A C T A I C H T H Y O L O G I C A E T P I S C A T O R I A

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Bazyli *CZECZUGA*, Anna *GODLEWSKA*

AQUATIC INSECTS AS VECTORS OF AQUATIC ZOOSPORIC FUNGI PARASITIC ON FISHES

OWADY WODNE JAKO WEKTORY ZOOSPOROWYCH GRZYBÓW PASOŻYTNICZYCH RYB

Department of General Biology, Medical University, Białystok, Poland

The authors investigated aquatic insects (32 species) as vectors of aquatic zoosporic fungi parasitic on fishes in six bodies of water of various trophic state. A total of 127 zoosporic fungus species were noted, with predominance by the Oomycetes (99) and Chytridiomycetes species (24). Out of these 127 species, 28 are known as parasites or necrotrophs of fishes.

INTRODUCTION

Mass mortalities of fishes, salmonids in particular, caused by the extensive growth of certain zoosporic fungus species have been known since the second half of the 19th century (Stirling 1880). Recent studies have revealed that these species grow also on other aquatic organisms, both alive and dead (Czeczuga et al. 1998), being the source of infection for fishes. Fish parasitic fungi occur on plankton crustaceans (Czeczuga et al. 2000), pelagic inhabitants, as well as on such benthic organisms as crustaceans (Czeczuga et al. 1999b) and shellfish (Czeczuga 2000) and even on avian excrements (Czeczuga and Mazalska 2000). A number of aquatic insect species or their developmental forms can be found in the littoral zone of lakes where fishes lay the eggs and where fry remain for a certain period of time. Therefore we have decided to investigate which aquatic insect species can be the source of mycotic infection causing fish death.

MATERIAL AND METHODS

Specimens of 32 aquatic insects species (Table 2) were collected from Białystok district, they were then killed by decapitation and experimental observations began the next day.

The water for experiments was collected from six different water bodies:

I. Spring Cypisek, limnokrenic type; width 0.41 m, depth 0.17 m, discharge 0.6 $dm^3 \cdot s^{-1}$, is in the southern part of the Knyszyńska Forest.

II. Spring Jaroszówka, limnokrenic type, width 0.65 m, depth 0.12 m, discharge 2.4 $dm^3 \cdot s^{-1}$, is in the northern part of Białystok, without trees.

III. River Supraśl, length 106.6 km, is the right-bank tributary of the middle part of the Narew River, flowing through the Knyszyńska Forest.

IV. Lake Komosa, 12.1 ha, max. depth 2.25 m, is surrounded by the densely-growing coniferous trees of the Knyszyńska Forest.

V. Pond Akcent, 0.45 ha, max. depth 1.50 m, is a habitat of wild ducks and breeding swans.

VI. Pond Fosa, 2.5 ha, max. depth 1.75 m, situated in the Palace Park—is a habitat of wild ducks and breeding swans, as well as crucian carp and tench bred for anglers.

Nineteen parameters of these samples were determined (Table 1) according to the methods of Greenberg et al. (1992).

Table 1

Chemical properties (in $mg \cdot dm^{-3}$) of water in particular water bodies ($n = 5$)

Specification	Spring Cypisek	Spring Jaroszówka	River Supraśl	Pond Akcent	Pond Fosa	Lake Komosa
Temperature (°C)	7.8	5.7	5.4	7.0	7.2	6.5
pH	7.78	7.86	7.88	7.77	7.61	7.86
O_2	8.20	9.40	9.20	2.20	3.65	9.42
BOD_5	3.20	5.60	5.80	1.80	0.50	5.40
COD (Oxidability)	4.30	5.58	7.84	12.54	22.97	8.02
CO_2	15.40	12.20	11.95	24.20	18.80	8.82
Alkalinity in $CaCO_3$ ($mval \cdot dm^{-3}$)	5.20	2.30	5.10	7.40	4.50	5.10
$N\text{-}NH_3$	0.280	0.290	0.250	3.530	1.500	0.140
$N\text{-}NO_2$	0.014	0.020	0.005	0.012	0.007	0.005
$N\text{-}NO_3$	0.080	0.010	0.070	0.090	0.900	0.012
$P\text{-}PO_4$	0.530	0.680	0.530	12.720	1.670	0.450
Sulphates	25.54	19.33	20.16	89.27	39.08	29.62
Chlorides	28.00	15.00	36.05	49.15	52.15	10.14
Total hardness in Ca	105.80	110.16	72.25	97.52	56.16	73.44
Total hardness in Mg	21.07	15.19	15.91	12.93	11.50	14.19
Fe	0.007	0.050	0.050	0.525	0.450	0.050
Dry residue	473.0	465.0	242.0	640.0	444.0	280.0
Dissolved solids	461.0	354.0	222.0	606.0	433.0	261.0
Suspended solids	12.0	111.0	20.0	34.0	11.0	19.0

