provide information on the nutrient status of the soil (*EI*) and changes in decomposition pathways in the soil food web (*CI*).

SOIL ABIOTIC AND MICROBIOLOGICAL CHARACTERISTICS

The values of the pH, organic matter and abundance of a*mmonifying bacteria* were determined in the soil under the colonies and in the control sites. The pH was measured with a Hach Sension+ apparatus in aqueous solution. The soil organic matter content (SOM) was calculated from loss on ignition (LOI) after heating at 800–900°C for 2–3 h (Baldock and Nelson, 2000). The abundance of a*mmonifying* bacteria was measured using the fermentation method. The ammonia (NH_4^+) content was determined on the basis of the orange colour change in the culture after using the Nessler reagent (Schlegel *et al.*, 2008). The results were given as colony-forming units (CFU) of bacteria in 1 g dry mass of soil, read from tables according to the Polish Committee for Standardisation and Measurements (PN-C-04615.05:1975). Additionally, total nitrogen input to the soil within the bird colonies was measured spectrophotometrically (with a Nanocolor UV-VIS II apparatus) at the beginning, during and at the end of the bird breeding season.

BIRD COUNTS IN COLONIES

Bird counts were carried out three times during the spring season. Bird counts in colonies were obtained by multiple counting in the same study site repeatedly in selected dates. The estimate number of birds counted was divided by number of squares counted (average density of birds per square) and multiplied by the total number of squares (Gregory, Gibbons and Donald, 2004).

STATISTICAL ANALYSIS

The results of nematode abundance were analysed with Shapiro–Wilk distribution normality test, and the homogeneity of variance was checked with the Laven's test. An ANOVA followed by Tukey's HSD post-hoc test was conducted to assess the effects of the site (colony/control), bird species, sampling date and soil layer on the density (total and for selected trophic groups) of soil nematodes. Calculations were performed in R version 3.5.2 with R Commander overlay (R Development Core T, 2018).

RESULTS

NUMBERS OF GREAT CORMORANTS AND GREY HERONS IN COLONIES

Bird numbers recorded during the breeding season by species are shown in Table 1. There were between 65 and 85 individuals in grey heron colony and from 71 to 88 individuals in the great cormorant colony.

NEMATODE DENSITY

During the study period, the average nematode density in the great cormorant colony was 62 ±9 individuals·10^4·m^{-2} in the topsoil (0–10 cm) and 12 ±3 ind.·10^4·m^{-2} in the subsoil (10–20 cm), while at the control site there were approximately 41 ±6 ind.·10^4·m^{-2} in the topsoil and 23 ±3 ind.·10^4·m^{-2} in the subsoil. On most dates, in both the great cormorant colony and the control site, significantly more nematodes were found in the topsoil than in the subsoil (F = 41.47, p < 0.0001) – Figure 1a, b.

Table 1. Data from bird surveys at breeding colonies in the Stawy Raszyńskie Nature Reserve

Date	Bird species	Number of birds ±*SD*
04.04.2015	grey heron	85 ±4
	great cormorant	77 ±3
06.05.2015	grey heron	76 ±3
	great cormorant	88 ±5
01.06.2015	grey heron	65 ±2
	great cormorant	71 ±3

Source: own study.

During the study period, under the grey heron colony, there was an average of 23 ±4 nematode ind.·10^4 m^{-2} in the topsoil and 21 ±3 ind.·10^4 m^{-2} in the subsoil. In the control site, 16 ±2 and 17 ±3 ind.·10^4 m^{-2} were found in the topsoil and subsoil, respectively.

Nematode density differed significantly between the colony of the great cormorant and the control site (F = 11.53, p < 0.001) – Figure 1a, b. A Tukey HSD post-hoc test revealed that the studied colony plots in the summer and autumn samplings hosted significantly higher nematode densities than the control plots.

The nematode communities in the soil of the grey heron colony were less numerous than those of the cormorant colony (Fig. 1c, d). During the study period, under the grey heron colony, there was an average of 23 nematode ind.·10^4 m^{-2} in the topsoil and 21 ind.·10^4 m^{-2} in the subsoil. In the control site, 16 and 17 ind.·10^4 m^{-2} were found in the topsoil and subsoil, respectively. No significant differences in nematode density between soil layers at any date were found (F = 2.21, p > 0.05) – Figure 1c, d. In each soil layer, there were generally more nematodes in the colony plots than in the control plots; however, the only significant difference was in spring in the subsoil.

