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Zoosporic Aquatic Fungi Growing on Avian Excrements in Various Types of Water Bodies

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With 4 Figures and 6 Tables

Key words: Water zoosporic and coprophilic fungi, bird-excrements, mineralization, water bodies, hydrochemical parameters

Abstract

Coprophilic fungi in the water from six different water bodies were studied between 1995–1997. For hydrochemical analysis samples of water were collected every three months while for estimation of fungus content every month. Excrements of 3 phytophagous (greylag goose, roman-nosed goose, mute swan), 4 carnivorous (grey heron, white stork, marsh harrier, cormorant) and 3 omnivorous bird species (musk-duck, mallard, black-headed gull) were used as bait.

Thirty-six fungus species growing on avian excrements in the water of all examined water bodies were found, 6 of these species belonged to Chytridiomycetes and 30 to Oomycetes. The largest number of fungus species was detected on excrements of musk duck, mallard and mute swan, the smallest one on excrements of roman-nosed goose, marsh harrier and cormorant. Such fungus species as *Achlya americana, Aphanomyces laevis, Dictyuchus monosporus, Pythium debaryanum, Pythium rostratum, Saprolegnia asterophora, Saprolegnia ferax* and *Saprolegnia parasitica* were detected on excrements of all birds examined. Out of these 36 species, 11 are known as parasites or necrotrophs of fish. *Rhizophydium ampullaceum* and *Diasporangium jonesianum* are reported for the first time from Poland.

Introduction

Accelerated rate of eutrophication of various types of water bodies is a main problem of today's limnology. Its main cause is agriculture intensification (LAMPERT & SOMMER 1997; DOBROWOLSKI & LEWANDOWSKI 1998). Also waterfowl, living on water bodies or in its surroundings contribute to eutrophication. It has been found that typical water birds like fen-duck or gull, excrete several dozen milligrams of phosphate in one gram of drymass of excrement (DOBROWOLSKI et al. 1976, 1996; GERE & ANDIKOVICS 1994; GWIAZDA 1996). Other water birds such as greylag goose, grey heron, mute swan and cormorant also play a role in eutrophication of water bodies (LEENTVAAR 1967; GOULD & FLECHTER 1978; KAMIŃSKI 1980; JANTA 1993).

Ground coprophilous mycoflora has been relatively well known (HARPER & WEBSTER 1964; MORAVEC 1968; CHMIEL & SADOWSKA 1994). However no special attention has been paid to aquatic mycoflora. The only publication issued (CZECZUGA & MAZALSKA 1996), reports on coprophilous species growing in river water on excrements of several bird species.

Therefore, we became interested in the mycoflora which is growing on excrements of water birds or of those indirectly connected with water and which contributes to mineralization of undigested food. Moreover, we wanted to establish fungus species growing on avian excrements which can be simultaneously found on the body of different fish species, thus causing losses in fish industry.

Materials and Methods

The investigations included the excrements of 10 bird species (Table 1). Excrements of heron, white stork, swan, gull and cormorant were collected at the sites of their nesting, while the excrements of the remaining species were collected in the Białystok Zoo. Eight chemical parameters were assayed using the commonly accepted methods (Table 1). The experiments were carried out for 2 years starting from 1995.

Water for the experiments with the excrements was collected from the following water bodies:

(1) Spring Pólko located in north part of Knyszyńska Forest; limnokrenic type, width 0.36 m, depth 0.16 m, discharge 0.9 l/sec;
(2) River Biała, length 9.8 km, left-bank tributary of the Supraśl River flowing through Białystok City;

Table 1. Chemical composition (in mg g^{-1} dry wt) of the different avian excrements.

Bird	Parameter							
	N (total)	P (total)	SO^{2-}_4	Cl^-	Ca^{2+}	Mg^{2+}	Fe^{3+}	Uric acid
1. *Anas moschata* L. – Muscovy duck	15.3	56.0	66.2	150.0	93.6	13.1	6.0	76.1
2. *Anas platyrhynchos* L. – mallard	17.8	34.0	58.0	140.0	100.8	3.5	7.0	19.2
3. *Anser anser* (L.) – greylag goose	16.8	31.0	78.7	120.0	72.0	7.5	7.5	31.3
4. *Anser cygnoides* (L.) – roman-nosed goose	11.3	47.0	62.1	120.0	108.0	6.5	6.0	21.4
5. *Ardea cinerea* L. – grey heron	32.8	186.0	62.1	110.0	152.8	11.6	7.0	28.4
6. *Ciconia ciconia* (L.) – white stork	36.8	189.0	70.4	160.0	95.6	9.1	9.0	49.9
7. *Circus aeruginosus* (L.) – marsh harrier	75.8	145.0	53.8	90.0	93.6	4.2	9.0	99.9
8. *Cygnus olor* (GM.) – mute swan	14.5	28.0	45.5	140.0	136.8	7.2	5.0	40.6
9. *Larus ridibundus* L. – black-headed gull	22.2	72.0	58.0	123.0	115.2	10.2	9.0	33.1
10. *Phalacrocorax carbo* L. – cormorant	12.5	168.0	62.1	90.0	165.6	13.3	0.5	24.9