Table 2

Insect species investigated and fungi found on this insects

Taxa of insect	Stage	Fungi (see Table 3)	Total number of fungus
Odonata			
1. *Aeshna grandis* L.	larvae	5,8,9,34,38,42,43,47,51,52,53,54,58,63,64,67,71,73,75,78,84,85,89,91,96,99,110,112, 114,116,122,124	32 (15)*
2. *Anex imperator* Leach.	larvae	8,13,15,38,54,63,65,71,74,94,99,116	12 (4)
3. *Erythromma najas* Hansemann	larvae	9,13,20,23,25,34,39,40,43,44,47,51,53,54,62,64,65,67,68,70,71,78,81,91, 99,113	26 (13)
Ephemeroptera			
4. *Ephemera vulgaris* L.	larvae	3,5,8,11,13,25,27,32,48,49,51,52,53,54,56,63,64,71,72,78,85,89,94,105	24 (9)
5. *Palingenia longicauda* (Ol.)	larvae	13,15,21,22,26,32,38,42,53,63,64,65,67,74,75,78,85,89,95,96,99,102,105,112,116,119, 122,127	28 (8)
6. *Salix flavilatera* (L.)	larvae	6,13,19,20,25,34,39,41,42,43,48,51,52,53,62,63,64,65,70,73,76,77,78,79,82,85,86,89,96, 101,107,121	32 (13)
Hemiptera			
7. *Aquarius paludum* F.	mature	5,8,16,25,34,38,40,44,53,55,57,58,59,65,67,70,72,77,78,82,85,89,96,105,115,121,122, 126	28 (11)
8. *Gerris lacustris* L.	mature	5,9,18,20,35,43,47,51,54,57,58,70,71,73,78,79,85,86,89,90,91,96,102, 111,112	25 (10)
9. *Nepa cinerea* L.	mature	4,6,9,13,17,19,20,34,38,41,42,43,46,47,52,54,58,63,64,65,67,70,71,73,75,78,79,80,81,83, 87,89,91,96,104,112,115,122	38 (16)
10. *Ranatra linearis* L.	mature	6,8,12,18,33,34,41,44,50,52,58,63,64,67,72,74,75,78,83,85,89,94,100,105,106,111,112	27 (9)
Diptera			
11. *Aedes vexans* (Melg.)	larvae	6,7,8,13,19,27,34,42,43,50,51,52,54,63,64,72,73,75,78,79,85,89,95,96,98,99,111,112, 114,116,117,118,124,127	34 (11)
12. *Chaoborus cristallinus* (de Geer)	larvae	1,13,14,28,29,32,54,55,58,61,78,85,96,108,114	15 (4)
13. *Chironomus anthracinus* L.	larvae	2,13,34,40,48,49,53,54,61,67,76,78,104,105,109,114,116	17 (5)
14. *Culex pipiens* L.	larvae	3,5,7,9,10,11,13,24,25,34,40,47,54,58,63,70,72,73,74,75,78,79,81,89,90, 94,110	27 (6)
15. *Dixa amphibia* Deg.	chrisalis	8,13,33,38,39,54,58,63,64,67,72,78,83,85,91,96,105,122	18 (10)

Table 2 (cont.)

Taxa of insect	Stage	Fungi (see Table 3)	Total number of fungus
16. *Eristalis tenax* L.	larvae	10,13,17,25,34,42,44,47,51,56,63,64,70,71,75,78,84,85,95,96,99,110,111, 118,125	25 (10)
17. *Pericoma decipiens* L.	larvae	13,51,52,63,64,67,78,96,99,127	10 (4)
18. *Tipula scripta* Melg.	larvae	8,13,22,24,25,28,30,31,33,34,39,40,41,43,51,62,63,64,70,78,83,84,85,94,95,96,112,121	28 (9)
Trichoptera			
19. *Anabolia laevis* (Zetterstedt)	larvae	9,13,20,23,25,34,37,39,40,43,44,47,51,53,54,63,64,65,67,68,70,71,78,81,85,91,95,99,113	29 (14)
20. *Glyphotaelius pellucidus* (Retzius	larvae	3,13,19,33,34,35,41,42,43,44,52,54,59,63,64,66,67,69,72,78,79,83,85,89,95,99,105,110, 111,113	30 (14)
21. *Grammotaulius atomarius* Fabr.	larvae	6,12,13,34,42,47,54,57,64,70,78,79,85,96,102,105,113	17 (8)
22. *Grammotaulius nitidus* (Mueler)	larvae	8,13,34,41,43,47,57,58,63,70,71,81,85,89,102,114	16 (6)
23. *Phryganea grandis* L.	larvae	8,15,34,35,41,43,51,52,54,57,59,63,67,70,71,75,78,79,83,84,85,89,91,93,95,96,103,113, 118,121	30 (12)
24. *Phryganea striata* L.	larvae	5,9,34,35,41,43,44,48,50,51,52,53,54,58,63,64,67,71,75,78,83,85,91,96,110,121,127	27 (14)
25. *Potamophylax latipennis* (Curtis)	larvae	27,34,42,43,45,48,51,52,53,54,63,67,71,75,76,78,79,81,85,89,94,96,101,123	24 (11)
Coleoptera			
26. *Agabus bipustulatus* L.	mature	9,13,34,40,47,50,52,55,62,64,70,72,75,78,79,80,81,83,85,90,94,97,105, 115,118	25 (10)
27. *Cantharis fusca* L.	mature	5,8,13,19,20,34,43,47,50,52,53,54,63,64,67,70,71,73,75,78,85,89,94,96,110,114,120	27 (11)
28. *Dytiscus marginalis* L.	mature	5,6,34,35,41,43,47,52,54,57,63,64,67,74,78,79,85,88,89,90,94,95,96,103,110,111,112, 116,127	29 (9)
29. *Haliplus ruficollis* (Degeer)	mature	6,16,20,28,34,41,43,47,52,58,60,64,70,73,74,78,81,82,85,89,94,96,110,122	24 (9)
30. *Hydrophilus caraboides* L.	mature	3,5,17,20,34,36,41,42,51,52,54,63,64,65,70,75,78,79,84,95,96,99,110,111,121,124	26 (10)
31. *Hydroporus palustris* L.	mature	7,24,31,34,40,63,64,70,78,105,110,112,115	13 (4)
32. *Laccophilus minutus* L.	mature	5,9,13,32,42,43,47,48,49,50,52,53,54,58,62,64,67,72,73,75,78,85,89,90,91,116	26 (11)

