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Article

Species diversity and composition of Oribatida (Acari: Sarcoptiformes) in former breeding colonies of the great cormorant (*Phalacrocorax carbo*) in Poland

Mateusz Oszust[1*] and Piotr Klimaszyk[2]

1. *Zakład Dydaktyki, Wielkopolska Akademia Społeczno-Ekonomiczna w Środzie Wlkp.- Akademia Nauk Stosowanych, Środa Wielkopolska, Poland; E-mail: oszustmateusz@zsasroda.onmicrosoft.com*
2. *Department of Water Protection, Faculty of Biology, Adam Mickiewicz University, Poznań, Poland; E-mail: piotr. klimaszyk @amu.edu.pl.*

[*] Corresponding author

ABSTRACT
The great cormorant (*Phalacrocorax carbo*) is a species that alters ecosystems significantly, mainly by depositions of guano, which changes the chemical properties of soil and can lead even to deforestation as well as have a significant impact on soil mite communities. The study was conducted on three islands: abandoned by cormorants recently (Z1), abandoned three years ago (LI) and a site without cormorants (Z2) for comparison. The species composition of island Z1 did not differ significantly from the fauna of the previously studied colonies. Many xerophilous and meadow species occurred on LI island, which was likely caused by deforestation because of cormorant activity.

KEYWORDS: Deforestation, guano, soil mites, species composition, xerophilous.

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INTRODUCTION

The great cormorant, *Phalacrocorax carbo* (L.) (Aves: Phalacrocoracidae) is a piscivorous species that alters ecosystems significantly, by breaking twigs and branches to build nests and by deposition of large amounts of rich in N and P guano that change soil chemistry. The mentioned factors cause a decrease in plant biomass and diversity, leading, among others, to deforestation, except for nitrophilous species, which growth is promoted in this habitat (Kolb *et al*. 2012).

Cormorants also affect other groups of organisms. Previous studies show that the abundance, density or species richness of among others Collembola, Coleoptera (herbivores) and Thysanoptera in breeding colonies of cormorants are lower than their reference sites (Kolb *et al*. 2010, 2012, 2015). On the other hand, due to the availability of carrion, faecal and other dead material, colonies attract scavenger beetles (Coleoptera), Brachycera flies, and astigmatic mites (Kolb *et al*. 2010, 2015; Oszust and Klimaszyk 2022). Fertilization of plant by nitrogen lead to an increased density of aphids and caterpillar, as well as their natural enemy e.g., parasitic Hymenoptera (Kolb *et al*. 2010). In previous works, the authors did not compare the studied islands in terms of the succession of

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species sensitive to cormorant activity. However, in most works, the density or species richness of invertebrate groups from abandoned colonies were similar (e.g. aphid) or higher (e.g. lepidopteran larvae) than their reference sites. In some cases, former colonies archived the highest density of some invertebrates (e.g., herbivores Coleoptera and web spiders) among studied sites (Kolb *et al*. 2010, 2012).

Oribatida is a group of mostly saprophagous mites (Acari) and they are most numerous in soil (Norton and Behan-Pelletier 2009). According to previous studies, cormorants create unfavorable conditions for many species of Oribatida, while other taxa prefer this habitat. However, Kolb *et al*. (2015) did not identify the species, while others' works focused only on several islands (Oszust and Klimaszyk 2022) or one peninsula (Petrauskiene *et al*. 2022), which means that the topic of ornithogenic influence on the Oribatida populations is still poorly understood.

We present data about the species diversity of Oribatida in soil from two islands left by cormorants. We hypothesized that leaving islands by cormorants leads to a succession of common oribatid species.

MATERIAL AND METHODS

Sampling methodology

For the purposes of this work, we consider colonies as former ones that were abandoned by cormorants and were devoid of these birds during the sampling.

In total, 25 soil samples were collected from random sites in the central part of each island using a metal core (10 cm in depth, 4 cm in diameter). Invertebrates were extracted with a Tullgren funnel and preserved in 75% ethanol. Only adult Oribatida were identified at the species level.