(3) River Supraśl, length 106.6 km, the right-bank tributary of the middle part of the Narew River, flowing through the Knyszyńska Forest;
(4) Pond Fosa in the Palace Park, 2.5 ha, max. depth of 1.75 m, in which swans are bred and wild ducks also come; in addition, crucian carp and tench are bred for anglers;
(5) Pond Akcent, 0.45 ha, max. depth of 1.50 m, in which swans are bred and wild ducks also come;
(6) Lake Komosa, 12.1 ha, max. depth of 2.25 m, is surrounded by extensive coniferous woods of Knyszyńska Forest.

All water bodies are located in the north-east of Poland, close to the Bielarus border (Spring Cypisek, Pond Akcent and Pond Fosa – 22°43'E longitude and 53°21' N latitude; River Supraśl and Lake Komosa – 22°52'E longitude and 53°35' N latitude).

The six water bodies are varying in morphological features and hydrochemical parameters, because these factors frequently influence the presence of some water fungus species. Samples of water were collected every month and for chemical analysis every three months, from each basin always at the same site, approximately 2 m from the shore and 30 cm under the surface.

Nineteen parameters of these water samples were determined (Table 2) according to the generally accepted methods (GOLTERMAN & CLYMO 1969).

For the determination of the presence of aquatic fungus species on the excrements the following procedure was employed: Certain amount of dry excrements (0.5–1.0 g) of each bird species was transferred to two 1.0 litre vessels filled with water from the water bodies examined and placed in the laboratory at the temperature approaching that of given environment. Part of the excrements from each vessel was observed under a microscope and the mycelium (forms of zoospores and oogonia) of aquatic fungi growing on the excrements was recorded. The methods were described in detail in the paper of

Table 2. Chemical composition (in mg l^{-1}) of the water (mean from 8 samples) in the water bodies investigated.

Parameter	Water bodies					
	Pólko Spring	Biała River	Supraśl River	Fosa Pond	Akcent Pond	Komosa Lake
Temperature (°C)	5.80	9.34	8.89	10.90	10.35	10.06
pH	7.24	7.19	6.95	7.36	7.22	7.33
O_2	8.77	13.32	12.70	9.90	9.52	13.52
BOD_5	7.85	4.77	4.10	6.17	7.45	5.22
Oxidability (COD)	4.49	10.91	9.72	14.98	17.67	10.90
CO_2	14.87	19.68	10.42	22.45	35.37	19.52
Alkalinity (mval dm^3)	3.72	5.74	4.77	6.65	7.35	4.16
$N(NH_4)$	0.06	1.15	0.27	0.63	2.02	0.27
$N(NO_2)$	0.003	0.060	0.014	0.005	0.016	0.006
$N(NO_3)$	0.150	0.160	0.180	0.070	0.112	0.110
$P(PO_4)$	0.620	1.710	0.980	2.100	3.500	0.340
$S(SO_4)$	37.44	55.23	24.82	45.05	85.42	42.94
Cl^-	15.37	31.87	19.50	40.75	48.50	18.25
Total hardness in Ca^{2+}	62.37	93.94	72.72	99.24	119.04	77.85
Total hardness in Mg^{2+}	25.85	27.47	29.24	30.75	34.89	26.08
Fe^{3+}	0.17	0.60	0.55	0.49	0.65	0.44
Dry residue	179.00	444.00	251.70	464.12	547.75	230.25
Dissolved solids	123.37	337.25	154.20	362.88	514.87	167.62
Suspended solids	55.63	106.75	97.50	101.24	32.88	62.63

FULLER & JAWORSKI (1986). The excrements of various bird species were examined for one week to one and a half weeks. For determinations of fungi six keys were used (JOHNSON 1956; SPARROW 1960; SEYMOUR 1970; BATKO 1975; KARLING 1977; DICK 1990).