* Numbers in parenthesis designate the total number of parasites or necrotrophs

To determine the presence of aquatic fungi on the insects, the following procedure was employed: 10–15 small fragments of each species insect were transferred to each two samples for each water basin in a 1-dm^3 vessel (altogether twelve vessels for each species) and placed in a glass tank (50 × 75 × 75 cm) at ambient temperature in the laboratory. Some pieces of insects from each vessel were observed under a microscope and the mycelium (zoosporic and oogonia and for *Saprolegnia parasitica* secondary cysts) of aquatic fungi growing on the insects was recorded. The methods are described in detail by Fuller and Jaworski (1986). The pieces of various insect species were observed under a microscope once a week, and each experiment lasted three weeks.

To identify the fungi, keys by Johnson (1956), Sparrow (1960), Waterhouse (1967, 1968), Seymour (1970), Batko (1975), Karling (1977), Dick (1990), and Pystina (1998) were used.

RESULTS

Hydrochemical parameters of water used for the experiment are presented in Table 2. The highest values of ammonium nitrogen and phosphates were found in pond Akcent and Fosa. Springs water appeared to the richest in nitrites, as well as in calcium.

We found 127 zoosporic aquatic fungus species on the fragments of 32 aquatic insects species (Table 3). The least colonised were the fragments of *Anex imperator* larvae (Odonata) and adult individuals of *Hydroporus palustris* (Coleoptera) (13 in each case), while the most colonised were the fragments of adult specimens of *Nepa cinerea* (Hemiptera) (37 species). Fourteen species have appeared new to Polish waters.

Table 3

Aquatic fungi found on the insects

Taxa fungi	Insect (see Table 2)	No of species
Chytridiomycetes		
Olpidiales		
1. *Blastulidium phaedophthorum* Perez	12	1
2. *Myiophagus ucrainica* (Wize) Sparrow	13	1
Chytridiales		
3. *Asterophlyctis irregularis* Karling	4,14,20,30	4
4. *Asterophlyctis sarcoptoides* Petersen	9	1
5. *Chytriomyces aureus* Karling	1,4,7,8,14,24,27,28,30,32	10
6. *Chytriomyces hyalinus* Karling	6,9,10,11,21,28,29	7
7. *Diplophlyctis intestina* (Schenk) Schroeter	11,14,31	3
8. *Karlingia chitinophila* Karling	1,2,4,7,10,11,15,18,22,23,27	11
9. *Phlyctochytrium aureliae* Ajello	1,3,8,9,14,19,24,26,32	9

Table 3 (cont.)

Taxa fungi	Insect (see Table 2)	No of species
10. *Podochytrium chitinophilum* Willoughby	14,16	2
11. *Podochytrium clavatum* Pfitzer	4,14	2
12. *Polychytrium aggregatum* Ajello	10,21	2
13. *Rhizidium chitinophilum* Sparrow	2,3,4,5,6,9,11,12,13,14,15,16, 17,18,19,20,21,22,26,27,32	21
14. *Rhizidium nowakowskii* Karling	12	1
15. *Rhizidium ramosum* Sparrow	2,5,23	3
16. *Rhizophydium globosum* (Braun) Rabenhorst	7,29	2
17. *Rhizophydium macrosporum* Karling	9,16,30	3
18. *Rhopalophlyctis sarcoptoides* Karling	8,10	2
19. *Siphonaria variabilis* Petersen	6,9,11,20,27	5
Blastocladiales		
20. *Blastocladiella britannica* Horenstein et Cantino	3,6,8,9,19,27,29,30	8
21. *Blastocladiopsis parva* (Whiffen) Sparrow	5	1
22. *Catenophlyctis variabilis* (Karling) Karling	5,18	2
23. *Coelomomyces lativittatus* Couch et Dodge	3,19	2
24. *Coelomomyces pentagulatus* Couch	14,18,31	3
Hyphochytriomycetes		
Hyphochytriales		
25. *Rhizidiomyces bivellatus* Nabel	3,4,6,7,14,16,18,19	8
26. *Rhizophlyctis petersenii* Sparrow	5	1
Oomycetes		
Lagenidiales		
27. *Lagenidium giganteum* Couch	4,11,25	3
28. *Lagenidium podbielkowski* Batko	12,18,29	3
29. *Lagenidium rabenhorstii* Batko	12	1
30. *Myzocytium megastomum* de Wildeman	18	1
31. *Myzocytium microsporum* (Karling) Sparrow	18,31	2
32. *Myzocytium zoophthorum* Sparrow	4,5,12,32	4
Saprolegniales		
33.**Achlya ambisexualis* Raper	10,15,18,20	4
34.**Achlya americana* Humphrey	1,3,6,7,9,10,11,13,14,16,18,19,20, 21,22,23,24,25,26,27,28,29,30,31	24
35.**Achlya apiculata* de Bary	8,20,23,24,28	5
36.**Achlya bisexualis* Coker et Couch	30	1
37. *Achlya cambrica* (Trow) Johnson	19	1
38.**Achlya caroliniana* Coker	1,2,5,7,9,15	6
39. *Achlya colorata* Pringsheim	3,6,15,18,19	5
40. *Achlya crenulata* Ziegler	3,7,13,14,18,19,26,31	8
41. *Achlya debaryana* Humphrey	6,9,10,18,20,22,23,24,28,29,30	11
42.**Achlya diffusa* Harvey et Johnson	1,5,6,9,11,16,20,21,25,30,32	11
43.**Achlya dubia* Coker	1,3,6,8,9,11,18,19,20,22,23,24, 25,27,28,29,30,32	18

