The influence of *Corvus frugilegus* nesting on soil parameters and plant composition in poor and fertile habitats

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Abstract The functioning of nesting colonies of birds can significantly affect the flora and the soil. Colony species that modify soil characteristics at their nesting sites include the Rook *Corvus frugilegus*. In order to assess the effect of this species on poor and fertile habitats, we analysed biogenic element concentrations and soil acidity, and investigated the taxonomic representation of plants under the nests and at control sites without nests. Two-way ANOVA showed that the habitats significantly differed in most of soil parameters. The presence of Rook colonies contributed to increased humidity and acidity of the soil and a higher biogenic element content. A varied influence of Rook colonies on plant species diversity was observed, depending on habitat type. Rook nesting caused a fall in the overall number of plant species in the poor habitats, and a corresponding rise in the fertile habitats. Rooks contributed to a rise in the mean number of ruderal species and a fall in the mean number of meadow species. A synergy between habitat type and collection site was identified in the case of ornithochorous species.

Keywords Rook · Faeces · Poor and fertile habitats · Soil · Chemical parameters · Floristic composition

Introduction

Nesting birds change the chemical parameters of the soil and the specific representation of plants in their habitats. Especially, the effect of seabird colonies on their breeding biotopes has been comprehensively analysed (Godzik 1991; Fourgurean et al. 1992; Odasz 1994; Otero Pérez 1998; Beyer et al. 2000; Bancroft et al. 2005; Liu et al. 2006; Jakubas et al. 2008; Mitoza 2009; Sigurdsson and Magnusson 2009; Khoreva and Mochalova 2009). What has far more seldom been the subject of analyses is the influence of land birds on soil transformations and the vegetation structure (Mun 1997; Hobara et al. 2005). The faeces deposits of birds forming large colonies contribute to modifying soil parameters by increasing the content of, for example, nitrogen, phosphorus and organic matter in the soil (Mun 1997; Ligęza and Smal 2003; Bancroft et al. 2005; Hobara et al. 2005; Yin et al. 2008). On the one hand, a high accumulation of nutrients in the soil resulting from excrement deposition by birds can disturb the soil/plant balance and lead to changes in the functioning of land ecosystems. This results in diminished plant diversity, changes in the taxonomic representation or even a complete disappearance of some plants (Ishida 1997; Mun 1997; Beyer et al. 2000; Khoreva and Mochalova 2009). The impact on plants depends on the concentration of chemical elements introduced into the soil along with excrements (Ishida 1997; Mun 1997). On the other hand, birds transport diaspores and then deposit them in their habitats, thus affecting the development of the specific representation of phytocoenoses (Marone et al. 2001; Clausen et al. 2002; Czarnecka and Kitowski 2008; Khoreva and Mochalova 2009; Orłowski and Czarnecka 2009).

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Colony species that can significantly affect the surface soil layer at their nesting sites include the Rook *Corvus frugilegus*. The Rook is strongly associated with open farmland and breeds in spatially distributed colonies of nests in tree canopies (Kasprzykowski 2007, 2008). The feeding ground changes depending on the season of the year, which diversifies the Rook's diet, which consists of both plant and animal matter (Gromadzka 1980; Kasprzykowski 2003; Orłowski et al. 2009). The functioning of large nesting colonies of Rooks can significantly affect both the flora and the soil under the nests. Apart from introducing excrement components into the soil, these birds also play a role in the dissemination of seeds (Czarnecka and Kitowski 2010, 2013). The literature describes the influence of Rook colonies on changes in the taxonomic representation of plants within park habitats (Czarnecka and Kitowski 2010, 2013). What is missing, though, is the complex information on the direction and magnitude of colony birds' impact on soil and vegetation characteristics in differentiated habitat types (fertile versus poor and under different magnitude of anthropogenic pressure). The work concerns two aspects of influence of the Rook colonies on ecosystem functioning: modification of soil properties and modification of vegetation structure in direct (seed dispersal) and indirect ways (as a consequence of habitat modification). We assumed the null hypothesis that Rooks do not affect soil properties and plant composition. However, we expected that the sites under the Rook nests could have more fertile soil and a higher concentration of biological elements as compared with control sites. We also attempted to answer the following question: does the presence of Rook colonies influence vegetation structure, depending on the habitat type?