In both bird colonies and both control plots, bacterivorous nematodes recorded the highest densities among the trophic groups (Fig. 1). A Tukey HSD post-hoc test revealed that the colony plots of both bird species, especially in the 0–10 cm soil layer, hosted significantly (F = 4.25, p < 0.05) higher densities of bacterial feeders than the control plots.

On most dates, the density of fungal feeders did not differ significantly between the bird colonies and their control plots.

In the great cormorant colony, herbivorous nematodes occurred in small numbers only in spring and only in the subsoil layer. In contrast, in the grey heron colony and in both control sites, herbivorous nematodes occurred on all dates. The densities of plant feeders in the grey heron colony were significantly (F = 6.11, p < 0.05) lower than in the control site.

No predatory nematodes were found under the bird colonies, and, in the case of the great cormorant colony, no omnivorous nematodes either. In the control sites, however, nematodes of these two groups, although in low densities, occurred on all dates.

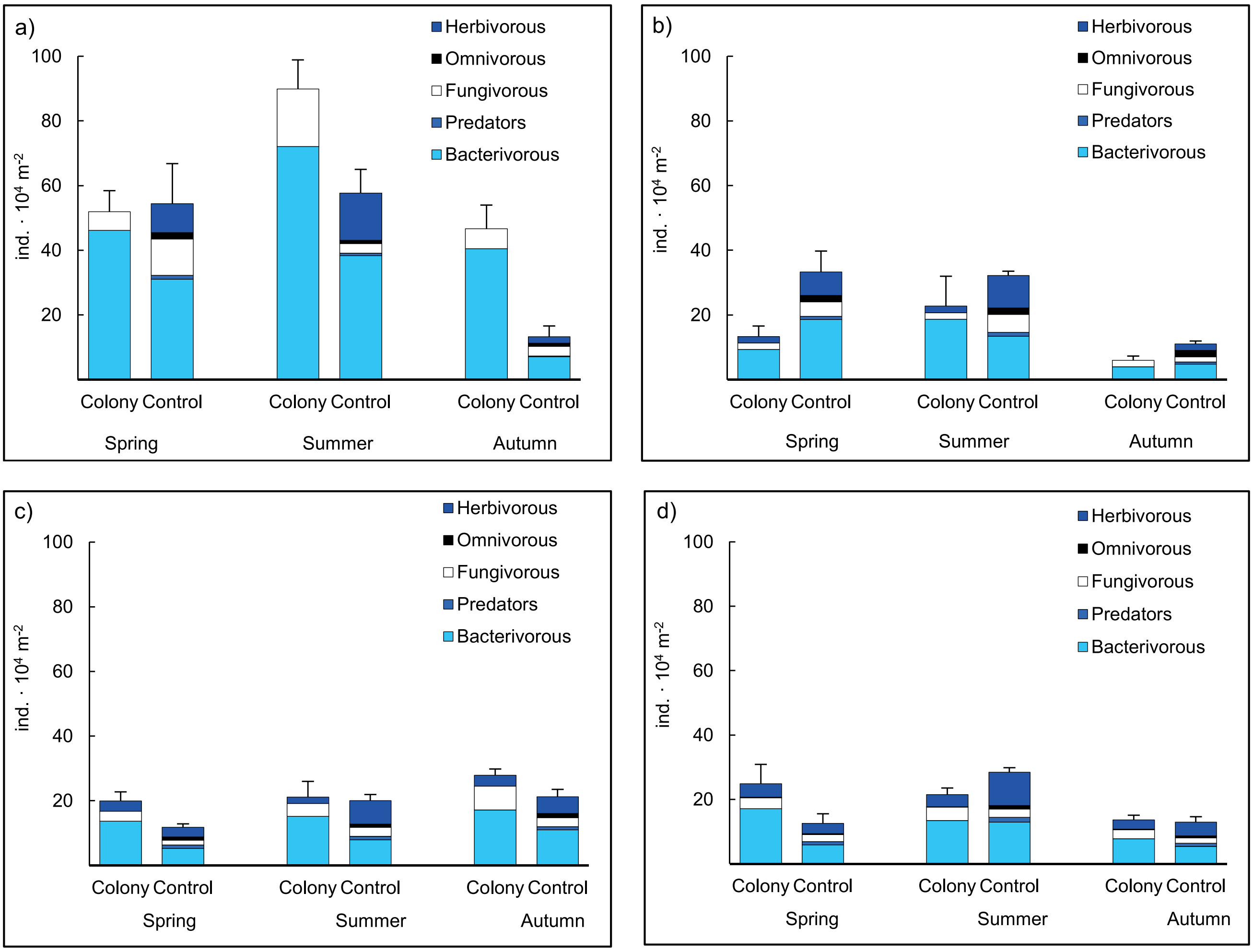

Fig. 1. Mean density (total +*SE* and trophic groups) of soil nematode communities in the soil within the great cormorant (a – 0–10 cm and b – 10–20 cm) and grey heron (c – 0–10 cm and d – 10–20 cm) colonies and corresponding control sites; source: own study

