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Aquatic Fungi Growing on Feathers of Wild and Domestic Bird Species in Limnologically Different Water Bodies

B. Czeczuga*, A. Godlewska, B. Kiziewicz

Department of General Biology, Medical University, Kilińskiego 1, 15-089 Białystok, Poland

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Abstract

The mycoflora developing on the feathers of wild and domestic bird species in the water of 6 limnologically different water bodies was investigated under laboratory conditions. 97 zoosporic fungus species were found to grow on the feathers investigated, including 21 Chytridiomycetes, 1 Hyphochytriomycetes, 74 Oomycetes and 1 Zygomycetes fungus. The most common fungus species included *Chytriomycetes annulatus, Rhizophydium keratinophilum, Blastocladiopsis parva, Catenaria anguillulae, Catenophlyctis variabilis, Aphanomyces helicoides, Aphanomyces irregularis, Leptolegniella piligena, Pythium afertile, Pythium aquatile, Pythium echinulatum, Pythium intermedium* and *Pythium tenue*. The most fungi were noted growing in water from Cypisek spring (64), the fewest in the ponds Akcent (45) and Fosa (47 species). Out of these 97 species, 17 are known as parasites or necrotrophs of fish. 13 fungus species were recorded for the first time in Poland.

Keywords: aquatic zoosporic and keratinophilic fungi, feathers of wild and domestic birds, water bodies, hydrochemical parameters

Introduction

Our preliminary studies on the aquatic keratinophilic fungi have revealed that species composition of this physiological group depends on the type of keratin-containing substrate as well as on water bodies, particularly on water chemism [1,2]. Since the mute swan was the only species whose feathers, being a keratin-containing substrate, had been examined [1], we decided to conduct more detailed investigations including feathers of 48 bird species, both aquatic and land, using water samples collected from 6 different water bodies. Moreover, fungus species of the genus *Pythium*, never before included in such studies, were examined.

*Corresponding author; e-mail: czecz@amb.edu.pl

Material and Methods

The feathers of 48 wild and domestic bird species were subjected to investigation (Table 2). The feathers (flight-feather and down) were obtained in summer from birds occurrence in natural conditions and in the Zoological Garden in Białystok. The water for experiments was collected from six different water bodies:

1. Cypisek Spring is located in the south part of Knyszyn Forest, limnokrenic type, width 0.41 m, depth 0.17 m, discharge 0.6 l/sek.
2. Jaroszówka Spring is located in the northern part of Białystok, limnokrenic type, width 0.65 m, depth 0.12 m, discharge 2.4 l/sek.
3. Supraśl River, length 106.6 km, this is the right-bank tributary of the middle part of the Narew River, flowing through the Knyszyn Forest.

Table 1. Chemical composition (in mg l^{-1}) of water from different sites (mean from 3 samples).

Parameter	Water bodies					
	Cypisek Spring	Jaroszówka Spring	Supraśl River	Akcent Pond	Fosa Pond	Komosa Lake
Temperature (°C)	6.0	3.8	4.5	2.3	1.4	2.8
pH	7.69	7.91	7.84	7.33	7.22	7.88
O_2	10.4	11.8	13.2	1.0	5.8	12.2
BOD_5	3.8	3.8	12.0	1.0	4.6	5.0
COD (Oxidability)	2.50	5.40	10.94	26.50	14.44	8.45
CO_2	13.2	15.4	8.8	41.8	17.6	8.8
Alkalinity in $CaCO_3$ (mval l^{-1})	5.2	5.9	4.4	8.2	6.1	4.3
$N\text{-}NH_3$	0.040	0.805	0.195	4.180	0.700	0.245
$N\text{-}NO_2$	0.027	0.194	0.013	0.032	0.006	0.008
$N\text{-}NO_3$	3.000	5.010	0.750	0.190	0.050	0.360
$P\text{-}PO_4$	0.800	3.565	0.750	7.080	1.245	0.735
Sulphates	50.60	54.71	19.75	91.74	47.31	32.91
Chlorides	24.0	23.0	16.0	46.0	44.0	14.0
Total hardness in Ca	117.36	123.84	79.20	150.48	101.52	79.20
Total hardness in Mg	16.77	15.48	14.19	31.82	29.67	9.89
Fe (total)	0.60	0.75	0.85	1.05	0.50	0.85
Dry residue	456	443	262	669	529	230
Dissolved solids	420	426	247	636	517	218
Suspended solids	36	17	15	33	12	12

4. Pond Akcent, 0.45 ha, max. depth of 1.50 m, is situated within the Zoological Garden in Białystok, in which swans are bred and wild ducks visit.
5. Pond Fosa, 2.5 ha, max. depth of 1.75 m, is situated in the Palace Park in Białystok, in which crucian carp and tench are bred.
6. Lake Komosa, 12.1 ha, max. depth 2.25 m, is surrounded by extensive coniferous woods of Knyszyńska Forest.

Nineteen water parameters of the above sampling sites were determined (Table 1) according to the methods of Greenberg et al. [3].