All samples were collected on 25.08.2018, at three sites in Poland.

LI: The former colony (53° 04′ 42″ N, 15° 57′ 47″E) is located on Lech Island on Lake Ostrowiec. The island is significantly raised above the lake level, with an area of about 1.2 ha. Since the late 1960s, cormorants have been observed there. In 2004 almost 300 inhabited nests were reported and, due to the withering of trees, the colony expanded from the central part of the island to an area closer to its edge. At the peak of colony development, the vegetation was almost destroyed, and the ground was covered with organic remains. Due to trees vanishing and the invasion of American mink, *Neogale vison* (Schreber) (Carnivora: Mustelidae) which prey on cormorant eggs, in 2015 birds abandoned the colony. During sampling, spontaneous vegetation regeneration, mainly nitrophilous species (like *Urtica dioica*) and mosses on soil have been occurring.

Z1: The cormorant colony (53° 04′ 58″ N, 16° 03′ 35″ E) was located on the eastern island of Lake Załom with an area of 0.6 ha. The island is overgrown with alders, oaks, birches, and willows and was inhabited by cormorants in the second decade of the 21st century. In zones where cormorant nests were most dense, the forest canopy is sparse, herbaceous vegetation is absent and forest litter is abundant. The colony consisted of over 200 nests occupied by cormorants; however, about 2 weeks before the sampling, both adults and juveniles flew away. One year later, the cormorants returned to the island.

Z2: Control island (53° 04′ 59″ N, 16° 03′ 49″ E) also located on Lake Załom and unaffected by cormorants is about 150 m West of the colony. It is similar to a colony island according to morphology and vegetation (but without any symptoms of a cormorant impact).

Other plants from the studied sites were not identified at the species level.

Data analysis

To classify individuals, adults of oribatid mites were macerated with 80% lactic acid. Subsequently, they were placed on a microscope cavity slide and covered by a coverslip for identification, with lactic acid as the medium. All species were identified according to Weigmann

(2006). To compare the study sites for each species' density and dominance, the Shannon-Wiener diversity index (SW) and modified Simpson's dominance index (SD) were calculated, according to Oszust and Klimaszyk (2022).

SW informs us about the difficulties associated with predicting the species to which the next individuals from the sample will belong. The value of SW increases with an increasing number of species and their participation in the sample, thus highly dependent on the number of species. Whereas the value of Simpson's dominance index (after modification by subtracting the result from one) means the probability that, two following individuals belong to different species. SD is in the range from 0 to 1 and pays more attention to the number of individuals from species that are more numerous (more frequent in the sample) than to rare ones (Krebs 2011).

Each species was assigned to one of the following groups based on their habitat preference: **dw -** dead wood; **fs -** forest soil and litter; **as -** acid soil; **or -** soil rich in organic carbon; **gn** – guano; **md -** meadow soil; **ml -** moss, lichen and tree bark; **nt** – nests; **wt -** wet soil, bogs; **xp -** xerophilous habitats soil; **eu -** eurytopic species; **uk -** species with unclear habitat preference.

The normalities of distributions of the number of species per sample, values of density and diversity indicators were checked with the Shapiro-Wilk test, which showed no normality in all data, even after transformation. Subsequently, the Kruskal-Wallis tests were performed for each set of data.

RESULTS

In total, 54 species were noted and the richest in taxa was LI, while the density of Oribatida was highest on Z2. Values of both biodiversity indexes are similar on LI and Z2, but higher than Z1 (Table 1). However, none of the differences was statistically significant. A list of species is present in Table 2. In LI, Z1 and Z2 the most common taxa are respectively *Oppiella nova* (Oudemans), *Rhinoppia nasuta* (Moritz) and *Atropacarus striculus* (C.L. Koch), with the following dominance: 14.93; 45.58 and 19.79%, respectively.