Table 3 (cont.)

Taxa fungi	Insect (see Table 2)	No of species
44.*_Achlya flagellata_ Coker	3,7,10,16,19,20,24	7
45. _Achlya hypogyna_ Coker et Pemberton	25	1
46. _Achlya inflata_ Coker	9	1
47.*_Achlya klebsiana_ Pieters	1,3,8,9,14,19,21,22,26,27,28,29,32	13
48. _Achlya megasperma_ Humphrey	6,13,24,25,32	5
49. _Achlya oblongata_ de Bary	4,13,32	3
50. _Achlya oligacantha_ de Bary	10,11,24,26,27,32	6
51.*_Achlya orion_ Coker et Couch	1,3,4,6,8,11,16,17,18,19,23,24,30	13
52.*_Achlya polyandra_ Hildebrand	1,4,6,9,10,11,17,20,23,24,25,26,27 ,28,29,30,32	17
53.*_Achlya prolifera_ Nees	1,3,4,5,6,7,13,19,24,25,27,32	12
54.*_Achlya proliferoides_ Coker	1,2,3,4,8,9,11,12,14,15,19,20,21, 23,24,25,27,28,30,32	20
55.*_Achlya racemosa_ Hildebrand	7,12,26	3
56. _Achlya rodriguesiana_ F.T. Wolf	4,16	2
57. _Achlya treleaseana_ (Humphrey) Kauffman	7,8,21,22,23,28	6
58. _Aplanes androgynus_ (Archer) Humphrey	1,7,8,9,10,12,14,15,24,29,32	11
59. _Aphanomyces amphigynus_ Cutter	7,20,23	3
60. _Aphanomyces astai_ Schikora	29	1
61. _Aphanomyces daphniae_ Prowse	12,13	2
62. _Aphanomyces helicoides_ Minden	3,6,18,19,26,32	6
63. _Aphanomyces irregularis_ Scott	1,2,4,5,6,9,10,11,14,15,16,17,18, 20,22,23,24,25,27,28,30,31	22
64.*_Aphanomyces laevis_ de Bary	1,3,4,5,6,9,10,11,15,16,17,18,19, 20,21,24,26,27,28,29,30,31,32	23
65.*_Aphanomyces stellatus_ de Bary	2,3,5,6,7,9,19,30	8
66. _Cladolegnia spiralis_ (Cornu) Johannes	28	1
67. _Cladolegnia unispora_ (Coker et Couch) Johannes	1,3,5,7,9,10,13,15,17,19,20,23,24, 25,27,28,32	17
68. _Dictyuchus magnusii_ Lindtstedt	3,19	2
69.*_Dictyuchus monosporus_ Leitgeb.	20	1
70.*_Dictyuchus sterile_ Coker	3,6,7,8,9,14,16,18,19,21,22,23,26, 27,29,30,31	17
71.*_Isoachlya monilifera_ (de Bary) Kauffman	1,2,3,4,8,9,16,19,23,24,25,27	12
72.*_Leptolegnia caudata_ de Bary	4,7,10,11,14,15,20,26,32	9
73. _Saprolegnia anisospora_ de Bary	1,6,8,9,11,14,27,29,32	9
74. _Saprolegnia asterophora_ de Bary	2,5,10,14,28,29	6
75. _Saprolegnia delica_ Coker	1,5,9,10,11,14,16,23,24,25,26,27, 30,32	14
76.*_Saprolegnia diclina_ Humphrey	6,13,25	3
77. _Saprolegnia eccentrica_ (Coker) Seymour	6,7	2

Table 3 (cont.)