For the determination of the presence of aquatic fungal species on the feathers, the following procedure was employed: feathers were cut into small pieces and certain amount of pieces (100-200) of each species of bird were transfered to two samples for each water in an 1.0 litre vessel (altogether twelve vessels for each species) and placed in the laboratory (in glass thermostat) at ambient temperature. A part of the pieces of feather from each vessel was observed under a microscope and the mycelium (zoosporic, oogonia and antheridia, and for *Saprolegnia parasitica* secondary cysts) [4] of aquatic fungi growing on the feather was recorded. The methods are described in detail by Fuller and Jaworski [5]. The feathers of the various bird species were observed under a microscope for one and a half weeks. The length of time of the experiments was six weeks. For determination of the fungi the following keys were used: Johnson [6], Sparrow [7], Seymour [8], Batko [9], Karling [10], Dick [11] and Pystina [12].

Results

Hydrochemical data of water used for the experiment are presented in Table 1. The highest values of ammonium nitrogen, and phosphates were found in the pond Akcent. Spring waters appeared to be richest in nitrates and nitrites, as well as in calcium.

The growth of 97 zoosporic aquatic fungus species of 7 orders was observed on the feathers of 48 bird species in the water of 6 limnologically different water bodies (Table 3, Fig. 1). The most common species included *Chytriomycetes annulatus* and *Rhizophydium keratinophilum* (Chytridiales), *Blastocladiopsis parva*, *Catenaria anguillulae* and *Catenophlyctis variabilis* (Blastocladiales), *Aphanomyces helicoides*, *Aphanomyces irregularis* and *Leptolegniella piligena* (Saprolegniales) and *Pythium*

Table 2. Occurrence of aquatic fungi on feathers of the investigated bird species.

	Species of bird	Fungi (see Table 3)	Number of fungus species
1.	*Accipiter gentilis* (L.) - goshawk	6,12,16,17,19,21,40,41,51	9
2.	*Acrocephalus arundinaceus* (L.) - grea reed-warbler	1,12,17,19,22,27,31,34,40,41,44,49,56	13
3.	*Anas crecca* L. - teal	2,3,12,18,21,23,31,34,40,42,48,62,65,68,69,92	16
4.	*Anas moschata* L. - muscovy duck	1,5,11,12,15,18,21,23,26,30,39,40,43,45,48,49,56,61,65,71,78,81,92,97	24
5.	*Anas platyrhynchos* L. - mallard	1,10,12,14,15,18,20,32,40,44,48,49,50,51,56,65,66,71,72,81,92	21
6.	*Anas strepera* L. - gadwall	3,8,10,12,15,16,20,21,23,25,26,29,30,39,40,49,50,51,62,65,69,71,81,82,93	25
7.	*Anser anser* (L.) - greylag goose	1,12,14,21,30,32,35,39,40,48,49,57,69,72,80,92,93	17
8.	*Anser domestica* L. - goose	5,9,10,12,14,18,20,21,26,30,39,40,48,50,56,57,61,65,71,72,80,81,92	23
9.	*Ardea cinerea* L. - grey heron	3,11,12,14,18,21,29,30,32,34,39,40,46,48,62,64,68,80,90,92	20
10.	*Aythya ferina* (L.) - pochard	1,2,12,14,17,18,21,29,40,41,42,60,61,62,65,69,73,76,88,92,94,95	22
11.	*Aythya fuligula* (L.) - tufted duck	1,3,14,19,21,28,32,34,40,42,48,50,51,58,62,65,73,90	18
12.	*Branta bernicla* (L.) - brent goose	3,5,9,12,15,20,21,25,29,30,32,39,40,49,50,51,57,65,72,86,90,92	22
13.	*Bubo bubo* (L.) - eagle owl	1,5,11,12,15,20,21,39,40,49,50,56,61,65,68,72,81,92	18
14.	*Buteo buteo* (L.) - common buzzard	1,3,12,17,18,21,23,31,40,41,48,49,53,56	14
15.	*Ciconia ciconia* (L.) - white stork	1,5,9,12,14,15,16,17,18,21,30,34,40,42,44,50,59,62,65,66,72,90	22
16.	*Ciconia nigra* (L.) - black stork	1,9,11,12,14,15,17,18,20,21,38,39,40,48,50,51,52,61,62,65,72,79,81	23
17.	*Columba domestica* L. - pigeon	10,12,15,16,18,20,21,22,23,29,33,40,41,49,50,56,61,65,66,72,73,78,81,90, 92,97	26
18.	*Columba palumbus* L. wood pigeon	1,11,12,15,18,21,29,30,34,40,51,53,56,61,62,65,66,72,80,81,90,92,94	23
19.	*Corvus corax* L. - raven	1,17,21,23,30,39,40,42,48,53,56,61,62,65,72,92,93,97	18
20.	*Corvus corone* L. - carrion-crow	1,3,8,16,17,18,21,27,41,47,49	11
21.	*Corvus frugilegus* L. - rook	5,12,15,17,21,23,25,30,34,39,40,42,48,49,56,61,65,72,73,92	20
22.	*Corvus monedula* L. - jackdaw	10,12,18,21,22,29,40,42,48,51,57,65,72,81,86,92,93	17
23.	*Cygnus olor* (Gmel.) - mute swan	1,5,8,10,12,21,22,26,32,34,38,39,40,42,48,65,66,71,72,77,90,92	22
24.	*Fulica atra* L. - coot	3,14,16,17,20,21,25,28,29,32,34,38,39,40,45,49,51,61,62,65,66,72,73,81,84,93	26
25.	*Gallus bankiva* L. - bantam	9,12,15,16,17,18,21,25,28,39,40,43,48,50,51,57,62,65,72,81,92,93	22
26.	*Gallus domesticus* L. - hen	11,12,14,15,18,21,23,34,39,40,42,44,50,53,62,65,70,72,81,92,97	21
27.	*Garrulus glandarius* (L.) - jay	2,3,12,15,19,20,21,24,28,42,58,61,62,65,68,78,88,92	18
28.	*Grus grus* (L.) - crane	1,3,4,9,14,20,21,41,48,50,62,65,85,91,92,95,96	17
29.	*Haliaeetus albicilla* (L.) - white-tailed eagle	1,6,12,17,18,22,23,40,41,45,48,53	12
30.	*Hirundo rustica* L. - swallow	2,11,17,18,21,32,40,41,42,58,62,69,89,92	14
31.	*Larus canus* L. - common gull	1,9,11,12,14,16,17,18,20,21,23,25,28,29,30,36,40,44,48,62,72,78,81,87	24
32.	*Larus ridibundus* L. - black-headed gull	1,9,12,14,21,28,40,50,51,56,61,62,65,73,77,78,81,92	18
33.	*Lyrurus tetrix* (L.) - black grouse	1,3,5,9,12,20,21,28,31,34,41,42,48,50,56,62,92	17
34.	*Meleagris gallopavo* L. - turkey	5,9,10,12,14,17,18,21,28,29,40,50,56,61,65,68,69,71,73,80,84,92,97	23
35.	*Mergus merganser* L. - goosander	1,10,11,12,14,15,16,17,18,20,21,28,32,34,39,40,48,50,56,59,62,81	22
36.	*Mergus serrator* L. - red-breasted merganser	3,14,18,21,28,31,32,37,41,42,45,50,54,65,67,73,83,92	18