Materials and methods

Nesting colonies were surrounded by agricultural landscape and bird feeding areas are located there. Spring corn, meadows and pastureland were of the greatest significance in the Rooks' foraging area (Kasprzykowski 2003). Four Rook colonies were located in eastern Poland, in two types of habitat: fertile and poor (Table 1). The fertile habitat was represented by samples collected in city parks: Biała Podlaska and Siedlce. The second type was represented by samples collected at pine forest sites in Podnieśno and Żelków. Both types of habitats were located on mineral soils, represented in the poor colonies by sand, and in the fertile colonies by loam. Vegetation in fertile habitats was dominated by deciduous trees, whereas the pine predominated in the poor ones. The habitat types clearly differed in

thickness and type of organic matter. All the colonies were over 20 years of age.

Ten experimental plots were randomly selected per each colony in locations under the Rook nests (nesting sites) and in places that were not exposed to the influence of the birds (control sites). The control sites were located at a minimal distance of 200 m away from the closest tree with nests.

An area of 1 m² (100 × 100 cm) was delineated at each experimental plot in April 2009. The species of plants present in the particular areas (plots) were identified in the period between April and October, three times in the following months: April, July and September.

Soil samples were collected for analysis from the selected sites in October. The soil was sampled down to a depth of 20 cm, after removing the litter and plants. Three soil samples were collected into nylon bags from each plot. The samples were subsequently mixed and treated as representative samples. Altogether, 80 soil samples were used for chemical analysis (40 from the nesting sites and 40 from the control sites). The soil samples were air-dried and then sifted through a sieve with a 2 mm mesh. This material was tested for the following parameters: moisture, pH, organic carbon, total nitrogen, total phosphorus, as well calcium, magnesium and potassium content, by means of the following methods:

- Moisture—Moisture Meter (type HH2, Ver. 2.3) measurements
- Reaction—pH was measured in 1 M KCl with a glass electrode in water (1:2.5 ratio),
- Organic carbon—by wet dichromate oxidation with sulphuric acid (Kalembasa and Jenkinson 1973),
- Total nitrogen with the phenylhypochlorite method (Solórzano 1969),
- Total phosphorus with the molybdenum blue method (Standard Methods 1999),
- Content of metals: Ca, Mg and K were analysed with the atomic absorption spectroscopy (AAS) method (Carter and Gregorich 2006).

With the aim of verifying the hypothesis stated in the introduction, two-way ANOVA was used. Site (nest vs. control) and habitat type (poor vs. fertile) were considered as independent variables, while each soil parameter and the number of plants in particular ecological groups were treated as dependent variables. Parametric tests were applied before the above testing for statistical normalisation—e.g., the Kolmogorov–Smirnov test. The χ^2 test was applied to determine differences in the maximal numbers of species and species characteristics of the different ecological groups between the habitats. The statistical processing was performed using the STATISTICA 10.0 package (Statsoft Inc. 2013).

Table 1 Characteristics of the study sites

	Poor habitat (forest)		Fertile habitat (park)	
Colony location	Podnieśno	Żelków	Biała Podlaska	Siedlce
Coordinates	52°30'N, 22°23'E	52°08'N, 22°11'E	52°02'N, 23°02'E	52°10'N, 22°18'E
Area (ha)	4.3	1.6	11.9	11.1
Number of the Rook nests	847	397	224	736
Number of tree species	3	3	7	8
Number of shrub species	4	1	3	4
Dominant trees	<i>Pinus sylvestris</i>	<i>Pinus sylvestris</i>	<i>Acer platanoides</i> , <i>Fraxinus excelsior</i> , <i>Aesculus hippocastanum</i> , <i>Alnus glutinosa</i> <i>Carpinus betulus</i>	<i>Ulmus leavis</i> , <i>Aesculus hippocastanum</i> , <i>Fraxinus excelsior</i> , <i>Tilia cordata</i>
Depth of organic horizon (cm)	0–12	0–10	0–2	0–2
Parent material	Fluvioglacial sand	Fluvioglacial sand	Moraine loam	Moraine loam
Type of organic material	Ol–Of–Oh–A	Ol–Of–Oh–A	Ol–A	Ol–A
Soil units (WRB 2006)	Podzols	Podzols	Cambisols	Cambisols

