

Freshwater Fungi

and Fungal-like Organisms

Edited by

E. B. Gareth Jones, Kevin D. Hyde and Ka-Lai Pang

DE GRUYTER

Contents

Preface — v .

List of contributing authors — xvii

E. B. Gareth Jones, Kevin D. Hyde and Ka-Lai Pang

1 Introduction — 1

- 1.1 Origin of freshwater fungi and fungal-like organisms — 4
- 1.2 Classification of freshwater fungi — 5
- 1.3 Estimated number of freshwater fungi — 6
- 1.4 World distribution — 8
- 1.5 Endophytic fungi — 8
- 1.6 Predacious fungi — 9
- 1.7 Bioactive compounds — 10
- 1.8 Barcoding of freshwater fungi — 12
- 1.9 One name one fungus ruling — 13
- 1.10 Role of fungi in freshwater habitats — 14
- 1.11 Objectives and outline of the volume — 15
- 1.12 Phylogeny of true freshwater fungi — 15
- 1.13 Phylogeny of fungus-like organisms — 15
- 1.14 Biodiversity of freshwater fungi and fungus-like organisms — 16
- 1.15 Ecology — 16
- Acknowledgments — 16
- References — 17

Phylogeny of freshwater fungi — 23

Carol A. Shearer, Ka-Lai Pang, Satinee Suetrong and Huzefa A. Raja

2 Phylogeny of the Dothideomycetes and other classes of freshwater fissitunicate Ascomycota — 25

- 2.1 Introduction — 25
- 2.2 Geographical distribution patterns — 26
- 2.3 Substrate distribution patterns — 26
- 2.4 Morphological adaptations — 26
- 2.5 Systematics — 28
- 2.5.1 General introduction — 28
- 2.5.2 Current phylogenetic placement based on molecular
systematics — 32
 - 2.5.2.1 Dothideomycetes-Pleosporomycetidae-Pleosporales — 32
 - 2.5.2.2 Pleosporales *incertae sedis* — 36
 - 2.5.3 Zopfiaceae, Dothideomycetes, family *incertae sedis* — 38
 - 2.5.4 Dothideomycetes *incertae sedis* — 38

2.5.4.1	Jahnulales — 38
2.5.4.2	Natipusillales — 39
2.5.4.3	<i>Minutisphaera</i> clade — 39
2.5.4.4	Freshwater asexual morphs with affinities to Dothideomycetes — 39
2.6	Conclusions — 40
	Acknowledgments — 40
	References — 40

Lei Cai, Dian-Ming Hu, Fang Liu, Kevin D. Hyde and E. B. Gareth Jones

3 The molecular phylogeny of freshwater Sordariomycetes and discomycetes — 47

3.1	Introduction — 47
3.2	Materials and methods — 48
3.2.1	Taxon sampling — 48
3.2.2	Phylogenetic analysis — 48
3.3	Discussion — 48
3.3.1	Sordariomycetidae — 56
3.3.1.1	Annulatasaceae — 56
3.3.1.2	Magnaporthales — 60
3.3.1.3	Calosphaeriales — 60
3.3.1.4	Coniochaetales — 61
3.3.1.5	Diaporthales — 61
3.3.1.6	Sordariales — 61
3.3.2	Sordariomycetidae <i>incertae sedis</i> — 62
3.3.3	Hypocreomycetidae — 62
3.3.3.1	Savoryellales — 62
3.3.3.2	Microascales — 63
3.3.3.3	Hypocreales — 63
3.3.4	Xylariomycetidae — 64
3.3.4.1	Xylariales — 64
3.3.4.2	Phyllachorales — 64
3.3.4.3	Trichosphaeriales — 64
3.3.5	Discomycetes — 64
3.3.5.1	Helotiales — 64
3.3.5.2	Pezizales — 65
3.3.5.3	Rhytismatales — 66
3.4	Concluding remarks — 66
	Acknowledgments — 66
	References — 67