NEMATODE TROPHIC STRUCTURE

In the soil from the bird colony areas, the trophic structure of the nematode communities was simpler than in the control sites (Fig. 2). In the topsoil, three trophic groups of nematodes were found under the grey heron colony, but only two groups were found under the great cormorant colony. Meanwhile, in the control sites, a complete trophic structure with all five trophic groups of nematodes was recorded. Bacterivorous nematodes had the highest percentages in the trophic structure of nematode communities at all dates in both the colonies and the controls (Fig. 2). However, the share of bacterivorous nematodes in the structure of the colony communities was much higher than in the corresponding control site.

Fungivorous nematodes (on most dates) and herbivorous and omnivorous nematodes (all dates) contributed more to the trophic structure of the communities in the control sites than to the corresponding bird colonies (Fig. 2).

NEMATODE FUNCTIONAL INDICES

In the colonies of both bird species, *EI* values were significantly higher and *CI* values were lower than at the corresponding control sites (Tab. 2). This trend was observed in each layer and at each date.

SELECTED ABIOTIC AND MICROBIOLOGICAL CHARACTERISTICS OF SOIL OUTSIDE AND INSIDE THE BIRD COLONIES

The soil under the great cormorant colony was characterised by significantly lower pH values in both layers compared to the control site (Tab. 3). In the case of the grey herons, a similar trend was observed, but the differences in soil pH values between the colony and the control site were much smaller.

During the summer, the organic matter content of the soil from the great cormorant colony was higher than that of the control site in each layer (Tab. 3). For the grey herons, a similar trend was found only in the subsoil.

For both bird species, the abundance of ammonifying bacteria in each soil layer from the colony was higher than at the corresponding control site (Tab. 3). The highest abundance of these bacteria in the soil of the colonies was recorded in the summer. The abundance of ammonifying bacteria in the great cormorant colony area was many times (from 10 to 100 times) higher compared to the control site. In the case of the grey heron, the differences between the colony and the control sites were less pronounced and ambiguous (Tab. 3).

As can be seen in Figure 3, the total nitrogen input to the colony sites decreased over time. The average nitrogen input to the soil in the cormorant colony was 200.25 mg $N \cdot m^{-2} \cdot day^{-1}$ at