The water chemistry data and aquatic fungal flora of these investigations were processed by statistical analysis (HUGH & GAUCH 1982).

Results

The excrements of the ten bird species differed in their chemical composition, particularly in the content of nitrogen, phosphorus and uric acid (Table 1). The highest content of nitrogen was revealed in excrements of marsh harrier, the lowest in roman-nosed goose. Excrements of white stork, grey heron, cormorant and marsh harrier were most abundant in phosphorus. Excrements of mute swan, greylag goose and mallard had the smallest amounts of phosphorus. The highest content of uric acid was found in excrements of marsh harrier and Muscovy duck, the lowest in mallard, roman-nosed goose and cormorant.

The results of chemical analysis of water used for the experiments are presented in Table 2.

The amount of oxygen dissolved in water, oxygen consumption and phosphorus content indicate in particular that

Table 3. Aquatic fungi found on the excrements of the particular birds.

Species of fungi	Bird (see Table 1)	Number of bird species
Chytridiomycetes		
1. *Chytridium xylophilum* CORNU	1,2,3,4,8	5
2. *Karlingia rosea* (DE BARY et WORONIN) JOHANSON	1,2,3,4,8	5
3. *Nowakowskiella elegans* (NOWAKOWSKI) SCHROETER	1,2,3,4,8	5
4. *Nowakowskiella macrospora* KARLING	1,2,3,4,8	5
5. *Phlyctochytrium aureliae* AJELLO	1,2,3,4,5,6,7,8,9	9
6. *Rhizophydium ampullaceum* (BRAUN) FISCHER	1,2,3,5,6,9	6
Oomycetes		
7.**Achlya americana* HUMPHREY	1,2,3,4,5,6,7,8,9,10	10
8. *Achlya debaryana* HUMPHREY	3,4,5,6,7,8,9,10	8
9.**Achlya dubia* COKER	2,6,9	3
10.**Achlya klebsiana* PIETERS	1,5,6,7,8,9,10	7
11. *Achlya oligacantha* DE BARY	5,6,7,9,10	5
12.**Achlya orion* COKER et COUCH	5,6,9	3
13. *Achlya treleaseana* (HUMPHREY) KAUFFMAN	5,7,9,10	4
14.**Aphanomyces laevis* DE BARY	1,2,3,4,5,6,7,8,9,10	10
15.**Aphanomyces stellatus* DE BARY	1,2,5,6,7,8,9,10	8
16. *Apodachlya pyrifera* ZOPF	1,2,3,4,6,8,9,10	8
17. *Cladolegnia unispora* (COKER et COUCH) JOHANNES	2,5,6,7,8,9,10	7
18. *Diasporangium jonesianum* HÖHNK	5,6,9	3
19.**Dictyuchus monosporus* LEITGEB	1,2,3,4,5,6,7,8,9,10	10
20.**Leptolegnia caudata* DE BARY	1,4,5,6,7,8,9,10	8
21.**Leptomitus lacteus* (ROTH) AGARDH	1,2,3,5,6,7,8,9,10	9
22. *Olpidiopsis saprolegnia* (BRAUN) CORNU	1,2,3,5,6,7,8,9,10	9
23. *Pythium aquatile* HÖHNK	1,2,3,4,5,6,8,9	8
24. *Pythium catenulatum* MATTHEWS	1,5,10	3
25. *Pythium debaryanum* HESSE	1,2,3,4,5,6,7,8,9,10	10
26. *Pythium gracile* SCHENK	1,2,3,6,8	5
27. *Pythium inflatum* MATTHEWS	1,2,3,4,5,7,8,9	8
28. *Pythium rostratum* BUTLER	1,2,3,4,5,6,7,8,9,10	10
29. *Pythium tenue* GOBI	1,2,3,4,8	5
30. *Pythium undulatum* PETERSEN	1,2,3,4,8	5
31. *Saprolegnia asterophora* DE BARY	1,2,3,4,5,6,7,8,9,10	10
32.**Saprolegnia ferax* (GRUITH.) THURET	1,2,3,4,5,6,7,8,9,10	10
33. *Saprolegnia litoralis* COKER	2,3,4,8	4
34. *Saprolegnia megasperma* COKER	1,2,6,7,9,10	6
35.**Saprolegnia parasitica* COKER	1,2,3,4,5,6,7,8,9,10	10
36. *Zoophagus insidians* SOMMERSTORFF	1,2,3,5,6,7,8,9,10	9

*) Known in literature as parasites or necrotrophs of fish.