Table 1. The total number of species, individuals and the mean value of density with standard error, the Shannon-Wiener diversity index (SW) and modified Simpson's dominance index (SD).

	LI	Z1	Z2
Number of species (total/mean)	33/5.24	12/3.67	27/5.36
Number of individuals	279/11.16	329/13.07	468/18
Density	8584.61 ± 1905.39	10544.87 ± 1518.76	13846.15 ± 3937.38
SW	1.87 ± 0.17	1.3 ± 0.12	1.86 ± 0.16
SD	0.65 ± 0.03	0.47 ± 0.06	0.63 ± 0.04

LI was the richest in both individuals and species considered as characteristics for forest species, meadows and xerophilous habitats (Figs. 1, 2). Even though in Z2, the total number of specimens from eurytopic species is higher, in LI all species from this ecology group (apart *A. striculus*) have higher density.

Meanwhile, Z1 due to the presence of *R. nasuta* and *Oribella pectinata* (Michael) was characterized by a higher number of specimens and species noted from organic soil, guano and nest, than other sites. Apart from the mentioned mites, in Z1 a significant number of forest oribatid mites occurred.

Z2 is dominated (besides eurytopic species) by mites preferring acid and wet habitats e.g., *Pilogalumna tenuiclava* which also were more common on this island than others.

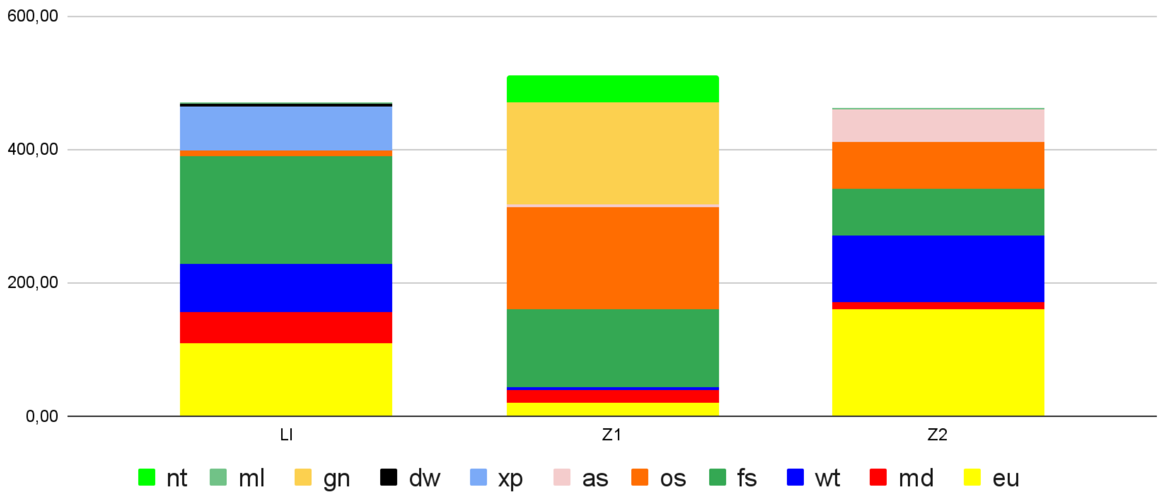

Figure 1. The abundance of oribatid mites from individual ecological groups in each studied site.