Table 2 continues on next page...

37.	*Motacilla alba* L. - white wagtail	1,10,12,14,17,20,21,23,28,29,30,32,38,39,49,40,42,49,50,56,62,65,70,72,79,81,92	27
38.	*Pavo cristatus* L. - peacock	1,5,10,12,17,18,21,23,32,39,40,49,56,61,62,64,65,92,93	19
39.	*Phalacrocorax carbo* (L.) - cormorant	1,11,12,14,15,16,20,21,28,29,38,39,40,49,50,51,61,62,65,81,82,89,90,92	24
40.	*Phasianus colchicus* L. - pheasant	1,10,12,17,18,21,28,35,39,40,48,56,62,65,72,92,97	17
41.	*Pica pica* (L.) - magpie	1,3,5,10,12,14,15,18,20,21,22,38,39,40,44,48,50,51,62,65,72,81,87,92,93,97	26
42.	*Picus canus* Gm. - grey-headed woodpecker	12,20,21,22,24,28,31,32,34,40,42,49,50,58,62,63,67,68,74,77,90	21
43.	*Picus viridis* (L.) - green woodpecker	11,12,16,17,21,26,32,33,39,40,44,50,57,61,62,65,80,81,89,90,92,93,94,97	24
44.	*Podiceps cristatus* (L.) - great crested grebe	11,12,14,21,27,30,32,39,40,50,51,61,62,65,78,82,90,91,93,97	20
45.	*Scolopax rusticola* L. - woodocock	1,12,15,17,18,19,27,40,41,47,50,56	12
46.	*Sterna hirundo* L. - common tern	1,3,8,9,12,13,14,17,18,21,23,26,27,34,35,40,48,66,70,72,80,81,92	23
47.	*Streptopelia decaocto* (Friv.) - collared turtle- dove	5,11,12,17,20,21,23,28,29,32,39,40,42,44,49,50,56,65,66,71,72,73,75,77, 80,81,90,93	28
48.	*Vanellus vanellus* (L.) - lapwing	1,5,7,9,12,14,15,20,21,28,31,32,34,40,42,55,58,62,69,77,83,92	22

afertile, Pythium aquatile, Pythium echinulatum, Pythium intermedium and *Pythium tenue* (Peronosporales). The largest numbers of fungi were found to grow on the feathers of *Streptopelia decaocto* (28), the smallest on *Accipiter gentilis* feathers (9). In water, most fungi were found in Cypisek Spring (64), the fewest in the ponds Akcent (45) and Fosa (47). Such species as *Rhizophydium keratinophilum, Rhizophydium macrosporum, Rhizophydium nodulosum, Blastocladiopsis parva, Catenaria verrucosa, Catenophlyctis variabilis, Lagenidium humanum, Aphanomyces helicoides, Aphanomyces irregularis, Aphanomyces laevis, Leptolegnia caudata, Saprolegnia asterophora, Pythium acanthicum, Pythium afertile, Pythium aquatile, Pythium intermedium, Pythium tenue* and *Zoophagus insidians* were observed on bird feathers in all six water bodies (Table 4). Out of these 97 species, 17 are known as parasites or necrotrophs of fish (Table 3). 13 fungus species were recorded for the first time in Poland.