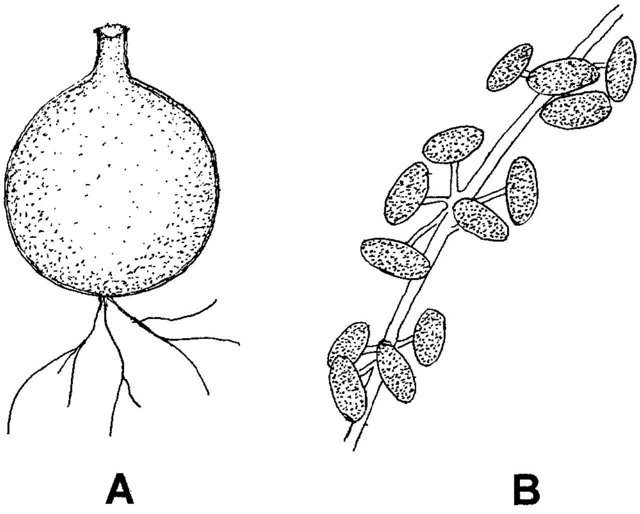

Fig. 1. Zoosporic fungus species new to Polish hydromycology: **A** – *Rhizophydium ampullaceum* – zoosporangium; **B** – *Diasporangium jonesianum* – fragment hyphae from sporangiophores.

the water of the spring Pólko was the least eutrophic, while the water of the ponds Fosa and Akcent the most eutrophic.

Thirty-six zoosporic fungus species were found to grow on excrements of the bird species examined, of which 6 belonged to Chytridiomycetes while the remaining species belonged to Oomycetes (Table 3). Such species as *Achlya americana, Aphanomyces laevis, Dictyuchus monosporus, Pythium debaryanum, Pythium rostratum, Saprolegnia asterophora, Saprolegnia ferax* and *Saprolegnia parasitica* were detected on excrements of all the birds examined. *Achlya dubia, Achlya orion, Diasporangium jonesianum* and *Pythium catenulatum* occurred only on excrements of three bird species. Two zoosporic fungus species, namely *Rhizophydium ampullaceum* (Chytridiomycetes) and *Diasporangium jonesianum* (Oomycetes), are new to the Polish hydromycology (Fig. 1). The former was found on excrements of six bird species in the water of clean spring Pólko and heavily polluted pond Akcent, while the latter only was found on excrements of grey heron, white stork and black-headed gull only in the River Supraśl and Lake Komosa. The largest number of all species was detected on excrements of Muscovy duck, mallard and mute swan, the smallest number on excrements of roman-nosed goose, marsh harrier and cormorant. Moreover majority of fungus species were observed on excrements mainly in spring, autumn and winter, seldom in summer.

Discussion

The zoosporic fungi growing on excrements of ten bird species examined, except for two new species to Polish hydromycology, have been already found in Polish waters (CZECZUGA 1991a,b; 1995a,b; 1996). Some of them are plant saprophytes (CZECZUGA et al. 1997) or they grow on chitin- or keratin-containing substrates (CZECZUGA & MUSZYŃSKA 1994), others can be found on fish eggs (CZECZUGA & MUSZYŃSKA 1998) or amphibian spawn (CZECZUGA et al. 1998b). *Rhizophydium ampullaceum*, new to Polish hydromycology, was first described in the middle of the previous century as a parasite of filiform algae and included in the genus *Chytridium* (BRAUN 1856). Later, FISCHER (1882) placed this fungus in the genus *Rhizophydium. Diasporangium jonesianum*, the other species new to Polish hydromycology, was first described by HÖHNK (1936) as a saprophyte.