Table 2 Mean values of soil parameters in control (c) and nesting sites (n) in two habitat sites

Parameter	Site	Poor habitat Mean $\pm$ SE (N = 20)	Fertile habitat Mean $\pm$ SE (N = 20)
Moisture (%)	c	12.0 $\pm$ 1.02	31.4 $\pm$ 1.26
	n	12.0 $\pm$ 0.96	30.8 $\pm$ 0.99
pH	c	4.47 $\pm$ 1.035	5.98 $\pm$ 0.546
	n	4.17 $\pm$ 0.940	4.81 $\pm$ 1.133
Corg (%)	c	1.25 $\pm$ 0.481	2.50 $\pm$ 1.009
	n	2.19 $\pm$ 1.398	4.62 $\pm$ 1.914
N (mg kg ⁻¹)	c	488.0 $\pm$ 217.85	1389.9 $\pm$ 471.13
	n	1033.6 $\pm$ 358.31	2616.9 $\pm$ 1202.51
P (mg kg ⁻¹)	c	183.9 $\pm$ 42.80	643.3 $\pm$ 144.76
	n	289.2 $\pm$ 92.74	1047.4 $\pm$ 349.23
Ca (mg kg ⁻¹)	c	391.6 $\pm$ 190.72	847.6 $\pm$ 497.19
	n	822.1 $\pm$ 480.70	457.8 $\pm$ 360.32
Mg (mg kg ⁻¹)	c	124.2 $\pm$ 125.47	577.3 $\pm$ 162.52
	n	153.9 $\pm$ 164.15	726.4 $\pm$ 419.22
K (mg kg ⁻¹)	c	9.5 $\pm$ 4.88	565.9 $\pm$ 140.71
	n	14.2 $\pm$ 5.16	622.8 $\pm$ 215.96

Sample size is given in parenthesis

Results

Soil properties

The poor habitats were found to have lower soil humidity and acidity, lower organic matter content, lower soil nitrogen and phosphorus concentrations, as well as clearly lower magnesium and potassium concentrations in comparison with the fertile habitats (Table 2). These differences were statistically

significant, with only calcium levels similar in both habitats (Table 3). The concentration of biogenic elements: nitrogen, phosphorus and Corg in the soil under the Rook nests was statistically significantly higher than at the control sites (Table 2). The presence of the colonies also contributed to a rise in soil acidity. The common denominator of both breeding biotopes was the lack of effect that Rook presence had on on Ca, Mg and K concentrations (Table 3). At the same time, N, P, Ca and Corg content in the soil and soil acidity were conditioned both by habitat quality and nest presence.

Vegetation structure

The fertile habitat was found to contain a greater mean number of all the species, as well as meadow and ruderal species, than the poor habitat (“Appendix”, Tables 3, 4). No significant differences were identified in the mean number of species between control and nesting sites. The presence of the Rook caused an increase in the mean number of ruderal species in both habitat types; ornithochorous species increased only in fertile ones, while their numbers decreased under the nests in poor habitats (Table 4). Among all the ecological groups of species that were analysed, only in the case of ornithochores did we find an interaction between habitat type and site type (Table 3).

The Rook colonies contributed to a decrease in the overall number of plant species found in the poor habitats (from 26 to 14), while, on the other hand, the fertile habitats saw a rise in the number of species (from 31 to 44) (see Appendix), with statistically significant differences (χ^2 with Yates cor. = 4.94, $p = 0.026$). Such regularities were not observed in the case of the particular ecological plant groups (χ^2 with Yates cor. $p > 0.136$ in the three cases).