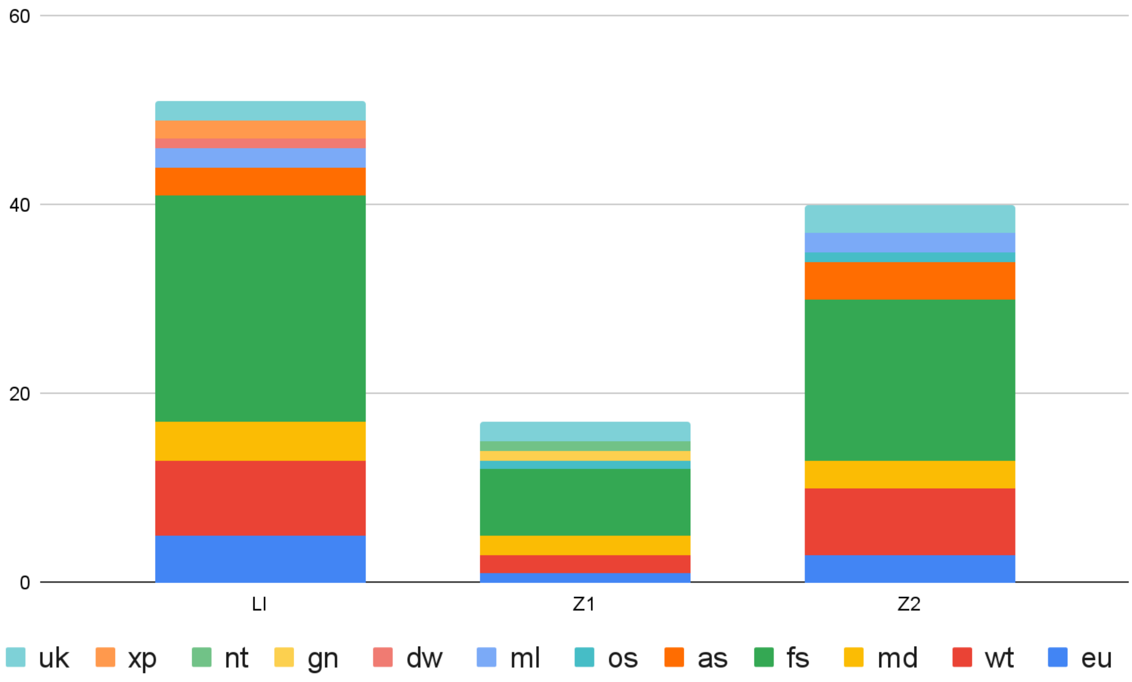

Figure 2. Number of species from individual ecological groups in each studied site.

DISCUSSION

The obtained results (Table 1) are similar to previous studies, because island Z1 was characterized by lower density and species diversity of Oribatida than their reference site (Kolb *et al*. 2015; Oszust and Klimaszyk 2022; Petrauskiene *et al*. 2022).

SW and SD values of LI and Z2 islands are nearly identical (Table 1) and slightly lower than the result from most reference islands studied by Oszust and Klimaszyk (2022). Also, the biodiversity of Oribatida from both islands is higher than most results from colonies studied in the mentioned publication. Therefore, the likely leaving of LI by cormorants allows for increasing species diversity of Oribatida, because of the succession of new species. Oribatida could come from the mainland with water, wind, insects or birds (Lehmitz *et al*. 2011).

The richest in taxa was LI, however, the difference between LI and Z2 in species diversity was not statistically significant and might be caused by the high number of species, which were represented by singular individuals, which is proven by a similar mean of species number per sample in both sites.

Most common taxa on LI belonged, among others, to the xerophilous mites like *Xenillus salamoni* Mahunka and *Pergalumna altera* (Oudemans) as well as associated with meadows *Liebstadia similis* (Michael) (Weigmann 2006; Ivan 2010; Oszust *et al*. 2021), that might be explained by deforestation due to cormorant activity and the change of the previous forest into an open area, which promotes the mentioned species.

In Z2 another species from the genus *Xenillus* was found - *X. tegocranus* (Hermann) that did not occur on LI, which was caused likely by their habitat preference. In previous studies, *X. tegocranus* was noted from open areas like alpine grasslands, but generally, this species prefers forest floor and is sensitive to soil disturbance (Todria *et al*. 2021). Therefore, *X. tegocranus* might have lived on LI earlier, but colonies of cormorants might have led to the extinction of this species on this island. A similar situation was on the island of Chrzypsko Wielkie Lake, where *X. tegocranus* was found at reference sites, but not on the colony (Oszust and Klimaszyk 2022).