Worthy of noting is that out of 30 species of Oomycetes representatives growing on excrements of ten bird species, eleven belong to the group of fungi found in fish as parasites or necrotrophs (Table 3). Such fungi as *Achlya americana, Aphanomyces laevis, Dictyuchus monosporus, Leptomitus lacteus, Saprolegnia ferax* and *Saprolegnia parasitica* have frequently caused mass loss of eggs in hatcheries or death of fry or adult fish (NEISH & HUGHES 1980; CZECZUGA & MUSZYŃSKA 1998). Well known is the Atlantic salmon mass loss due to *Saprolegnia ferax* in British rivers in the years 1877-1881 (STIRLING 1880). The relevant literature of later years has reported on losses due to *Saprolegnia ferax* (FRICK & REINHOLD 1987; DUDKA et al. 1989). Also *Saprolegnia parasitica* has been the cause of serious disasters on fish farms, like death of 50% of fry of the Pacific salmon *Oncorhynchus kisutch* in Miyagi Prefecture in Japan (HATAI & HOSHIAS 1992 a,b). Moreover, these two species of aquatic fungi are known to be the cause of mycotic infections in 40% of adult population of perch in certain Swiss lakes (MENG 1980). Together with other fungi, mainly of the genus *Achlya,* they lead to 90% losses of incubated eggs of acipenserid fish in hatcheries (LARTSEVA 1986). In the case of other fish species they can induce total destruction of eggs in some hatcheries (SATI & KHULBE 1983; DUDKA et al. 1989).

Chemical composition of excrements depends largely on the type of consumed food. Birds whose excrements were examined with respect to food can be divided into three groups: phytophagous, carnivorous and omnivorous. All thirty-six isolated fungus species were growing on excrements of omnivorous birds. Such species as *Chytridium xylophilum, Karlingia rosea, Nowakowskiella elegans, Nowakowskiella macrospora, Pythium tenue, Pythium undulatum* and *Saprolegnia litoralis* were found to grow only on excrements of phytophagous birds, while *Achlya dubia, Achlya oligocantha, Achlya orion, Achlya treleaseana, Diasporangium jonesianum, Pythium catenulatum* and *Saprolegnia megasperma* were found on excrements of carnivorous birds (Table 4). Chemical analysis reveals that excrements of carnivorous birds are particularly abundant in phosphorus. Statistical analysis (Figs. 2–4) shows that the higher concentration of phosphorus, nitrogen or uric acid in excrements is, the fewer zoosporic fungi species grow there. At lower values of

Table 4. Aquatic fungi found on the excrements of the phytophagous, carnivorous and omnivorous birds.

Species of fungi	Food type of bird		
	phytophagous*	carnivorous**	omnivorous***
Chytridiomycetes			
Chytridium xylophilum CORNU	x		x
Karlingia rosea (DE BARY et WORONIN) JOHANSON	x		x
Nowakowskiella elegans (NOWAKOWSKI) SCHROETER	x		x
Nowakowskiella macrospora KARLING	x		x
Phlyctochytrium aureliae AJELLO	x	x	x
Rhizophydium ampullaceum (BRAUN) FISCHER	x	x	x
Oomycetes			
Achlya americana HUMPHREY	x	x	x
Achlya debaryana HUMPHREY	x	x	x
Achlya dubia COKER		x	x
Achlya klebsiana PIETERS	x	x	x
Achlya oligacantha DE BARY		x	x
Achlya orion COKER et COUCH		x	x
Achlya treleaseana (HUMPHREY) KAUFFMAN		x	x
Aphanomyces laevis DE BARY	x	x	x
Aphanomyces stellatus DE BARY	x	x	x
Apodachlya pyrifera ZOPF	x	x	x
Cladolegnia unispora (COKER et COUCH) JOHANNES	x	x	x
Diasporangium jonesianum HÖHNK		x	x
Dictyuchus monosporus LEITGEB	x	x	x
Leptolegnia caudata DE BARY	x	x	x
Leptomitus lacteus (ROTH) AGARDH	x	x	x
Olpidiopsis saprolegnia (BRAUN) CORNU	x	x	x
Pythium aquatile HÖHNK	x	x	x
Pythium catenulatum MATTHEWS		x	x
Pythium debaryanum HESSE	x	x	x
Pythium gracile SCHENK	x	x	x
Pythium inflatum MATTHEWS	x	x	x
Pythium rostratum BUTLER	x	x	x
Pythium tenue GOBI	x		x
Pythium undulatum PETERSEN	x		x
Saprolegnia asterophora DE BARY	x	x	x
Saprolegnia ferax (GRUITH.) THURET	x	x	x
Saprolegnia litoralis COKER	x		x
Saprolegnia megasperma COKER		x	x
Saprolegnia parasitica COKER	x	x	x
Zoophagus insidians SOMMERSTORFF	x	x	x
Total number	29	29	36

*) Greylag goose, roman-nosed goose, mute swan.
**) Grey heron, white stork, marsh harrier, cormorant.
***) Muscovy duck, mallard, black-headed gull.

these three substances more fungus species can be found. Water chemistry also affects the total numbers of fungus species growing on avian excrements. The largest number of fungus species was detected on excrements in the rivers Biala and Supraśl, while the fewest in the most chemically polluted water of pond Akcent (Table 5). We observed this type of phenomenon when studying the growth of different types of keratin- and chitinophilic fungi in water bodies (CZECZUGA & MUSZYŃSKA 1994; CZECZUGA & GODLEWSKA 1998).