Table 3 Results of two-way ANOVA analysis of differences in mean values of soil parameters and mean number of plant species between studied sites (habitat types: poor and fertile; site types: nesting and control)

Parameter	Habitat		Site		Habitat × Site	
	$F_{1,76}$	p	$F_{1,76}$	p	$F_{1,76}$	p
Soil parameters						
Moisture	325.18	<0.001	0.07	0.798	0.08	0.780
pH	26.19	<0.001	12.17	<0.001	4.38	0.040
Corg	39.33	<0.001	27.22	<0.001	3.97	0.049
N	66.99	<0.001	34.08	<0.001	5.04	0.028
P	193.32	<0.001	33.85	<0.001	11.64	0.001
Ca	0.26	0.611	0.05	0.821	20.88	<0.001
Mg	85.91	<0.001	2.61	0.110	1.16	0.284
K	408.25	<0.001	1.15	0.288	0.82	0.368
Plant species						
All species	147.57	<0.001	2.50	0.118	1.27	0.262
Ornithochorous	0.13	0.719	2.08	0.154	10.51	0.002
Meadow	33.14	<0.001	4.17	0.045	1.69	0.198
Ruderal	10.60	0.002	5.08	0.027	0.01	0.934

Table 4 Mean number ($\pm$ SE) of plant species in control sites (c) and nesting sites (n)

	Poor habitat		Fertile habitat	
	c ($N = 20$)	n ($N = 20$)	c ($N = 20$)	n ($N = 20$)
All species	3.6 $\pm$ 0.51	3.9 $\pm$ 0.28	9.7 $\pm$ 0.46	11.2 $\pm$ 0.82
Ornithochorous	0.5 $\pm$ 0.15	0.2 $\pm$ 0.09	0.1 $\pm$ 0.05	0.7 $\pm$ 0.21
Meadow	1.3 $\pm$ 0.23	0.4 $\pm$ 0.11	2.5 $\pm$ 0.34	2.3 $\pm$ 0.33
Ruderal	0.5 $\pm$ 0.11	1.2 $\pm$ 0.19	1.5 $\pm$ 0.34	2.2 $\pm$ 0.44

Discussion

The effect of the presence of the Rook colonies on the taxonomic plant composition in park (fertile) habitats has been explored earlier (Czarnecka and Kitowski 2010, 2013). What is missing, though, is information on the effect of Rook colonies on pine forest (poor) habitats, although Kasprzykowski (2003) has reported that Rooks also select such places to set up colonies. As shown by studies, poor habitats clearly differ in specific soil parameters from fertile habitats. Rook colony presence in both types of habitats leads to, among other things, an increase in organic matter volume, biogenic element content in the soil and soil acidity. Birds can act as a prominent soil-forming factor, influencing ecosystem development through guano deposition (Mun 1997; Ligęza and Smal 2003; Bancroft et al. 2005; Liu et al. 2006; Jakubas et al. 2008; Sigurdsson and Magnusson 2009; Czarnecka and Kitowski 2010, 2013), as well as contributing to soil eutrophication (Mun 1997; Bancroft et al. 2005; Hobara et al. 2005). On the one hand, the increase in soil fertility in both habitats under the nests can result from bird faeces deposition. Additionally, a rise

in phosphorus content was observed at the nesting sites as opposed to the control sites. Phosphorus is an element that is principally accumulated in mineral soil particles (clay fraction) (Raczuk 1990). Both habitat types (poor and fertile) were located on a mineral base. Hence, independent from the habitat type, the effect of phosphorus retention in the soil under the nests was similar.

It should be reiterated that Rook presence increases soil acidity, which was particularly prominent in the fertile environment. Our results concerning soil pH decrease at the nesting sites correspond with other authors' results (e.g. Mun 1997; Ueno et al. 2006; Okazaki et al. 1993; Sigurdsson and Magnusson 2009). Although the habitats differed significantly in Mg and K content in the soil, Rook colony activity eliminated the differences in the content of these metals in both habitats. At a low pH, some elements are characterised with high mobility and can penetrate to deeper soil strata. Attention was pointed to this fact by Hobara et al. (2005).