Surprisingly, a significant number of forest species were found in LI. However, most of them were represented by singular individuals or had more complex ecology and often occurred in different habitats. For example, *Hafenrefferia gilvipes* (C.L. Koch) besides forest soil, is usually common in dead wood and mosses, which occurred abundantly on LI. On the other hand, the occurrence of some species on LI is difficult to explain, for example, *Galumna lanceata* (Oudemans). Even though some authors considered *G. lanceata* as xerophilous species (Bardel and Pfingstl 2018), it is mostly known from forest soil (Weigmann 2006). Perhaps *G. lanceata* and other species come to LI from forests around the lake and an appropriate concentration of nutrients in the soil of the former colony accelerated the succession of this species.

Among the species considered as characteristic of cormorant colonies in previous studies, only *Acrogalumna longipluma* (Berlese) occurred on both LI and Z1 islands, while *Rhinoppia nasuta* was found just on Z1, where it was the dominant taxon (see Table 2). Another species noted in all the studies is *Oribella pectinate* (Michael). Petrauskiene *et al*. (2022) noted it only in the abandoned part of the colony, while Oszust and Klimaszyk (2022) did not find it (except for one individual), even in the colony in Załom Lake one year later. This species is mostly known from nests (Oszust and Klimaszyk 2022), where it likely feeds on organic remnants, thus leaving the colonies by cormorants, could have forced the mites to search for food outside the nests.

In Z1, similar to active breeding colonies, specimens of Suctobelbidae (except *Suctobelba altvateri* Moritz and one individual of *Suctobelbella baloghi* (Forsslund)), Phthiracaridae and Nothrina (Malaconothridae, Crotoniidae, Nothridae) were not noted. In LI, Phthiracaridae and Nothrina were also rare (represented by singular species). They are groups of k strategy mites, sensitive to soil disturbance with, among others, long life spans, and low dispersion rates, and they rarely occur in open areas like meadows (Gulvik 2007). Therefore, higher densities of these mites can be expected if the forest reappears on the island. On the other hand, *Suctobelbella subcornigera* (Moritz), which in active cormorant colonies are rare or absent, on the former colony (LI) was one of the dominant taxa with a density slightly higher than on an island unaffected by this bird species (Z2). *Suctobelbella subcornigeria*, as well as *Oppiella nova* and *Tectocepheus velatus sarekensis* Trägårdh (which are also common in LI) are eurytopic species with short life spans and parthenogenetic reproduction, that brings them closer to the r strategy and might favor the rapid succession of these mites (Norton and Behan-Pelletier 2009; Ivan 2010). The dominance of these taxa over k strategy mites (with a significant share of the latter) suggests that biocenosis is at the structuring stage of succession, while r strategy arachnid will be gradually replaced in dominance by other mites (Ryabinin and Pan'kov 2009).

Table 2. List of species with mean density and standard error (DEN) and dominance (DOM).