Taxa fungi	Insect (see Table 2)	No of species
78.*_Saprolegnia ferax_ (Gruith.) Thuret	1,3,4,5,6,7,8,9,10,11,12,13,14, 15,16,17,18,19,20,21,23,24,25, 26,27,28,29,30,31,32	30
79. _Saprolegnia glomerata_ (Tiesenhausen) Lund	6,8,9,11,14,20,21,23,25,26,28,30	12
80. _Saprolegnia hypogyna_ (Pring.) de Bary	9,26	2
81. _Saprolegnia latvica_ Apinis	3,9,14,19,22,25,26,29	8
82. _Saprolegnia litoralis_ Coker	6,29	2
83.*_Saprolegnia monoica_ Pringsheim	9,10,15,18,20,23,24,26	8
84. _Saprolegnia papillosa_ (Humphrey) Apinis	1,16,18,23,30	5
85.*_Saprolegnia parasitica_ Coker	1,4,5,6,7,8,10,11,12,15,16,18, 19,20,21,22,23,24,25,26,27,28, 29,32	24
86. _Saprolegnia pseudocrustosa_ Lund	6,8	2
87.*_Saprolegnia subterranea_ Dissmann	9	1
88. _Saprolegnia terrestris_ Cookson et Seymour	28	1
89. _Saprolegnia torulosa_ de Bary	1,4,5,6,7,8,9,10,11,14,20,22,23,2 7,28,29,32	17
90. _Saprolegnia uliginosa_ Johannes	8,14,26,28,32	5
91.*_Traustotheca clavata_ (de Bary) Humphrey	1,3,8,9,15,19,23,24,32	9
Leptomitales		
92. _Apodachlya pyrifera_ Zopf	20	1
Peronosporales		
93. _Phytophthora fischeriana_ (Höhnk) Sparrow	23	1
94. _Pythium acanthicum_ Drechsler	2,10,14,18,25,26,27,28,29	9
95. _Pythium afertile_ Kanouse et Humphrey	5,11,16,18,19,20,23,28,30	9
96. _Pythium aquatile_ Höhnk	1,5,6,7,8,9,11,12,15,16,17,18, 21,23,24,25,27,29,30	19
97. _Pythium aristosporum_ Vanterpool	26	1
98. _Pythium arrhenomanes_ var. _philippinense_ Roldan	11	1
99. _Pythium butleri_ Subramaniam	1,2,3,5,11,16,17,19,20,30	10
100. _Pythium cactacearum_ Preti	10	1
101. _Pythium catenulatum_ Matthews	6,25	2
102. _Pythium debaryanum_ Hesse	5,8,21,22	4
103.*Pythium deliense* Meurs	23,28	2
104. _Pythium dissotocum_ Drechsler	9,13	2
105. _Pythium elongatum_ Matthews	4,5,7,10,13,15,20,26,31	9
106. _Pythium epigynum_ Höhnk	10	1
107. _Pythium equiseti_ Sadebeck	6	1
108. _Pythium globosum_ Schenk	12	1
109. _Pythium graminicola_ Subramaniam	13	1
110. _Pythium helicandrum_ Drechsler	1,14,16,20,24,27,28,29,30,31	10

Table 3 (cont.)

Taxa fungi	Insect (see Table 2)	No of species
111. *Pythium imperfectum* Höhnk	8,10,11,16,20,28,30	7
112. *Pythium inflatum* Matthews	1,5,8,9,10,11,18,28,31	9
113. *Pythium jirovecii* Cejp	3,19,20,21,23	5
114. *Pythium myriotylum* Drechsler	1,11,12,13,22,27	6
115. *Pythium oedochilum* Drechsler	7,9,26,31	4
116. *Pythium polysporum* Sorokin	1,2,5,11,13,28,32	7
117.* *Pythium proliferum* Schenk	11	1
118. *Pythium rostratum* Butler	11,16,23,26	4
119. *Pythium salpingophorum* Drechsler	5	1
120. *Pythium tardicrescens* Vanterpool	27	1
121. *Pythium tenue* Gobi	6,7,18,23,24,30	6
122.* *Pythium ultimum* Trow	1,5,7,9,15,29	6
123. *Pythium undulatum* Petersen	25	1
124. *Pythium volutum* Vanterpool	1,11,30	3
125. *Rheosporangium aphanidermatus* Edson	16	1
Zygomycetes		
Zoopagales		
126. *Zoophagus insidians* Sommerstorff	7	1
127. *Zoophthora rhizospora* (Thaxter) Batko	5,11,17,24,28	5

* Known in literature as parasites or necrotrophs of fish.

The most aquatic fungus species were found on aquatic insects in spring water (Cypisek 89, Jaroszówka 80 species), the fewest in pond water (Akcent 32, Fosa 61 species—Table 4). Out of these 127 species, 28 are known as parasites or necrotrophs of freshwater fishes. The most common fungus species included *Rhizidium chitinophilum, Achlya americana, Achlya dubia, Achlya polyandra, Achlya proliferoides, Aphanomyces irregularis, Aphanomyces laevis, Cladolegnia unispora, Dictyuchus sterilis, Saprolegnia ferax, Saprolegnia parasitica, Saprolegnia torulosa*, and *Pyhium aquatile* were found on the fragments of most insects species examined.

DISCUSSION

The present study has revealed that aquatic insects are a good substratum for the growth of 127 aquatic zoosporic fungus species, including a number of species of fish parasites new to Polish waters.