The results of the study show Rook presence of no effect on soil moisture, although some authors (Mun 1997; Bancroft et al. 2005) have reported a substantial decrease in soil humidity in pine forests under the nests of, e.g., *Adria cinerea* and *Egretta alba modesta*.

The study shows differences in chemical parameters and plant species composition between the nesting and control sites. The chemical composition of the soil can affect the presence of particular ecological plant groups. A rise in habitat fertility, particularly under Rook nests, causes a concomitant rise in the numbers of species with a preference for eutrophic habitats, e.g., *Gagea lutea*, *Ficaria verna*, *Lamium purpureum*, *Melandrium album* or *Veronica chamaedrys*. Similar observations relating to the presence of plant species that prefer eutrophic habitats have been

made concerning sites under the nests of *Adrea cinerea* and *Egretta alba modesta* (Mun 1997). The group of plants that prefer eutrophic soils also includes ruderal species, e.g., *Berteroa incana*, *Fallopia convolvulus*, *Galeopsis pubescens*, *Polygonum aviculare* and *Tripleurospermum inodorum*. The presence of Rook nests causes a rise in soil acidity, which can lead to the disappearance of such plant species as, e.g., *Achillea millefolium*, *Juncus conglomeratus*, *Melandrium album*, *Poa trivialis*, *Symphytum officinale* from nesting sites in comparison with the control sites. The above plant species prefer neutral and alkaline habitats.

The numbers of ruderal species (e.g., *Artemisia vulgaris*, *Cichorium intybus*, *Fallopia convolvulus* and *Galeopsis pubescens*) rose in both habitats. As compared with the poor habitats, the numbers of ornithochorous plant species, such as *Crataegus monogyna*, *Prunus insititia* and *Pyrus communis*, were found to have risen in the fertile habitat. The seeds of such plant species are spread by birds (Figuerola et al. 2003; Rodríguez et al. 2007), including Rooks (Orłowski and Czarnecka 2009, 2013). It can be surmised that the seeds of ornithochorous plants are also transferred to poor habitats by birds. However, owing to a notably lower humidity in comparison with fertile habitats, the seeds of these plant species probably do not find favourable sprouting conditions there (Harper 1977; Leck et al. 1989; Bekker et al. 1997). As stressed by Beyer et al. (2000), the principal factor limiting vegetation growth at sites exposed to the effects of bird faeces is water availability. The above ornithochorous plant species sprout in conditions of elevated humidity.

The plant species representation at the nesting sites can also result from the flora diversity around Rook colonies, at the feeding ground. The essential role of birds in diaspore dissemination has been pointed out repeatedly (Clausen et al. 2002; Higgins et al. 2003; Orłowski and Czarnecka 2009; Orłowski et al. 2011). Our study has shown that Rooks can play a significant role in disseminating diaspores of ruderal plants.

The factors that condition the habitat at *Corvus frugilegus* colony sites include both habitat fertility and bird colony presence. The results of interaction between the two factors are: an increase in organic matter content in the soil, a rise in biogen content, a fall in soil acidity, as well as a rise in the number of plant species defined as ornithochorous. However, owing to differences in soil parameters between poor and fertile habitats, the influence of *Corvus frugilegus* colonies on the taxonomic plant composition is varied. The presence of the Rook colonies contributed to a rise in species diversity in fertile habitats, whereas the diversity of plant species decreased in poor habitats.