Species	Indicator	LI	Z1	Z2	Ecology	Reference
***Hypochthoniella minutissima* (Berlese, 1903)**	DEN	184.61 ± 80.43	-	1169.23 ± 732.61	as	e
	DOM	1.95	-	8.09		
***Hypochthonius rufulus* Koch, 1835**	DEN	-	92.31 ± 68.99	215.38 ± 94.42	as, fs, md	e; a
	DOM	-	0.89	1.49		
***Acrotritia duplicata* (Grandjean, 1953)**	DEN	92.31 ± 67.64	-	123.08 ± 72.70	fs	e
	DOM	0.97	-	0.85		
***Microtritia minima* (Berlese, 1904)**	DEN	30.77 ± 30.77	-	-	as	e
	DOM	0.32	-	-		
***Atropacarus striculus* (Koch, 1835)**	DEN	-	-	2861.54 ± 1223.95	eu	c
	DOM	-	-	19.79		
***Phthiracarus clavatus* Parry, 1979**	DEN	30.77 ± 30.77	-	-	fs	c
	DOM	0.32	-	-		
***Phthiracarus globosus* (Koch, 1841)**	DEN	-	-	338.46 ± 109.51	fs	e
	DOM	-	-	2.34		
***Phthiracarus longulus* (Koch, 1841)**	DEN	-	-	184.62 ± 127.79	fs	c
	DOM	-	-	1.28		
***Phthiracarus* sp.**	DEN	61.54 ± 42.6	-	-	uk	
	DOM	0.65	-	-		
***Malaconothrus monodactylus* (Michael, 1888)**	DEN	-	-	61.54 ± 61.54	wt	e
	DOM	-	-	0.43		
***Nothrus pratensis* Sellnick, 1928**	DEN	30.77 ± 30.77	-	-	wt	c
	DOM	0.32	-	-		
***Heminothrus peltifer* (Koch, 1839)**	DEN	30.77 ± 30.77	-	-	eu	c
	DOM	0.32	-	-		
***Adoristes ovatus* (Koch, 1839)**	DEN	-	-	61.54 ± 42.6	as, fs	a
	DOM	-	-	0.43		
***Xenillus salamoni* Mahunka, 1996**	DEN	1384.61 ± 341.13	-	-	xp, fs	d
	DOM	14.61	-	-		
***Xenillus tegeocranus* (Hermann, 1804)**	DEN	-	-	30.77 ± 30.77	fs	e
	DOM	-	-	0.21		
***Hafenrefferia gilvipes* (Koch, 1839)**	DEN	61.54 ± 42.6	-	-	fs, dw, ml	e
	DOM	0.65	-	-		

a - Norton and Behan-Pelletier (2009); b - Ivan (2009); c - Olszanowski *et al.* (1996); d - Oszust *et al.* (2021); e - Weigmann (2006).

Table 2. Continued.

Species	Indicator	LI	Z1	Z2	Ecology	Reference
***Carabodes areolatus* Berlese, 1916**	DEN	30.77 ± 30.77	-	-	fs, dw, m	e
	DOM	0.32				
***Carabodes ornatus* Štorkán, 1925**	DEN	92.31 ± 51.02	-	-	as	e
	DOM	0.97	-	-		
***Tectocepheus velatus sarekensis* Trägårdh, 1910**	DEN	523.08 ± 220.81	-	-	eu	e
	DOM	5.52	-	-		
***Conchogneta delacarlica* Forsslund, 1947**	DEN	92.31 ± 67.64	64.1 ± 43.43	-	fs	e
	DOM	0.97	0.62	-		
***Multioppia glabra* (Mihelčič, 1955)**	DEN	92.31 ± 51.02	-	-	fs, wt	e
	DOM	0.97	-	-		
***Oppiella nova* (Oudemans, 1902)**	DEN	1415.38 ± 526.76	576.92 ±	738.46 ± 327.8	eu	e
	DOM	14.93	5.58	5.11		
***Oppiella nova propinqua* Mahunka & Mahunka-Papp, 2000**	DEN	-	-	3015.38 ± 621.63	uk	e
	DOM	-	-	20.58		
***Microppia minus* (Paoli, 1908)**	DEN	246.15 ± 192.15	-	30.77 ± 30.77	fs	e
	DOM	2.60	-	0.21		
***Rhinoppia nasuta* (Moritz, 1965)**	DEN	-	4711.54 ±	-	os, gn	e
	DOM	-	45.58	-		
***Rhinoppia obsoleta* (Paoli, 1908)**	DEN	-	30.77 ± 30.77	-	eu	e
	DOM	-	0.30	-		
***Lauroppia falcata marginedentata* (Strenzke, 1951)**	DEN	123.08 ± 123.08	30.77 ± 30.77	61.54 ± 61.54	fs	e
	DOM	1.30	0.30	0.43		
***Quadroppia hammerae* Mínguez Ruiz & Subías, 1985**	DEN	61.54 ± 61.54	30.77± 30.77	738.46 ± 327.8	uk	e
	DOM	0.65	0.30	5.11		
***Suctobelba altvateri* Moritz, 1970**	DEN	-	123.08 ± 68.82	-	wt	e
	DOM	-	1.19	-		
***Suctobelba granulata* Hammen, 1952**	DEN	30.77 ± 30.77	-	-	fs, wt	e
	DOM	0.32	-	-		
***Suctobelba reticulata* Moritz, 1970**	DEN	-	-	61.54 ± 61.54	fs	e
	DOM	-	-	0.43		
***Suctobelba trigona* (Michael, 1888)**	DEN	61.54 ± 61.54	-	-	fs	e
	DOM	0.65	-	-		