E. B. Gareth Jones, Darlene Southworth, Diego Libkind and Ludmila Marvanová

4 Freshwater Basidiomycota — 73

4.1	Group 1 freshwater yeasts — 82
-----	--------------------------------

4.1.1	Agaricomycotina — 83
4.1.1.1	Tremellomycetes — 83
4.1.2	Pucciniomycotina — 85
4.1.2.1	Cystobasidiomycetes — 85
4.1.2.2	Microbotryomycetes — 85
4.1.2.3	Microbotryomycetes <i>Incertae sedis</i> — 86
4.1.3	Ustilaginomycotina — 87
4.1.3.1	Ustilaginomycetes — 87
4.2	Group 2 filamentous fungi — 87
4.2.1	Agaricomycotina — 87
4.2.1.1	Agaricomycetes — 87
4.2.1.2	Exobasidiomycetes — 92
4.2.1.3	Tremellomycetes — 92
4.2.2	Pucciniomycotina — 92
4.2.2.1	Atractiellomycetes — 92
4.2.2.2	Classicalomycetes — 93
4.2.2.3	Microbotryomycetes — 94
4.2.3	Ustilaginomycotina — 95
4.2.3.1	Ustilaginomycetes — 95
	Basidiomycota — <i>incertae sedis</i> — 95
4.3	Group 3 endophytes — 99
4.4	Adaptation to freshwater habitats — 99
	Acknowledgments — 100
	References — 100

Dian-Ming Hu, Lei Cai, E. B. Gareth Jones, Huang Zhang, Nattawut Boonyuen
and Kevin D. Hyde

5 Taxonomy of filamentous asexual fungi from freshwater habitats, links to sexual morphs and their phylogeny — 109

5.1	Introduction — 109
5.2	Morphological taxonomy — 110
5.2.1	Hyphomycetes — 110
5.2.2	Coelomycetes — 112
5.2.3	Asexual-sexual connections — 112
5.3	Phylogeny — 113
5.3.1	Dothideomycetes — 114
5.3.1.1	Capnodiales — 114
5.3.1.2	Dothideales — 114
5.3.1.3	Hysteriales — 117
5.3.1.4	Jahnulales — 117
5.3.1.5	Mytilinidiales — 117
5.3.1.6	Pleosporales — 117
5.3.1.7	Tubeufiales — 118

5.3.2	Leotiomycetes — 119
5.3.3	Orbiliomycetes — 120
5.3.3.1	Orbilliales — 120
5.3.4	Sordariomycetes — 120
5.3.4.1	Glomerellales — 123
5.3.4.2	Hypocreales — 123
5.3.4.3	Sordariales — 123
5.3.4.4	Savoryellales — 124
5.4	Discussion — 125
	Acknowledgment — 126
	References — 126

Martha J. Powell and Peter M. Letcher

6	Phylogeny and characterization of freshwater Chytridiomycota (Chytridiomycetes and Monoblepharidomycetes) — 133
6.1	Introduction — 133
6.2	Chytridiomycetes — 138
6.2.1	Order 1. Chytridiales (Chytridiaceae, Chytriomycetaceae) — 138
6.2.2	Order 2. Spizellomycetales (Spizellomycetaceae, Powellomycetaceae) — 140
6.2.3	Order 3. Rhizophlyctidiales (Rhizophlyctidaceae, Sonoraphlyctidaceae, Arizonaphlyctidaceae, Borealophlyctidaceae) — 141
6.2.4	Order 4. Rhizophydiales (10 families described) — 141
6.2.5	Order 5. Lobulomycetales (Lobulomycetaceae) — 144
6.2.6	Order 6. Cladochytriales (Cladochytriaceae, Nowakowskiallaceaee, Septochytriaceae, Endochytriaceae) — 144
6.2.7	Order 7. Polychytriales (no families described) — 146
6.3	<i>Incertae sedis</i> — 147
6.4	Monoblepharidomycetes (Harpochytriales, Monoblepharidales, Hyaloraphidiales) — 148
	Acknowledgments — 148
	References — 148

Phylogeny of fungus-like organisms — 155

Ray Kearney and Frank H. Gleason

7	Microsporidia — 157
7.1	Ecology — 160
7.2	Classification — 162
7.3	Evolutionary origins — 165
7.4	Cell structure and spore significance — 166
7.5	Metabolism — 167
7.6	Genome structure — 168

7.7	Discussion and conclusion — 168
7.8	Further research avenues — 170
	References — 171

Agostina V. Marano, Ana L. Jesus, Carmen L. A. Pires-Zottarelli, Timothy Y. James,
Frank H. Gleason and Jose I. de Souza

**8 Phylogenetic relationships of Pythiales and Peronosporales
(Oomycetes, Straminipila) within the “peronosporalean
galaxy” — 177**