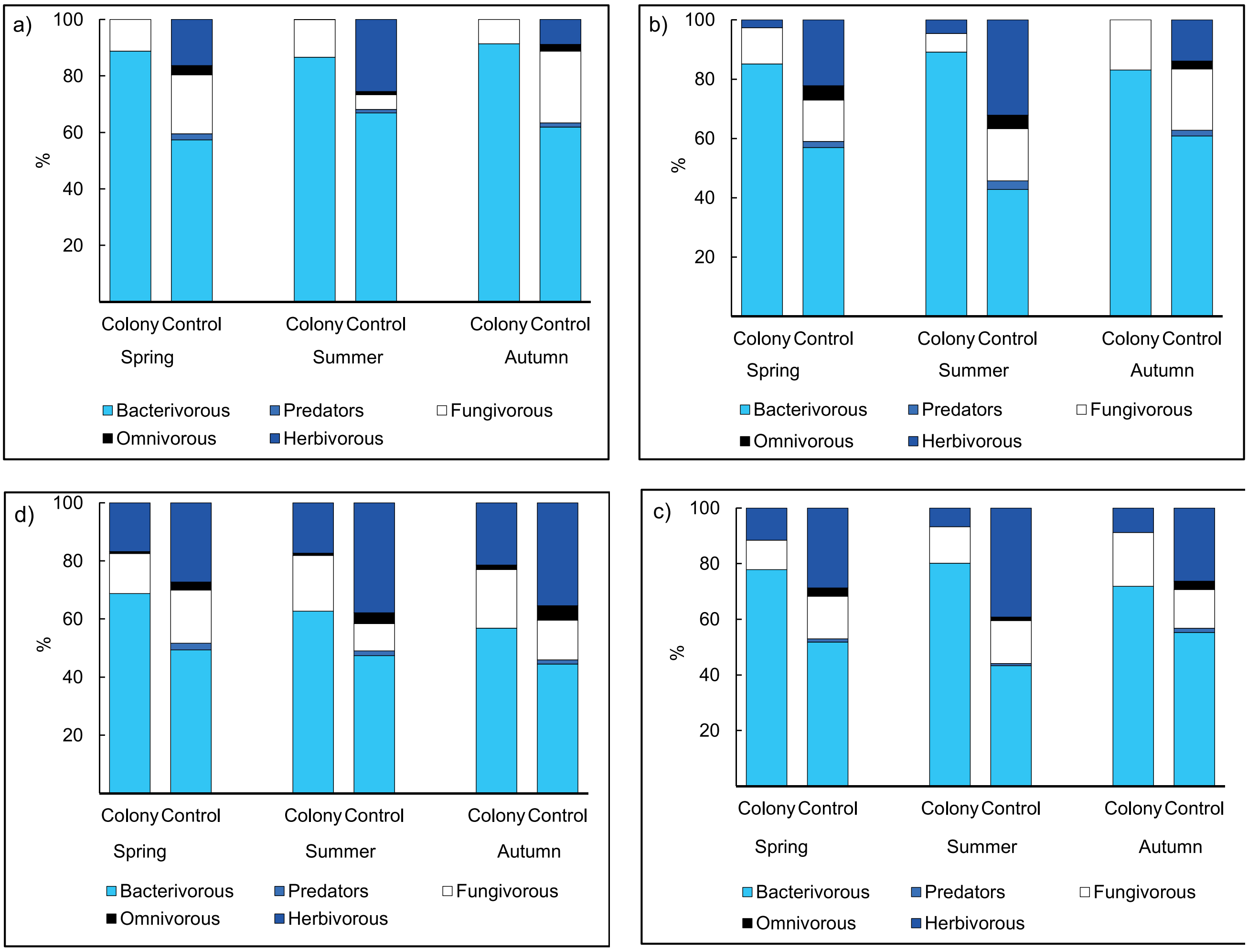

Fig. 2. Percentages of nematode trophic groups in the soil within the great cormorant (a – 0–10 cm and b – 10–20 cm) and the grey heron (c – 0–10 cm and d – 10–20 cm) colonies and the corresponding control sites; source: own study

Table 2. Functional indices of nematode communities in the topsoil (0–10 cm) and subsoil (10–20 cm) in the great cormorant and grey heron colonies and corresponding control sites

Bird species	Index	Season	Value for			
			colony		control	
			0–10 cm	10–20 cm	0–10 cm	10–20 cm
Great cormorant	*EI*	spring	82.48	86.81	72.42	68.40
		summer	88.65	91.33	71.01	70.86
		autumn	75.32	81.71	65.17	73.62
	CI	spring	5.03	4.87	16.10	13.38
		summer	4.87	2.25	14.71	17.94
		autumn	10.29	7.67	22.56	15.21
Grey heron	*EI*	spring	87.52	88.50	71.85	79.21
		summer	88.69	85.94	80.31	82.66
		autumn	79.37	72.20	74.45	65.45
	CI	spring	4.57	6.11	13.85	16.02
		summer	5.36	9.18	12.24	17.39
		autumn	10.33	14.21	11.35	17.91

Explanations: *EI* = the enrichment index, *CI* = the channel index.
Source: own study.

Table 3. Minimum and maximum pH values and the ammonifying bacteria numbers and mean organic matter content in the soil in the bird colonies and the control sites in summer

Parameter	Bird species	Value for soil in			
		colony		control	
		0–10 cm	10–20 cm	0–10 cm	10–20 cm
pH	great cormorant	3.7–4.4	3.4–4.2	5.1–6.1	5.5–6.8
	grey heron	4.4–5.3	4.2–5.3	4.7–6.2	4.4–6.3
Organic matter content (%)	great cormorant	35	11	20	6
	grey heron	33	27	21	31
Ammonifying bacteria ($CFU \cdot g^{-1}$ soil)	great cormorant	$4.6 \cdot 10^7$–$2.4 \cdot 10^8$	$2.3 \cdot 10^6$–$4.3 \cdot 10^6$	$4.3 \cdot 10^6$–$1.5 \cdot 10^7$	$9.3 \cdot 10^5$–$4.3 \cdot 10^6$
	grey heron	$9.3 \cdot 10^6$–$4.3 \cdot 10^7$	$2.3 \cdot 10^6$–$2.3 \cdot 10^7$	$2.3 \cdot 10^6$–$4.3 \cdot 10^6$	$2.3 \cdot 10^6$–$7.6 \cdot 10^6$