Discussion

Most frequently, after a few days the first fungus species appeared to grow on feathers of the birds examined, including *Chytriomyces annulatus* and *Rhizophydium keratinophilum* (Chytridiales), *Blastocladiopsis parva*, *Catenaria anguillulae* and *Catenophlyctis variabilis* (Blastocladiales), *Aphanomyces helicoides*. *Aphanomyces irregularis* and *Leptolegniella piligena* (Saprolegniales) and *Pythium afertile, Pythium aquatile, Pythium echinulatum, Pythium intermedium* and *Pythium tenue* (Peronosporales). About a week or two later the feathers of a certain number of birds showed *Rhizophydium macrosporum* and *Rhizophydium nodulosum* (Chytridiales), *Catenaria verrucosa* (Blastocladiales), *Lagenidium humanum* (Lagenidiales). At that time the feathers were also colonized by *Achlya debaryana*, *Achlya dubia, Achlya klebsiana, Achlya orion, Leptolegnia caudata, Leptolegniella keratinophila, Saprolegnia asterophora* and *Saprolegnia parasitica* (Saprolegniales), *Pythium acanthicum, Pythium rostratum, Pythium teratosporum* and *Zoophagus insidians* (Peronosporales). The remaining aquatic fungus species appeared on feathers in the final phase of the experiments.

Specificity and dissimilarity of the keratin-containing substrate affect the colonization of a given substrate by certain fungus species. For instance, *Aphanomyces keratinophilus* was found to grow only on feathers of 8 bird species, while on animal hair it was observed on a three times larger number of species. This refers also to other zoosporic fungus species [2].

In the present study more fungus species developed on feathers in water samples collected from running water basins (springs and the river Supraśl) than from stagnant waters (ponds and lake Komosa). Moreover, the number of fungus species growing on bird feathers is also affected by the load of biogenes and organic matter, which is well seen in the pond Akcent, where the fewest zoosporic fungus species were observed. Such a phenomenon was also observed while studying other physiological aquatic fungus groups, including chitinophilic fungi [13-16] and those growing on the eggs of freshwater fish species [17-19], on the amphibian spawn [20], on avian excrements [21] or on the remains of plants [22]. This would explain differences in the composition of keratinophilic fungus species in limnologically diverse water bodies, except the pond Akcent. A few species appeared the characteristic of each water body, others colonized feathers only in some of them.

Out of these 97 zoosporic fungus species which were found to grow on the feathers, 17 are known as parasites or necrotrophs of fresh-water fish. The most common were species *Achlya* and *Saprolegnia* genus [17-19]. The present study has revealed that bird feathers are the vectors of many fungus species, being fish parasites.

Table 3. Aquatic fungi found on feathers of particular birds.

Species of Fungi		Bird (see Table 2)	Number of bird species
Chytridiomycetes			
Chytridiales			
1.	*Chytriomyces annulatus* Dogma	2,4,5,7,13,14,15,16,18,19,20,23,29,31,32,35,37,38,39,40,41,45,46,48	24
2.	*Chytriomyces lucidus* Karling	3,10,27,30	4
3.	*Chytriomyces poculatus* Willoughby et Townley	6,9,12,14,20,24,41,46	8
4.	*Chytriomyces spinosus* Fay	28	1
5.	*Chytriomyces stellatus* Karling	4,8,12,13,15,21,23,34,38,41,47,48	12
6.	*Mitochytridium regale* Hassan	1,29	2
7.	*Rhizophlyctis lovetti* Karling	48	1
8.	*Rhizophydium apiculatum* Karling	6,20,23,46	4
9.	*Rhizophydium condylosum* Karling	8,12,15,16,25,31,32,34,46,48	10
10.	*Rhizophydium gibbosum* (Zopf) Fischer	5,6,8,17,22,23,34,35,37,38,40,41	12
11.	*Rhizophydium globosum* (Braun) Rabenhorst	4,9,13,16,18,26,31,35,39,43,44,47	12
12.	*Rhizophydium keratinophilum* Karling	1,2,4,5,6,7,8,9,12,13,14,15,16,17,18,21,22,23,25,26,29,31,32,34,35, 37,38,39,40,41,43,44,45,46,47,48	36
13.	*Rhizophydium laterale* (Braun) Rabenhorst	46	1
14.	*Rhizophydium macrosporum* Karling	5,7,8,9,15,16,24,26,31,32,34,35,37,39,41,44,46,48	18
15.	*Rhizophydium nodulosum* Karling	4,5,6,12,13,15,16,17,18,21,25,26,35,39,41,45,48	17
16.	*Rhizophydium piligenum* Ookubo et Kobayashi	1,6,15,17,20,24,25,31,35,39,43	11
Blastocladiales			
17.	*Blastocladiopsis parva* (Whiffen) Sparrow	1,2,14,15,16,19,20,21,24,25,29,31,34,35,37,38,40,43,45,46,47	21
18.	*Catenaria anguillulae* Sorokin	4,5,8,9,14,15,16,17,18,20,22,25,26,29,31,34,35,38,40,41,45,46	22
19.	*Catenaria sphaerocarpa* Karling	1,2,45	3
20.	*Catenaria verrucosa* Karling	5,6,8,12,13,16,17,24,31,35,37,39,41,47,48	15
21.	*Catenophlyctis variabilis* (Karling) Karling	1,4,6,7,8,9,12,13,14,15,16,17,18,19,20,21,22,23,24,25,25,31,32,34, 35,37,38,39,40,41,43,44,46,47,48	35
Hypochytriomycetes			
Hypochytriales			
22.	*Hyphochytrium catenoides* Karling	2,17,22,23,29	5
Oomycetes			
Leganidiales			
23.	*Lagenidium humanum* Karling	3,5,11,14,16,18,23,24,25,29,30,37,38	13
Saprolegniales			
24.	*Achlya abortiva* Coker et Braxton	27,42	2
25.	**Achlya bisexualis* Coker et Couch	6,12,21,24,25,31	6
26.	**Achlya caroliniana* Coker	4,6,8,23,43,46	6
27.	*Achlya colorata* Pringsheim	2,20,44,45,46	5

Table 3 continues on next page...