Table 4

Aquatic fungi found on the insects in different water

Water from	Fungi (see Table 3)	Only in one water	Total number of fungi
Cypisek Spring	3,5,6,7,8,9,10,11,13,18,19,20,21,22,24,25,30,31,33,34,38,39,41,42,43,47, 49,50,51,52,53,55,56,57,58,59,60,61,62,63,64,65,67,69,70,71,73,74,75,77, 78,79,80,82,83,85,86,88,89,90,91,92,93,94,95,96,99,101,102,103,104,105, 106,107,110,111,112,114,115,116,121,122,124,126,127	18,21,22,30,69,88,92,93,124,126	85 (20)*
Jaroszówka Spring	2,4,5,6,7,8,9,10,11,13,15,20,24,25,26,31,33,34,35,37,38,39,40,41,42,43, 44,47,48,49,50,51,52,53,54,56,57,58,63,64,65,67,68,70,71,72,74,75,76,78, 79,80,81,82,83,85,86,87,89,90,91,94,95,96,98,99,103,104,105,106,107,109,1 10,112,113,115,116,122	2,4,37,68,87,98,109	78 (24)
Supraśl River	3,5,6,8,9,10,13,16,17,20,25,26,28,34,35,36,38,39,41,42,43,44,45,46,47,48, 50,51,52,53,54,56,58,59,60,62,63,64,65,66,67,70,71,72,73,75,78,79,81,83, 85,89,90,91,94,95,96,97,100,101,105,110,112,116,118,119,121,122	17,36,45,46,66,97,100,118,119	68 (22)
Komosa Lake	1,3,7,8,13,14,15,16,19,25,26,28,29,31,32,33,34,35,38,41,43,44,47,48,49,50,5 1,52,53,54,56,58,59,61,62,63,64,67,70,71,72,73,74,75,76,77,78,79,81,82, 83,84,85,89,94,95,96,99,102,105,106,108,110,111,112,114,115,118,120, 121,122,123	1,14,29,108,120,123	72 (20)
Akcent Pond	5,6,9,13,19,23,25,43,51,52,54,55,58,59,62,63,64,78,79,83,85,89,91,95,96, 99,105,110,111,115,121,125,127	23,125	33 (10)
Fosa Pond	3,5,6,8,9,12,13,15,24,25,27,32,33,34,35,40,41,42,43,47,51,53,54,57,58,62, 63,64,67,70,71,73,74,75,78,79,81,83,84,85,89,91,94,95,96,99,102,105,110, 111,112,113,114,115,116,117,121,127	12,27,117	58 (17)

* Numbers in parenthesis designate the total number of parasites or necrotrophs.

Fewest fungus species were found to grow on fragments of aquatic insects species in the water of pond Akcent and Fosa. The water of these both ponds were found the lowest oxygen content and indices of BOD_5, and is characterised by a comparatively highest content of oxidability (COD), CO_2, ammonium nitrogen, nitrates, phosphates, sulphates, chlorides, and iron.

Interesting is also the occurrence of numerous fungus species known to cause death of noble crayfish and many fish species. *Aphanomyces astaci,* first described by Schikora (1903), causes the so called crayfish plague. In our study this fungus colonised chitin covers of *Haliplus ruficollis* individuals in the water of spring Cypisek and the river Supraśl. Our earlier studies revealed that *Aphanomyces astaci* can grow on dragon-fly wings (Czeczuga and Godlewska 1994, 1998) on certain plankton crustaceans of the Cladocera (Czeczuga et al. 2000) and benthic crustaceans (Czeczuga et al. 1999 b). Moreover, *Aphanomyces astaci* grows on fragments of dead crayfish specimens (Czeczuga et al. 1998). The crayfish cuticle, when shed, becomes a carrier of *Aphanomyces astaci* for healthy crayfish.

A relatively large number of fungus species being fish parasites were found to grow on the aquatic insect species examined. The most aquatic fungus species, known as fish parasites were found to grow on the insects in the water of spring Jaroszówka (24), the fewest in the water of pond Akcent (10) (Table 4). Most aquatic fungus species, fish parasites, were found to grow on *Nepa cinerea* specimens (16), fewest on the larvae of *Anex imperator, Chaoborus cristallinus, Pericoma decipiens*, and on adult specimens of *Hydroporus palustris* (4 species on each—Table 2).

The fragments of aquatic insects examined were inhabited by a number of fungus species which frequently cause significant losses in fish farming, including *Achlya americana, Achlya dubia, Achlya flagellata, Achlya polyandra, Achlya proliferoides, Aphanomyces laevis, Dictyuchus sterilis, Leptolegnia caudata, Pythium proliferum, Saprolegnia ferax, Saprolegnia monoica*, and *Saprolegnia parasitica.* The most common fungus species of this group found on the insects examined were *Saprolegnia ferax* (30 out of 32), *Saprolegnia parasitica* (24), *Achlya americana* (24) and *Aphanomyces laevis* (23) (Table 3). Several years ago on a fish farm in England more than half of the *Salmo trutta* L. population died of saprolegniosis (Ferguson and Ride 1980). Three species of *Saprolegnia* known as fish parasites (Neish and Hughes 1980) were found on the fragments of aquatic insects,