Source: own study.

the beginning of the breeding period, 121.7 mg $N \cdot m^{-2} \cdot day^{-1}$ in the middle and 30.95 mg $N \cdot m^{-2} \cdot day^{-1}$ at the end of the season. In the grey heron colony, the daily nitrogen input averaged 256.55 mg $N \cdot m^{-2} \cdot day^{-1}$ at the beginning of the breeding season, 97 mg $N \cdot m^{-2} \cdot day^{-1}$ in the middle and 10.65 mg $N \cdot m^{-2} \cdot day^{-1}$ at the end.

DISCUSSION

Wetland birds are an important link between food webs and an essential driver of organic matter cycling and energy flow in terrestrial and aquatic ecosystems (Anderson and Polis, 1999; Ellis, 2005; Ellis, Fariña and Witman, 2006; Towns *et al.*, 2009; Mulder *et al.*, 2011). Bird droppings are usually rich in mineral and organic components (Scherer *et al.*, 1995; Irick *et al.*, 2015; Zwolicki *et al.*, 2016), containing nitrogen, phosphorus and calcium compounds with a small amount of water. The consequence of such allochthonous input can be a significant nutrient enrichment of soils (Ligęza and Smal, 2003).

The great cormorant and grey heron colonies located in the Stawy Raszyńskie Nature Reserve can be classified as small, both in terms of area and the number of birds. Our research showed that the supply of total nitrogen during the breeding season ranged from 3.2 mg $N \cdot m^{-2} \cdot day^{-1}$ to 279.8 mg $N \cdot m^{-2} \cdot day^{-1}$, and a greater supply was found in the cormorant colony than in the grey heron colony. These differences are most likely due to differences in the abundance of the nesting birds, as well as the characteristics of both bird species, such as body size and diet. Our results are in line with those for the cormorant colony in the Wielkopolski National Park, where inputs of about 200 mg $N \cdot m^{-2} \cdot day^{-1}$ and monthly inputs of 6 g $N \cdot m^{-2} \cdot day^{-1}$ were found (Klimaszyk *et al.*, 2015). Significantly higher values of nitrogen input (about 800 mg $N \cdot m^{-2} \cdot day^{-1}$, giving a monthly input of 24 g $N \cdot m^{-2} \cdot day^{-1}$) were recorded for cormorant colonies in evergreen forests in Japan (Hobara *et al.*, 2005).

An increase in nitrogen content in the soil can cause acidification (Otchere-Boateng, 1979). In our study, the soil under the two bird colonies had significantly lower soil pH values compared to the soil from the control areas. This effect is caused by ammonium ions, a decomposition product of uric acid, resulting from the activity of ammonifying microorganisms.

Our results also indicated a higher content of organic matter in soil from the great cormorant and grey heron colonies compared to the corresponding control sites. Most probably, the increase of soil organic matter content at bird-inhabited sites is driven by the cyclical deposition of food residues and accelerated leaf defoliation from trees on which birds in the colonies reside (García *et al.*, 2011; Domínguez *et al.*, 2017).

The accumulation of organic matter may consequently increase food resources for many soil invertebrate groups (Byzova *et al.*, 1995; Zmudczyńska *et al.*, 2012). It may also provide a base for the growth of many microorganisms, which are known to be a good food source for nematodes. This can explain the higher densities of nematode communities, mainly bacterivorous, found in the soil from the colonies compared to the control sites.

Increased densities of soil fauna, e.g. mites, springtails (Ilieva-Makulec *et al.*, 2016; Oszust and Klimaszyk, 2022) and nematodes (Ilieva-Makulec, Bjarnadottir and Sigurdsson, 2015; Ilieva-Makulec, Kozacki and Makulec, 2018; Pen-Mouratov and Dayan, 2019) in areas influenced by large aggregations of birds are often recorded. In the above-mentioned research as well as in our study, the effect of bird activity on the soil fauna was most pronounced (higher densities) in the topsoil than in the subsoil. Comparing the two bird species, the great cormorant had a greater impact on nematodes than the grey heron, which may be due to differences in bird biology and diet (Hahn, Bauer and Klaassen, 2007). High nutrient (especially nitrogen) enrichment in the soil has been found to enhance the growth of certain functional groups of bacteria, mainly ammonifying bacteria (Wright *et al.*, 2010; Teixeira *et al.*, 2013; Domínguez *et al.*, 2017). In our study also, the abundance of these bacteria in bird-affected (especially in the cormorant colony) soil was 10-fold or even 100-fold higher compared to the soil in the control sites.