28.	*Achlya debaryana* Humphrey	24,25,31,32,34,35,37,39,40,47,48	11
29.	**Achlya dubia* Coker	6,9,12,17,18,22,24,31,34,37,39	11
30.	**Achlya klebsiana* Pieters	4,6,7,8,9,12,15,18,19,21,31,37,44	13
31.	*Achlya oligocantha* de Bary	2,14,48	3
32.	**Achlya orion* Coker et Couch	5,7,9,12,23,24,35,37,38,43,44,47,48	13
33.	*Achlya papillosa* Humphrey	17,41,43	3
34.	**Achlya polyandra* Hildebrand	2,9,15,18,21,23,24,26,35,46,48	11
35.	**Achlya proliferoides* Coker	7,40,46	3
36.	**Achlya racemosa* Hildebrand	31	1
37.	*Achlya treleaseana* (Humphrey) Kauffman	36	1
38.	*Aphanomyces amphigynus* Cutter	16,23,24,37,39,41	6
39.	*Aphanomyces helicoides* Minden	4,6,7,8,9,12,13,16,19,21,23,24,25,26,35,37,38,39,40,41,43,44,47	23
40.	*Aphanomyces irregularis* Scott	1,2,4,5,6,7,8,9,12,13,14,15,16,17,18,19,21,22,23,24,25,26,29,31,32, 34,35,37,38,39,40,41,43,44,45,46,47,48	38
41.	*Aphanomyces keratinophilus* (Ookubo et Kobayashi) Seym. et John.	1,2,6,14,17,20,29,45	8
42.	**Aphanomyces laevis* de Bary	15,19,21,22,23,37,47,48	8
43.	*Aphanomyces ovidestruens* Gickelhorn	4,25	2
44.	**Aphanomyces stellatus* de Bary	2,5,15,26,31,43,47	7
45.	*Aplanes androgynus* (Archer) Humphrey	4,24,29	3
46.	*Cladolegnia unispora* (Coker et Couch) Johannes	9	1
47.	**Dictyuchus sterile* Coker	20,45	2
48.	**Leptolegnia caudata* de Bary	4,5,7,8,9,14,16,19,21,22,23,25,29,31,35,41,46	17
49.	*Leptolegniella keratinophila* Huneycutt	2,4,5,6,7,12,13,14,17,20,21,24,37,38,39,47	16
50.	*Leptolegniella piligena* Ookubo et Kobayasi	1,5,6,8,12,13,15,16,17,25,26,32,34,35,37,39,41,43,44,45,47	21
51.	*Saprolegnia asterophora* de Bary	5,6,12,16,18,22,24,25,32,39,41,44	12
52.	*Saprolegnia eccentrica* (Coker) Seymour	16	1
53.	**Saprolegnia ferax* (Gruith.) Thuret	14,18,19,26,29	5
54.	*Saprolegnia glomerata* (Tiesenhausen) Lund	36	1
55.	**Saprolegnia monoica* Pringsheim	48	1
56.	**Saprolegnia parasitica* Coker	2,4,5,8,13,14,17,18,21,32,34,35,37,38,40,45,47	17
57.	**Saprolegnia subterranea* (Dissmann) Seymour	8,12,22,25,43	5
58.	*Sommerstorffia spinosa* Arnaudow	11,27,30,42,48	5
	Leptomitales		
59.	*Apodachlya brachynema* (Hildebrand) Pringsheim	15,35	2
	Peronosporales		
60.	*Nematosporangium epiphanosporon* Sideris	10	1
61.	*Pythium acanthicum* Drechsler	4,8,13,16,17,18,19,21,24,32,34,38,39,43,44	15

Table 3 continues on next page...

62.	*Pythium afertile* Kanouse et Humphrey	6,9,15,16,18,19,24,25,26,31,32,35,37,38,39,40,41,43,44,48	20
63.	*Pythium akanense* Tokunaga	42	1
64.	*Pythium angustatum* Sparrow	9,38	2
65.	*Pythium aquatile* Höhnk	4,5,6,8,12,13,15,16,17,18,19,21,22,23,24,25,26,32,34,37,38,39,40,41, 43,44,47	27
66.	*Pythium aristosporum* Vanterpool	5,15,17,18,24,37,46,47	8
67.	*Pythium arrhenomanes* Drechsler	36	1
68.	**Pythium artotrogus* de Bary	9,13,34	3
69.	*Pythium butleri* Subramaniam	6,7,34,48	4
70.	*Pythium catenulatum* Matthews	26,37,46	3
71.	*Pythium deliense* Meurs	4,5,6,8,23,34,47	7
72.	*Pythium echinulatum* Matthews	5,7,8,12,13,15,16,17,18,19,21,22,23,24,25,26,31,37,40,41,46,47	22
73.	*Pythium elongatum* Matthews	17,21,24,32,34,47	6
74.	*Pythium erihaceus* Robertson	42	1
75.	*Pythium gracile* Schenk	47	1
76.	*Pythium hemmianum* Takahashi	10	1
77.	*Pythium helicandrum* Drechsler	23,32,47,48	4
78.	*Pythium imperfectum* Höhnk	4,17,31,32,44	5
79.	*Pythium indicum* Balakrishman	16,37	2
80.	*Pythium inflatum* Matthews	7,8,9,18,34,43,46,47	8
81.	*Pythium intermedium* de Bary	4,5,6,8,16,17,18,22,24,25,26,31,32,35,37,39,41,43,46,47	20
82.	*Pythium jirovecii* Cejp	6,39,44	3
83.	*Pythium maritimum* Höhnk	36,48	2
84.	*Pythium myriotylum* Drechsler	24,34	2
85.	*Pythium oedochilum* Drechsler	28	1
86.	*Pythium oligandrum* Drechsler	12,22	2
87.	*Pythium periilum* Drechsler	31,41	2
88.	*Pythium perniciosum* Serbinow	10,27	2
89.	*Pythium polysporum* Sorokin	39,43	2
90.	*Pythium rostratum* Butler	9,12,15,17,18,23,39,43,44,47	10
91.	*Pythium splendens* Braun	28	1
92.	*Pythium tenue* Gobi	4,5,7,8,9,12,13,17,18,19,21,22,23,25,26,32,34,37,38,39,40,41,43,44, 46,48	26
93.	*Pythium teratosporum* Sideris	6,7,19,22,24,25,38,41,43,44,47	11
94.	*Pythium torulosum* Coker et Patterson	18,43	2
95.	*Pythium undulatum* Petersen	10,28	2
96.	*Rheosporangium aphanidermatum* Edson	28	1
Zygomycetes			
Zoopagales			
97.	*Zoophagus insidians* Sommerstorff	4,17,19,26,34,40,41,43,44	9