a - Norton and Behan-Pelletier (2009); b - Ivan (2009); c - Olszanowski *et al.* (1996); d - Oszust *et al.* (2021); e - Weigmann (2006).

Table 2. Continued.

Species	Indicator	LI	Z1	Z2	Ecology	Reference
***Suctobelbella acutidens* (Forsslund, 1941)**	DEN	-	-	215.38 ± 83.32	eu	e
	DOM	-	-	1.49		
***Suctobelbella acutidens sarekensis* (Forsslund, 1941)**	DEN	92.31 ± 67.64	-	-	eu	e
	DOM	0.97	-	-		
***Suctobelbella baloghi* (Forsslund, 1958)**	DEN	61.54 ± 61.54	30.77 ± 30.77	861.54 ± 308.72	fs	e
	DOM	0.65	0.30	5.96		
***Suctobelbella subcornigera* (Forsslund, 1941)**	DEN	1323.08 ± 524.58	-	1107.69 ± 525.63	eu	e
	DOM	13.96	-	7.66		
***Suctobelbella subcornigera vera* (Moritz, 1964)**	DEN	92.31 ± 51.02	-	-	fs	e
	DOM	0.97	-	-		
***Suctobelbella subtrigona* (Oudemans, 1900)**	DEN	153.85 ± 76.92	-	30.77 ± 30.77	fs	e
	DOM	1.62	-	0.21		
***Achipteria coleoptrata* (Linnaeus, 1758)**	DEN	61.54 ± 42.6	-	61.54 ± 61.54	fs, md, wt	e
	DOM	0.65	-	0.43		
***Oribella pectinata* (Michael, 1885)**	DEN	-	1230.77 ±	-	nt	e
	DOM	-	11.91	-		
***Liebstadia similis* (Michael, 1888)**	DEN	1323.08 ± 524.58	-	-	fs, md, wt	e
	DOM	13.96	-	-		
***Ceratozetes gracilis* (Michael, 1884)**	DEN	30.77 ± 30.77	-	-	fs, md, wt	e
	DOM	0.32	-	-		
***Euzetes globulus* (Nicolet, 1855)**	DEN	430.77 ± 133.82	-	-	fs, wt	e
	DOM	4.55	-	-		
***Chamobates cuspidatus* (Michael, 1884)**	DEN	-	-	369.23 ± 126.55	os	e
	DOM	-	-	2.55		
***Chamobates subglobulus* (Oudemans, 1900)**	DEN	-	-	30.77 ± 30.77	as	e
	DOM	-	-	0.21		
***Chamobates* sp.**	DEN	-	-	184.61 ± 91.88	uk	
	DOM	-	-	1.28		
***Zygoribatula exilis* (Nicolet, 1855)**	DEN	-	-	30.77 ± 30.77	ml	e
	DOM	-	-	0.21		
***Scheloribates laevigatus* (Koch, 1835)**	DEN	-	-	30.77 ± 30.77	fs, md	e
	DOM	-	-	0.21		
***Scheloribates pallidulus* (Koch, 1841)**	DEN	30.77 ± 30.77	-	30.77 ± 30.77	fs, md	e
	DOM	0.32	-	0.21		

a - Norton and Behan-Pelletier (2009); b - Ivan (2009); c - Olszanowski *et al.* (1996); d - Oszust *et al.* (2021); e - Weigmann (2006).