We found that bacterivorous nematodes clearly responded to the increased abundance of bacteria in the colony areas. The densities of bacterial feeders in the colonies' soil were higher than in the control sites. Such a result is indicative of a more intensive process of organic matter decomposition and mineralisation taking place in the soils within the colonies. Moreover, these changes were well reflected in the higher *EI* values recorded in the bird colony sites. Similarly, a very clear positive response of bacterivorous nematodes to the presence of bird colonies was observed in other studies (Andriuzzi *et al.*, 2013; Ilieva-Makulec, Bjarnadottir and Sigurdsson, 2015; Ilieva-Makulec, Kozacki and Makulec, 2018; Pen-Mouratov and Dayan, 2019).

In agreement with other studies (Ilieva-Makulec *et al*., 2018; Pen-Mouratov and Dayan, 2019), we did not find a clear effect of birds on the density of fungivorous nematodes. We can infer the predominance of bacteria rather than fungi in the decomposition of organic matter in the soil under the bird colonies by the lower *CI* values recorded there in comparison to the control sites. Similar trends were found in previous studies on nematode communities inside a bird colony on the island of Surtsey (Ilieva-Makulec, Bjarnadottir and Sigurdsson, 2015), under corvid roosts (Ilieva-Makulec *et al*., 2018) and under migratory bird colonies (Pen-Mouratov and Dayan, 2019). In all these studies, the most positive response was mainly from nematode genera that require plentiful food resources.

Existing research clearly shows that bird pressure on vegetation often leads to complete transformation of the phytocenoses. For example, Ishida (1996) found that the effect of cormorants nesting in evergreen forests in Japan resulted in a simplification of their structure and species composition, while Klimaszyk *et al*. (2015) observed an increase in the proportion of nitrophilous plant species with a parallel reduction in total biodiversity. The reduced number of plant species and the associated reduction of root systems that serve as a food base for herbivorous nematodes may be the reason for the lower density of this nematode trophic group under the bird colonies in our study. In the soil from the great cormorant colony, herbivorous nematodes were barely present, while in the grey heron colony, although they were found on each sampling date, they were far less abundant compared to the control area.

In addition to increased nitrogen inputs, large accumulations of other elements, including heavy metals, are usually recorded under bird colonies. Increased concentrations of different contaminants in such environments were confirmed by Lebedeva (1997), Ligęza and Misztal, (1999) and Ziółek, Bartmiński and Stach (2017). In our study, the complete absence of predatory nematodes and very low abundance of omnivorous nematodes in soils from the bird colonies could be a result of such contamination. Predatory and omnivorous nematodes represent the highest trophic levels among soil microfauna and are often used as indicators of community stability (Bongers and Bongers, 1998; Zhao and Neher, 2013). Their abundance and diversity tend to decrease with increased pollution and environmental degradation (Wasilewska, 1999; Dmowska and Ilieva-Makulec, 2004), including increased heavy metal content (Korthals *et al*., 1996; Ekschmitt and Korthals, 2006). Our findings are in agreement with those of other researchers, indicating a clear reduction in the abundance of these trophic groups in soil influenced by bird presence (Ilieva-Makulec, Kozacki and Makulec, 2018; Pen-Mouratov and Dayan, 2019).

CONCLUSIONS

In summary, our results indicate that nematode communities from the great cormorant and grey heron breeding colony areas differed from those in the control areas in terms of their density and trophic structure. Among the two bird species, the cormorant had a greater impact on nematodes than the grey heron, which may be due to differences in bird biology and ecology. Our research hypotheses were verified and the results confirmed that:

- the density of soil nematodes in the soil from the colony areas was higher than in the control sites;
- the trophic structure of the soil nematode communities was less diverse in the soils in the colonies;
- bacterivorous nematodes had higher numbers at the bird breeding colony sites compared to the control sites;
- the nematode community parameters we analysed reflect the shifts in abiotic and microbiological parameters in soil from bird colony sites, which confirms their bioindicative value.

Our results indicate that allochthonous input in soil under bird colonies promotes microbial activity and the most opportunistic trophic group of nematodes, which may at least temporarily affect nutrient cycling in the wetland soil.

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