*species known in literature as parasites or necrotrophs of fish

Worth noting is the finding of five Chytridiales representatives, new to Polish waters, namely *Chytriomyces lucidus, Chytriomyces spinosus, Chytriomyces stellatus, Rhizophydium gibbosum* and *Rhizophlyctis lovetti*, on the feathers of several bird species in almost all water samples used in the experiment. In the literature of the subject *Chytriomyces lucidus* and *Chytriomyces stellatus* was described by Karling [23] in Maryland and are known as a saprophyte, but not of such substrates as bird feathers [10]. *Chytriomyces spinosus* was found on the feathers of *Grus grus* in the water of Cypisek Spring only. This fungus was first isolated by Fay [24]. The water of Cypisek is characterized by a comparatively low content of ammonium nitrogen. Water of this spring had the lowest oxidability (COD). *Rhizophydium gibbosum* was described already at the end of the 19th century as a parasite of algae [25]. It is also known as a parasite of rotifers and their eggs [9]. *Rhizophlyctis lovetti* was found on the feathers of *Vanellus vanellus* in the springs Cypisek and Jaroszówka. This fungus was first isolated in India on human fibrin film as bait by Karling [26].

Also new to Polish waters is *Achlya abortiva*, which was found on the feathers of *Garrulus glandarius* and *Picus canus* only in the water of pond Akcent. The water of pond Akcent had the lowest content of oxygen and BOD_5 but by the largest amounts of CO_2, ammonium nitrogen, phosphates, sulphates, chlorides, calcium, magnesium and iron. Water of this pond had the highest oxidability (COD) and alkalinity. This fungus was first isolated as a soil saprophyte [27].

The feathers of certain bird species showed a number of Peronosporales representatives, never before observed on such a substrate. The most common fungus species encountered on feathers included *Pythium afertile, Pythium aquatile, Pythium echinulatum, Pythium intermedium* and *Pythium tenue*. These species are observed mostly on the substrates of plant origin, only *Pythium echinulatum* is known as an animal saprophyte growing on freshwater fish eggs [28]. *Nematosporangium epiphanosporon* and among the species of the genus *Pythium* colonizing bird feathers *Pythium angustatum, Pythium deliense, Pythium hemmianum, Pythium indicum, Pythium teratosporon* and *Rheosporangium aphanidermatum* are new to Polish waters. *Nematosporangium epiphanosporon* was found to grow only on feathers of *Aythya ferina* in Cypisek, was described by Sideris [29] from the diseased roots of *Ananas sativa* grown on the island of Oahu of the Hawaiian Archipelago. *Pythium angustatum* was found on the feathers of *Ardea cinerea* and *Pavo eristatus* in Jaroszówka Spring. The water of Jaroszówka was found to have a high content of nitrate and nitrite nitrogen and highest pH. This fungus was first isolated as a parasite of green algae