Table 2. Continued.

Species	Indicator	LI	Z1	Z2	Ecology	Reference
***Scheloribates pallidulus latipes* (Koch, 1844)**	DEN	-	492.31 ±	-	fs	e
	DOM	-	4.76	-		
***Acrogalumna longipluma* (Berlese, 1904)**	DEN	400 ± 126.55	2923.08 ± 416.6	-	fs	e
	DOM	4.22	28.28	-		
***Galumna lanceata* (Oudemans, 1900)**	DEN	153.85 ± 62.81	-	-	fs	e
	DOM	1.62	-	-		
***Pergalumna altera* (Oudemans, 1915)**	DEN	646.15 ± 181.38	-	-	xp	b
	DOM	6.82	-	-		
***Pilogalumna tenuiclava* (Berlese, 1908)**	DEN	-	-	1815.38 ± 661.54	as, wt	e
	DOM	-	-	12.55		
Total number of species		**33**	**12**	**27**		

a - Norton and Behan-Pelletier (2009); b - Ivan (2009); c - Olszanowski *et al.* (1996); d - Oszust *et al.* (2021); e - Weigmann (2006).

Previous studies show that the colonization of islands by cormorants leads to a change in the composition of the Oribatida species, e.g., by eliminating mites sensitive to soil disturbance. However, the obtained results indicate that leaving the island by cormorants allows a succession of the previous community; this process however is gradual and runs more efficiently for eurytopic taxa. Deforestation due to the ornithogenic impacts also creates optimal habitats for xerophilous and meadow species. Further studies are needed to check the mentioned conclusion and to learn the dynamics of the Oribatida communities in cormorant colonies.

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تنوع گونه‌ای و ترکیب Oribatida (Acari: Sarcoptiformes) در کلنی‌های سابق تکثیر باکلان بزرگ (*Phalacrocorax carbo*) در لهستان

متئوژ اوژوست[۱*] و پیوتر کلیماژیک[۲]

۱. گروه آموزشی، دانشگاه اجتماعی و اقتصادی ویلکوپولسکا در شرودا ویلکوپولسکا - آکادمی علوم کاربردی، شرودا ویلکوپولسکا، لهستان؛ رایانامه: *oszustmateusz@zsasroda.onmicrosoft.com*

۲. گروه حفاظت از آب، دانشکدهٔ زیست‌شناسی، دانشگاه آدام میکیویژ، پوزنان، لهستان؛ رایانامه: *piotr.klimaszyk@amu.edu.pl*

* نویسندهٔ مسئول

چکیده

باکلان بزرگ (*Phalacrocorax carbo*) گونه‌ای است که اکوسیستم‌ها را به مقدار زیادی تغییر می‌دهد؛ بیشتر با رسوبات گوانو، که خواص شیمیایی خاک را تغییر می‌دهد و می‌تواند حتی منجر به جنگل زدایی شود و همچنین تأثیر زیادی بر جوامع کنه‌های خاک داشته باشد. این مطالعه در سه جزیره انجام شد: به تازگی توسط باکلان رها شده (Z1)، سه سال پیش رها شده (LI) و سایتی بدون باکلان (Z2) برای مقایسه. ترکیب گونه‌ای جزیره Z1 تفاوت زیادی با جانوران کلنی‌های پیش‌تر مورد مطالعه نداشت. بسیاری از گونه‌های خشکی‌دوست و علفزار در جزیره LI پیدا شدند که به احتمال به دلیل جنگل‌زدایی در اثر فعالیت باکلان ایجاد شده است.

واژگان کلیدی: جنگل‌زدایی، گوانو، کنه‌های خاکزی، ترکیب گونه‌ها، خشکی‌دوست.

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