Saprolegnia monoica occurs on eggs of salmonids (Florinskaya 1971; Osipian et al. 1988), coregonids (Czeczuga and Muszyńska 1998), and other fishes (Czeczuga and Muszyńska 1999a,b). However, the major losses in fish farms are due to the other two species: *Saprolegnia ferax* and *Saprolegnia parasitica* (cf. Chien 1981; Frick and Reinhold 1987; Dudka et al. 1989). *Saprolegnia ferax,* together with other fungi, causes death in acipenserid fish hatcheries, where losses in incubated eggs can reach 70% (Lartseva and Dudka 1990). Many cases of saprolegniosis caused by *Saprolegnia ferax* are known (Neish and Hughes 1980; Dudka et al. 1989). Destructive actions of *Saprolegnia parasitica* were reported from fish farms in Miyagi Prefecture, Japan, where in 1987 alone about 30–50% of coho salmon, *Oncorchynchus kisutch* (Walbaum) died (Hatai and Hoshiai 1992). Apart from *Saprolegnia ferax, Saprolegnia parasitica* is the commonest fungus found in saprolegniosis-induced fish death and growing on the spawn of certain amphibians (Czeczuga et al. 1998).

Achlya americana and *Achlya dubia* attack both eggs and adult individuals of many economically valuable fish species on different continents (Scott and Warren 1964; Bhargava et al. 1971). *Achlya flagellata* infects eggs of many fish species (Florinskaya 1971; Sati and Khulbe 1981), and *Achlya polyandra* infects eggs of salmonid fishes (Lartseva 1986). However, the major losses in fish farms of India are due to the other two species such as *Achlya proliferoides* and *Dictyuchus sterilis* (cf. Srivastava 1976). *Aphanomyces laevis* attacks both eggs and adult individuals of many economically valuable fish species (Dudka et al. 1989). Likewise, *Leptolegnia caudata* occurs on acipenserid eggs (Dudka et al. 1989). *Pythium proliferum* is encountered on both eggs and adults of various fish species (Florinskaya 1969; Czeczuga 1996). Fungi of the genus *Pythium* are frequently found on fishes; however, because of the difficulty of determining species of *Pythium*, only the generic name is used (Scott and O'Bier 1962; Stuart and Fuller 1968; Shah et al. 1977). Our detailed studies demonstrated that several species of *Pythium* inhabited the eggs of various species of freshwater fishes (Czeczuga 1996).

The present study indicates that aquatic insects are a substrate for a number of zoosporic fungi habitats are foci for fungi parasitising fish.

One of the new species is *Blastulidium phaedopthorum*, found in our study on larvae of *Chaoborus cristallinus* in lake Komosa. It was described by Perez (1903) as a parasitises of embryos of plankton crustaceans of the genus *Daphnia*. Later it turned out that this fungus parasites also on other crustaceans of the Cladocera (Jirovec 1955). The water of

lake Komosa is characterised by a comparatively highest content of oxygen but by the lowest content of CO_2, ammonium and nitrite nitrogen, phosphates, and chlorides. *Myiophagus ukrainica*, another fungus new to Polish hydromycology, colonized the fragments of *Chironomus atracinus* larvae in spring Jaroszówka. Water of this spring had the lowest alkalinity, nitrate nitrogen, and sulphates but by the highest content of nitrite nitrogen and calcium. It was first described by Wize (1904) as an insecticidal fungus parasiting on *Cleonus punctiventris*, a beet pest. It was later encountered in Great Britain (Petch 1940), in Bermuda (Karling 1948), in Canada and the United States as a parasite of other land plant pest insects (Fisher 1950).

Rhizidium nowakowskii, also a new fungus, was found to grow on three insect species in the water of spring Jaroszówka, pond Fosa and lake Komosa. It was described by Nowakowski (1876) and then encountered by Karling (1944) in Brazil. The water of pond Fosa is characterised by a comparatively lowest content of calcium and magnesium but by the highest content of nitrates nitrogen and chlorides. Water of this pond had the lowest BOD_5 and the highest oxidability (COD). *Rhizophydium macrosporum* was observed on *Gerris lucustris* individuals in spring Cypisek. It was first described by Karling (1938) on cooked beef. The water of spring Cypisek had the lowest oxidability and iron but by the highest content of magnesium.

The two species of the genus *Coelomomyces*, have also appeared new to Polish waters. *Coelomomyces lativittatus* grew on the individuals of a few insect species in the water of all six reservoirs, while *Coelomomyces pentagulatus* colonized only fragments of *Palingenia longicuada* larvae in spring Jaroszówka, river Supraśl and lake Komosa. The water of river Supraśl had the highest BOD_5. They were both described as parasites of mosquito larvae—the former growing on larvae of the genus *Anopheles* (Couch 1945), the latter parasitising on the genus *Culex* (cf. Couch and Dodge 1947).

Myzocytium megastomum was found on the fragments of four aquatic insect species in pond Fosa and lake Komosa. It was described by de Wildeman (1890) as a parasite of algae, both green and desmidia, and is known in the literature of the subject as an alga parasite (Batko 1975). This would be the first report on the occurrence of *Myzocytium megastomum* on animal substratum.

Achlya cambrica, never before encountered in Polish waters, was found on four insect species in the water of spring Jaroszówka and river the Supraśl. In the literature of the subject (Johnson 1956, Batko 1975) it is described as an aquatic saprophyte.