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Appendix

See Table 5

Table 5 Vegetation structure in studied habitat types

Species	Ecological categories	Habitat			
		Poor		Fertile	
		n	c	n	c
<i>Acer platanoides</i> L.	W			+	+
<i>Acer pseudoplatanus</i> L.	W			+	
<i>Achillea millefolium</i> L.	M				+
<i>Aegopodium podagraria</i> L.	W			+	+
<i>Agropyron repens</i> (L.) P. BEAUV.	R		+		
<i>Agrostis</i> sp.		+			
<i>Anthriscus sylvestris</i> (L.) HOFFM.	W			+	+
<i>Artemisia vulgaris</i> L.	R	+			
<i>Atriplex</i> sp.	R			+	
<i>Berteroa incana</i> (L.) DC.	R		+	+	
<i>Calamagrostis</i> sp.			+		
<i>Carex hirta</i> L.	M			+	
<i>Chelidonium majus</i> L.	R	+	+	+	+
<i>Cichorium intybus</i> L.	R			+	
<i>Crataegus monogyna</i> JACQ.	W O			+	
<i>Dactylis glomerata</i> L. subsp. <i>glomerata</i>	M	+	+	+	+
<i>Euonymus europaeus</i> L.	W			+	+
<i>Fallopia convolvulus</i> (L.) Á. LÖVE	R			+	
<i>Festuca gigantea</i> (L.) VILL.	M			+	+
<i>Festuca rubra</i> L. s. s.	M	+			
<i>Ficaria verna</i> HUDS.	W			+	+
<i>Fragaria vesca</i> L.	W O		+		
<i>Gagea lutea</i> (L.) KER GAWL.	W			+	+
<i>Galeopsis pubescens</i> BESSER	R			+	
<i>Galium aparine</i> L.	W	+	+	+	+
<i>Geranium robertianum</i> L.	W	+	+	+	+
<i>Geum urbanum</i> L.	W	+	+	+	+
<i>Glechoma hederacea</i> L.	W		+	+	+
<i>Hieracium pilosella</i> L.	M	+			
<i>Hieracium umbellatum</i> L.	W		+		
<i>Juncus conglomeratus</i> L. em. LEERS	M		+		
<i>Lamium purpureum</i> L.	R			+	+
<i>Lysimachia nummularia</i> L.	M			+	+
<i>Melandrium album</i> (MILL.) GÄRCKE	R				+
<i>Moehringia trinervia</i> (L.) CLAIRV.	W		+	+	+

Table 5 continued

Species	Ecological categories	Habitat			
		Poor		Fertile	
		n	c	n	c
<i>Mycelis muralis</i> (L.) DUMORT.	W		+		
<i>Philadelphus coronarius</i> L.	W		+		
<i>Poa nemoralis</i> L.	W			+	+
<i>Poa pratensis</i> L.	M			+	+
<i>Poa trivialis</i> L.	M				+
<i>Polygonum aviculare</i> L.	R			+	
<i>Prunus insititia</i> L.	W O			+	
<i>Pyrus communis</i> L.	W O			+	
<i>Quercus robur</i> L.	W	+	+		
<i>Ranunculus repens</i> L.	M		+	+	+
<i>Rhamnus catharticus</i> L.	W O		+	+	
<i>Rubus idaeus</i> L.	W O		+		
<i>Rumex acetosa</i> L.	M		+	+	
<i>Rumex obtusifolius</i> L.	M		+	+	
<i>Sambucus nigra</i> L.	W O	+	+	+	+
<i>Scrophularia nodosa</i> L.	W			+	
<i>Stellaria media</i> (L.) VILL.	R	+	+	+	+
<i>Symphytum officinale</i> L.	M				+
<i>Taraxacum</i> sp.		+	+	+	+
<i>Tilia cordata</i> MILL.	W			+	+
<i>Tripleurospermum inodorum</i> (L.) Schulz-Bip.	R			+	
<i>Urtica dioica</i> L.	W	+	+	+	+
<i>Veronica chamaedrys</i> L.	M			+	
<i>Veronica persica</i> POIR.	R			+	+
<i>Viola odorata</i> L.	W		+	+	+
<i>Viola reichenbachiana</i> JORD. ex BOREAU	W			+	+
Total number of recorded species		14	26	44	31

Species: M meadow, W woodland, R ruderal, O ornitochorous

Nomenclature of species after Mirek et al. (2002)

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