Statistical analysis demonstrates that the level of sulphates, chlorides and calcium exerts great effect on the total fungus content (Table 6), so the highest content of these components in water causes the fewest number of zoosporic

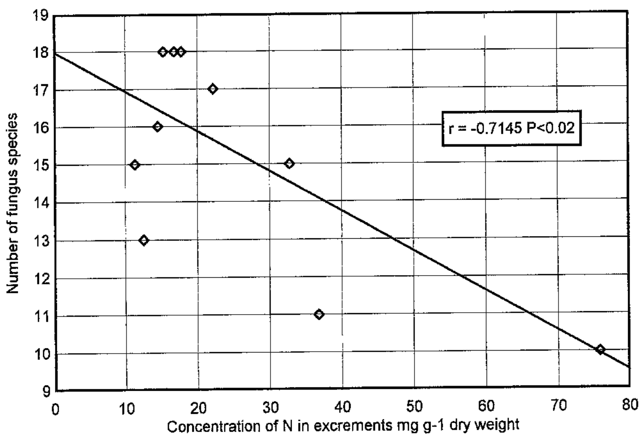

Fig. 2. Concentration of nitrogen (total) in excrements and number of fungus species.

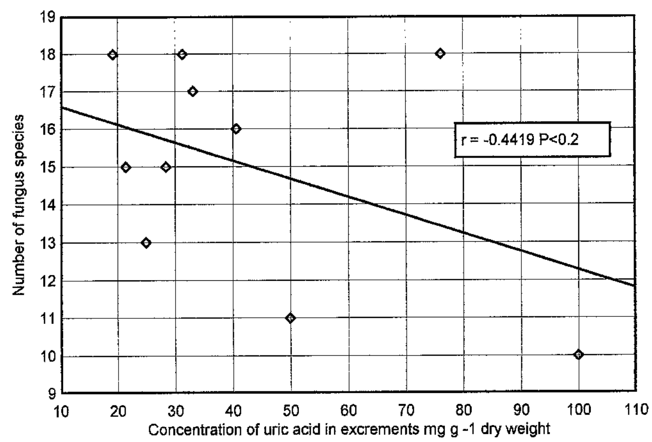

Fig. 4. Concentration of uric acid in excrements and number of fungus specis.

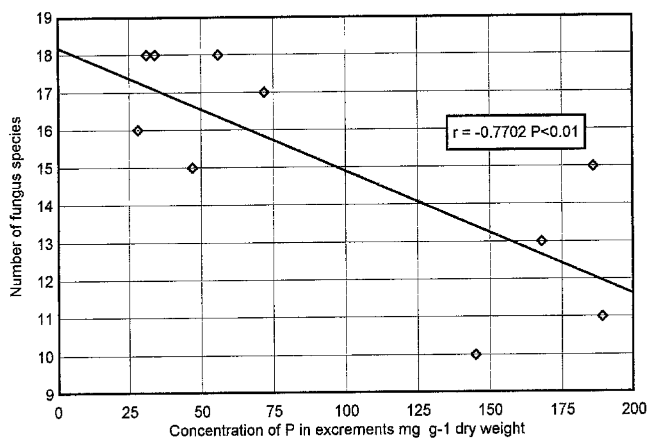

Fig. 3. Concentration of phosphorus (total) in excrements and number of fungus species.

fungi on avian excrements. A negative correlation between the number of zoosporic fungi and the bulk of biogenic components in water or the amount of organic matter was observed in our earlier studies on phytosaprophytes (CZECZUGA & PRÓBA 1987; CZECZUGA 1994), keratinophilic fungi (CZECZUGA & MUSZYŃSKA 1994) and chitinophilic fungi (CZECZUGA & GODLEWSKA 1998).