A number of fungus species belonging to the Peronosporales have appeared new to Polish hydromycology. *Phytophthora fischeriana* was found on larvae of *Phryganea grandis* in spring Cypisek. *Pythium deliense,* first isolated from tobacco in Sumatra (Meurs 1934), colonized fragments of adult individuals of *Dytiscus marginalis* also in spring Cypisek. *Pythium salpingophorum* colonized fragments of *Palingenia longicauda* larvae in the river Supraśl. It was first described from decaying roots of pea *Pisum sativum* L. near Eden in the State of New York (Drechsler 1930). *Pythium tradicrescens* was found in lake Komosa on fragments of adult *Cantharis fusca.* It was first isolated by Vanterpool (1938) as a parasite of wheat roots *Triticum aestive* L. in Canada. *Rheosporangium aphanidermatus*, was found on fragments of *Eristalis tenax* larvae in pond Akcent. It was first described by Edson (1915) as a parasite on sugar beets and radishes. The water of pond Akcent is characterised by a comparatively lowest content of oxygen but by the highest content of CO_2, ammonium nitrogen, phosphates, sulphates and iron. Water of this pond had the highes alkalinity. Moreover, worth noting is the occurrence of such three rare *Pythium* species as *Pythium arrhenomanes* var. *philippinense*, *Pythium equiseti*, and *Pythium volutum. Pythium equiseti* was previously found on the pollens of certain plants (Czeczuga and Muszyńska 2000), the other two species on dragon-flies (Czeczuga et al. 1999a).

CONCLUSIONS

The mycoflora developing on dead specimens of 32 aquatic insect species was investigated under laboratory conditions. A total of 127 zoosporic fungus species were found to grow on the fragments of aquatic insect species investigated, including 24 chytridiomycetes, 2 hyphochytriomycetes, 99 oomycetes, and 2 zygomycetes fungus.

The most aquatic fungus species were found on aquatic insects in springs water (Cypisek 89, Jaroszówka 80 species), the fewest in ponds water (Akcent 32, Fosa 61 species).

Out of these 127 species, 28 are known as parasites or necrotrophs of fishes. The most aquatic fungus species, fish parasites were found to grow on the insects in the water of spring Jaroszówka (24), the fewest in the water of pond Akcent (10). The most common

fungus species of this group found on the insects examined were *Saprolegnia ferax* (30 out of 32), *Saprolegnia parasitica* (24), *Achlya americana* (24), and *Aphanomyces laevis* (23).

Fourteen fungus species were recorded for the first time from Poland.

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Bazyli *CZECZUGA*, Anna *GODLEWSKA*

OWADY WODNE JAKO WEKTORY ZOOSPOROWYCH GRZYBÓW PASOŻYTNICZYCH RYB

STRESZCZENIE

Autorzy badali w warunkach laboratoryjnych rozwój zoosporowych grzybów wodnych na fragmentach osobników 32 gatunków form larwalnych lub doskonałych owadów wodnych w wodzie sześciu różnych zbiorników wodnych o różnej troficzności. Do doświadczeń wodę pobierano ze źródeł Cypisek i Jaroszówka, z rzeki Supraśl, ze stawów Akcent i Fosa oraz z jeziora Komosa oznaczając w niej niektóre parametry fizykochemiczne. Najbardziej zasobną w biogeny i inne wskaźniki troficzności była woda obu stawów.

Na fragmentach badanych gatunków owadów wodnych rozwijało się 127 gatunków zoosporowych grzybów wodnych, z których 24 gatunki należały do Chytridiomycetes, 2 do Hypochytriomycetes, 99 do Oomycetes oraz 2 gatunki do Zygomycetes. W najmniejszym stopniu kolonizowane były fragmenty larw *Anex imperator* (Odonata) oraz dorosłe osobniki *Hydrophorus palustris* (Coleoptera) (po 13 gatunków grzybów w obu przypadkach), zaś w największym stopniu fragmenty dorosłych osobników *Nepa cinerea* (Hemiptera) (38). Najwięcej gatunków grzybów wodnych kolonizowało fragmenty badanych owadów wodnych w wodzie obu źródeł, najmniej zaś – w wodzie obu stawów.

Wśród stwierdzonych gatunków grzybów zoosporowych rozwijających się na badanych gatunkach owadów wodnych znalazł się *Aphanomyces astaci* powodujący wśród raków szlachetnych tak zwaną dżumę raczą oraz 28 gatunków rozwijających się na ikrze i dorosłych osobnikach ryb, powodujących nieraz ogromne straty w rybostanie. Najwięcej gatunków grzybów wodnych pasożytów ryb rozwijało się na osobnikach *Nepa cinerea* (16), najmniej zaś na larwach *Anex imperator, Chaoborus cristallinus, Pericoma decipiens* oraz na osobnikach dorosłych *Hydroporus palustris* (po 4 gatunki). Najczęściej spotykanymi gatunkami grzybów z tej grupy na badanych owadach były *Saprolegnia ferax* (na 30 z 32 badanych), *Saprolegnia parasitica* (24), *Achlya americana* (24) oraz *Aphanomyces laevis* (23). Ponadto 14 gatunków grzybów rozwijających się na fragmentach owadów wodnych okazały się nowymi dla hydromykologii Polski.

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Author's address:
Bazyli Czeczuga, DSc Prof
Department of General Biology
Medical University in Białystok
Kilińskiego 1, 15-230 Białystok, Poland