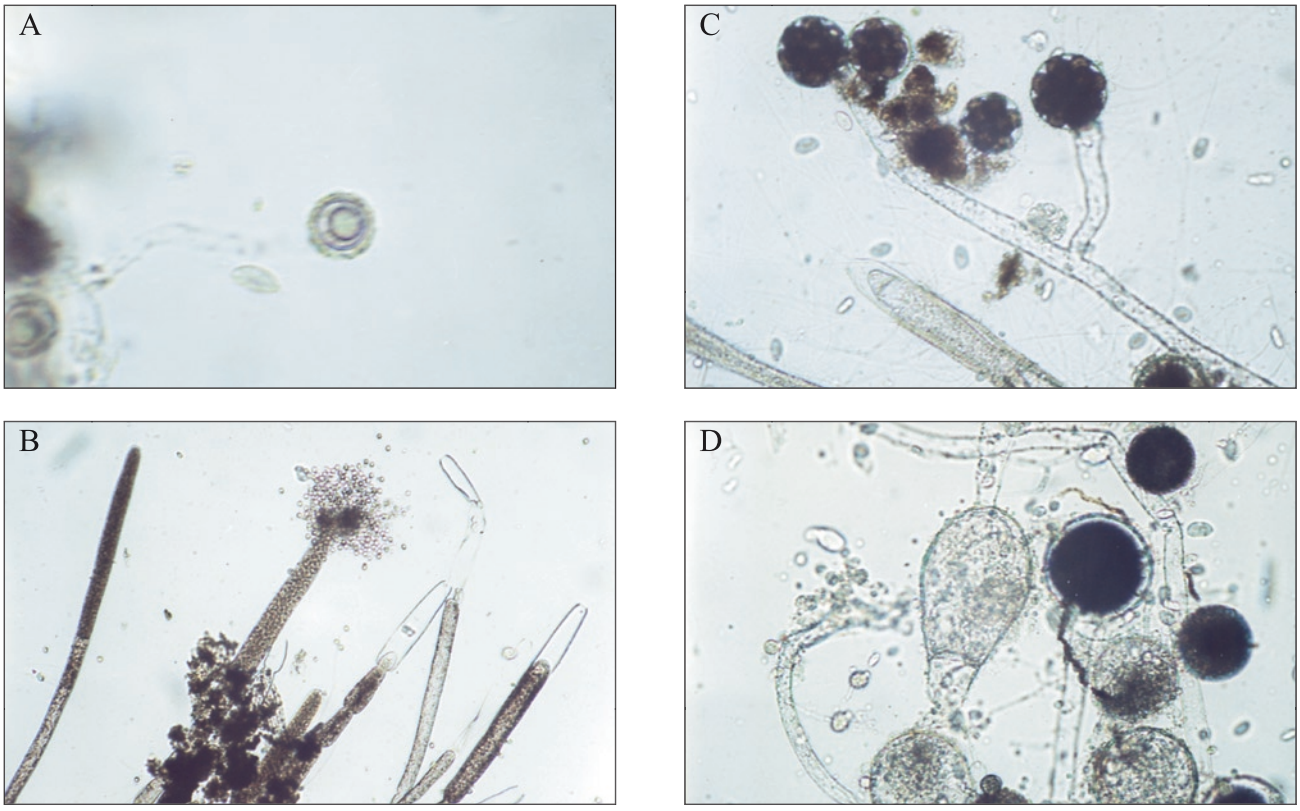

Fig. 1. Some keratinophilic (A) and non-keratinophilic (B, C, D) fungus species growing on the feathers (x 200).
A – *Aphanomyces irregularis* – hyphae from oogonia (15-25 μm); B – *Saprolegnia ferax* – discharge sporangium; C – *Saprolegnia glomerata* – hyphae (10-40 μm diameter) from oogonia (46-58 μm); D – *Saprolegnia parasitica* – hyphae (30-120 μm diameter) from oogonia (62-75 μm)

Table 4. Aquatic fungi found on the feathers in the water from different water bodies.

Water bodies	Fungi (see Table 3)	Only in one water	Number of fungus species
Cypisek Spring	1, 2, 3, 4, 5, 7, 8, 9, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 23, 28, 29, 30, 32, 34, 35, 37, 39, 40, 41, 42, 43, 44, 45, 48, 50, 51, 56, 57, 59, 60, 61, 62, 63, 65, 66, 68, 69, 70, 71, 72, 73, 77, 80, 81, 83, 84, 86, 87, 90, 91, 92, 93, 94, 97	4, 13, 35, 37, 60, 63, 83, 87, 91, 94	64
Jaroszówka Spring	1, 2, 3, 5, 6, 7, 8, 9, 10, 11, 12, 14, 15, 16, 17, 18, 19, 20, 21, 23, 25, 26, 27, 29, 30, 38, 39, 40, 41, 42, 43, 44, 48, 49, 50, 51, 53, 56, 61, 62, 64, 65, 67, 68, 70, 72, 73, 75, 77, 78, 81, 82, 86, 90, 92, 93, 97	27, 64, 75	57
Supraśl River	1, 3, 5, 6, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 23, 25, 26, 28, 29, 33, 34, 36, 39, 40, 41, 42, 44, 45, 48, 49, 50, 51, 52, 55, 56, 59, 61, 62, 65, 66, 68, 69, 70, 72, 73, 74, 77, 78, 80, 81, 85, 89, 90, 92, 93, 97	33, 36, 52, 55, 74, 85	60
Akcent Pond	1, 2, 5, 6, 9, 10, 11, 12, 14, 15, 17, 18, 19, 20, 21, 22, 23, 24, 25, 28, 29, 30, 31, 38, 39, 40, 41, 42, 44, 48, 49, 50, 51, 56, 57, 61, 62, 65, 67, 68, 72, 81, 92, 93, 97	24	45
Fosa Pond	1, 3, 5, 8, 9, 10, 11, 12, 14, 15, 17, 20, 21, 22, 23, 28, 29, 30, 31, 32, 34, 39, 40, 41, 42, 44, 47, 48, 50, 51, 54,58, 61, 62, 65, 69, 72, 73, 76, 78, 81, 90, 92, 93, 95, 96, 97	47, 54, 58, 76, 96	47
Komosa Lake	1, 3, 5, 6, 9, 10, 11, 12, 14, 15, 16, 17, 18, 19, 20, 21, 23, 25, 30, 39, 40, 41, 42, 44, 45, 46, 48, 49, 51, 53, 56, 57, 61, 62, 65, 68, 69, 71, 72, 78, 79, 81, 82, 84, 88, 89, 90, 92, 95, 97	46, 79, 88	50

of the genus *Spirogyra* [30]. *Pythium deliense*, which colonized feathers of 7 bird species in the spring Cypisek and lake Komosa, was described from Sumatra as causing stemburn in *Deli tobacco* [31]. *Pythium hemmianum* was first isolated as causing a damping off of seedlings of *Luffa cylindrica* at Kamigano pref., Kyoto by Takahashi [32]. This fungus was found to grow on the feathers of *Aythya ferina* in water of all water bodies except Cypisek Spring.