During the two-year study only 1–3 fungus species were found on each excrement fragment in containers, irrespective of bird species. Though recent studies revealed that ground coprophilous fungi produce substances limiting the growth of other fungi (GAMBLE et al. 1975; ALFATAFA et al. 1994; WHYTE et al. 1996; WANG et al. 1997), however it was demonstrated that certain caprophilous fungi produced substances which stimulated the growth of other coprophilous fungi (WEBER & WEBSTER 1997). The production of substances which inhibit the growth of other aquatic organisms, including fungi, has also been demonstrated for a number of lower aquatic fungus species belonging to Hyphomycetes (GULIS & STEFANOVICH 1999; WHEELER et al. 1999).

The data obtained suggest that zoosporic fungi, like bacteria, take an active part in the mineralization of avian excrements in water thus contributing to self-purification of natural water bodies and at the same time introducing the released elements into the cycle. Considering that approximately some kg/ha of avian excrements get into surface waters as natural impurities (DOBROWOLSKI & LEWANDOWSKI 1988), it can be assumed that fungi together with bacteria cause decomposition of this type of pollutants.

Table 5. Aquatic fungi found on the avian excrements in the water from different water bodies.

Water bodies	Fungi (see Table 3)	Number of fungus species
Pólko Spring	1,2,3,4,5,6,7,8,10,13,14,15,16,17,19,20,22,23,24,25,27,28,29,30,31,32,33,34,35,36	30
Biała River	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,19,20,21,22,23,25,26,27,28,30,31,32,33,34,35,36	33
Supraśl River	1,2,3,4,5,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,30,31,32,34,35,36	33
Fosa Pond	1,2,3,4,5,6,7,8,9,10,11,13,14,15,17,19,20,22,23,25,27,28,29,30,32,35,36	27
Akcent Pond	1,2,3,5,14,15,17,19,20,22,23,25,27,28,30,32,35,36	18
Komosa Lake	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,17,18,19,20,21,22,23,26,27.28,30,32,33,35,36	30

Table 6. Correlation coefficients between the environmental factors and number of fungus species in different water bodies (*p < 0.05; **p < 0.005; ***p < 0.001).

Parameter	Water bodies						
	Pólko Spring	Biała River	Supraśl River	Fosa Pond	Akcent Pond	Komosa Lake	Total
Temperature	–0.3388	–0.1301	0.0482	0.2416	0.0798	–0.0914	–0.0483
pH	0.0642	–0.2599	0.0389	–0.1390	0.3725	–0.6674	–0.1257
O_2	–0.1722	0.0656	–0.6977	–0.3100	–0.3898	0.4077	0.1011
BOD_5	–0.1623	–0.0649	–0.6570	0.0675	–0.3429	0.0423	–0.2150
Oxidability (COD)	–0.2647	–0.0479	–0.5876	0.0420	–0.2425	0.1735	–0.4072**
CO_2	–0.5167	–0.7268*	–0.1370	–0.2189	0.4376	–0.6409	–0.4004**
Alkalinity	0.5384	0.1231	0.1492	0.1840	0.2177	0.3508	–0.3362*
$N(NH_4)$	0.5132	0.0029	–0.8498**	0.2246	0.1859	0.6864	–0.3037*
$N(NO_2)$	0.4145	–0.0489	–0.2817	0.2869	0.2463	0.2530	0.1329
$N(NO_3)$	0.4665	–0.3246	–0.0832	0.1439	0.1878	–0.2783	0.2359
$P(PO_4)$	–0.0445	–0.5503	–0.1292	0.1315	0.2781	0.2237	–0.2858*
$S(SO_4)$	–0.0254	–0.8042*	–0.2488	0.2423	0.2309	–0.1513	–0.5449***
Cl^-	0.3878	–0.4084	–0.3452	0.1300	0.4893	–0.4477	–0.4696***
Total hardness in Ca^{2+}	–0.4823	–0.1688	–0.6601	–0.3548	–0.2859	0.1466	–0.5438***
Total hardness in Mg^{2+}	–0.0891	–0.2491	0.6109	0.3910	–0.1360	0.2071	–0.0311
Fe^{3+}	0.3203	0.3453	–0.0157	0.3463	–0.0417	0.2695	–0.0303
Dry residue	0.7026	–0.2615	–0.1618	0.4922	0.3497	0.6123	–0.2427
Dissolved solids	0.5574	0.3033	–0.1176	0.1652	0.4264	0.6295	–0.3534*
Suspended solids	0.4340	–0.7344*	–0.0299	0.6320	–0.3706	0.3968	0.2062

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