Pythium indicum was found to grow on the feathers of *Ciconia nigra* and *Motacilla alba* only in the water of lake Komosa. It was described in India by Balakrishnan [33] from fallen fruits of *Hibiscus esculentu*s. The water of lake Komosa is characterized by a comparatively low content of CO_2, calcium, chlorides and magnesium. Water of this lake had the lowest alkalinity. *Pythium teratosporon*, found to colonize feathers of 11 bird species in the water of all water bodies exscept lake Komosa, was first isolated on Hawaii from diseased roots of *Spinacea oleracea* [34]. *Rheosporangium aphanidermatum* was found on the feathers of *Grus grus* in the pond Fosa. This fungus was described in Wisconsin (USA) by Edson [35] from damped - off seedlings of sugar beet *Beta vulgaris*. The water of pond Fosa was found to have a low content of nitrate and nitrite nitrogen and iron. Water of this pond had the lowest temperature and pH.

Moreover, worth noting is the finding of two interesting fungus species *Mitochytridium regale* and *Sommerstorffia spinosa* on the feathers of several bird species. The former was encountered on *Accipiter gentilis* and *Motacilla alba* in the water of Jaroszówka Spring, Supraśl River, and ponds Akcent and Fosa. *Mitochytridium regale* was first described by Hassan [36] as keratinophilic waters fungus in the pond in the Łazienki Park of Warsaw. This fungus was reported for the second time in Poland from lake Necko [37]. *Sommerstorffia spinosa* was observed on the feathers of *Aythya fuligula, Garrulus glandarius, Hirundo rustica, Picus canus* and *Vanellus vanellus* in water of pond Fosa only. This fungus is a relatively rare predacious fungus catching rotifers. It has been mainly isolated from soil samples more seldom from water [38]. We have shown its growth in spring, rivers, ponds and lakes of varied trophic states [39].

Keratin, a protein belonging to scleroids, is the main component of bird feathers. The compound, insoluble in water, is very resistant to the action of different chemical compounds and proteolytic enzymes. Keratin is made of cysteine and cystine (3-15%), and alkaline amino acids. The first two play a role in the formation of protein structure, showing the ability to form permanent disulphide bindings between the respective twisting of the peptide chain or separate chains. If the amount of cysteine and cystine increases, keratin becomes more resistant to enzymatic hydrolysis [40, 41]. The secondary structure of keratin is characterized by a parallel arrangement of numerous fibres composed of polypeptide chains, each assuming the form of differently extended L-helix. The respective helixes are additionally mutually twisted like a “ship rope”. The structure so arranged is maintained by means of numerous disulphide bindings formed due to a substantial content of cysteine and cystine in this protein; it determines mechanical strength of keratin-built fibres. Bird feathers and mammalian hair are built of keratin, in which cysteine and cystine content reaches 15%. As it is known, keratin containing large amounts of these two amino acids easily bind with heavy metals, which in turn considerably inhibit enzymatic activity of fungi [42]. This is perhaps one of many factors that influence

the number of fungus species growing on feathers of bird species examined. In the present study, the smallest number of fungus species developed on the feathers of the predacious goshawk (*Accipiter gentilis*), the largest number on the feathers of collared turtle-dove (*Streptopelia decaocto*). The goshawk is known to be the terminal link in the longer alimentary chain as the second or even third degree consumer, compared with the turtle-dove, a first degree consumer. The longer the alimentary chain is, the more heavy metals accumulate in its terminal link [43]. It is no doubt that the number of fungus species growing on feathers depends on some other factors, such as the structure of protein forming the keratin-containing substrate, its melanin content [2] or trophicity of water reservoir. The more polyor eutrophic the water is, the fewer fungi grow on different substrates of animal origin [1,2,13-20].

In water, feathers of domestic fowl (a waste product in farming) or those from moulting wild fowl and mammalian hair are immediately colonized by bacteria [44] and saprophytic fungi [45]. The latter use feathers or fur as a substrate which provides carbon, nitrogen, and sulphur, but first of all as a source of energy [46]. By means of broad-substrate keratinases [47], they decompose these substrates to obtain smaller and smaller peptides [48-50] until complete keratin dissolution occurs. A number of non-keratinophilic fungi can be observed on smaller fragments of peptide chains formed (Fig. 1) as the result of decomposition by keratinophilic fungi [51]. In our study, this group of non-keratinophilic fungi consisted of numerous species belonging to Oomycetes, including a number of fish parasites and necrotrophs, as well as a predacious fungus *Sommerstorffia spinosa*, but first of all a considerable number of *Pythium* species, which lead a parasitic life on the conidia of many plant species [12].

Finally, it should be stated that aquatic zoosporic fungus species substantially contribute to the mineralization of insoluble in water protein substrates, with keratin as the basic component, and thus play an important role in the self-purification of water in natural reservoirs and in various types of treatment plants [52,53].

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