8.1	Introduction — 177
8.2	The monophyly of Chromalveolata and the relationships between heterotrophic straminipile lineages — 178
8.3	Major lineages within the Oomycetes: the “galaxies” — 179
8.4	The “peronosporalean galaxy”: a marine origin? — 179
8.5	Ecological and economical significance — 180
8.6	The phylogeny of Pythiales and Peronosporales — 181
8.6.1	Clade 1: Albuginales — 185
8.6.2	Clade 2: Pythiales — 185
8.6.2.1	<i>Pythiogeton</i> — 186
8.6.2.2	<i>Pythium</i> , <i>Lagenidium</i> and <i>Phytophytium</i> — 186
8.6.3	Clade 3: Peronosporales — 187
8.6.3.1	Downy mildews — 188
8.6.3.2	<i>Phytophthora</i> and <i>Peronophythora</i> — 188
8.6.3.3	<i>Halophytophthora</i> and <i>Salisaplia</i> — 190
8.7	Conclusions and future perspectives — 192
	Acknowledgments — 194
	References — 194

Biodiversity of freshwater fungi — 201

Sally L. Glockling, Wyth L. Marshall, Rodolphe E. Gozlan, Agostina
V. Marano, Osu Lilje and Frank H. Gleason

**9 The ecological and economic importance of zoosporic Mesomycetozoan
(Dermocystida) parasites of freshwater fish — 203**

9.1	Phylogeny — 203
9.2	Life cycles — 205
9.3	The zoospore — 206
9.4	Symptoms of disease — 207
9.5	Ecological and economic significance — 209
9.6	Discussion and conclusion — 211
	Acknowledgment — 212
	References — 212

Mohammad N. Sarowar, Marcia Saraiva, Casey N. Jessop,
Osu Lilje, Frank H. Gleason and Pieter van West

- 10 Infection strategies of pathogenic oomycetes in fish — 217**
- 10.1 Introduction — 217
 - 10.2 Taxonomy of oomycetes pathogenic to fish — 221
 - 10.3 Physical adaptation and strategy for infection:
macroscopic infection, the face of infection on hosts — 223
 - 10.4 Oomycete zoospores, the first line of attack — 224
 - 10.5 Triggers for zoospore formation, waking up the beast — 225
 - 10.6 Encystment and germination, one step closer to infection — 225
 - 10.7 Repeated zoospore emergence, the back-up plan — 227
 - 10.8 Chemotactic response of zoospores, the specialization — 228
 - 10.9 Proteins and amino acids as substrates for growth — 229
 - 10.10 Sexual reproduction, seeing through the bad times — 231
 - 10.11 Molecular adaptation and strategy in setting infection:
microscopic infection — 231
 - 10.12 Host responses to oomycete infections — 233
 - 10.13 The animal trade is responsible for the spread of pathogens into novel
and wild ecosystems — 234
 - 10.14 Future perspectives — 235
 - Acknowledgments — 236
 - References — 236

Frank H. Gleason, Jodi L. Rowley, Casey N. Jessop and Osu Lilje

- 11 Zoosporic parasites of amphibians — 245**
- 11.1 Chytridiomycota — 245
 - 11.2 Mesomycetozoea — 247
 - 11.3 Oomycota (oomycetes or water moulds) — 250
 - 11.4 Perkinsozoa — 251
 - 11.5 The Fisher concept of emerging infectious diseases (EIDs) — 252
 - 11.6 Host switching by parasites — 252
 - 11.7 Genetic variation in parasite populations — 254
 - 11.8 Proteases — 255
 - 11.9 International animal trade — 255
 - 11.10 Discussion and conclusion — 256
 - Acknowledgments — 257
 - References — 257

Angkana Chaiprasert and Theerapong Krajaejun

- 12 Pythiosis — 263**
- 12.1 History — 263
 - 12.2 Biology — 263
 - 12.3 Molecular typing — 265

12.4	Epidemiology — 266
12.5	Pathogenesis — 266
12.6	Clinical features — 267
12.6.1	Human pythiosis — 267
12.6.2	Animal pythiosis — 269
12.7	Diagnosis — 269
12.8	Management — 271
12.9	Research direction — 272
	Acknowledgment — 273
	References — 274

Frank H. Gleason, Sergey A. Karpov, Osu Lilje, Deborah J. Macarthur, Floris F. van Otgen and Telesphore Sime-Ngando

13 Zoosporic parasites of phytoplankton — 279

13.1	The main groups of zoosporic parasites and parasitoids of phytoplankton — 280
13.1.1	Aphelidea — 280
13.1.2	Chytridiomycota — 283
13.1.3	Blastocladiomycota — 293
13.2 ^a	Ancient interactions — 294
13.3	Novel food webs — 295
13.3.1	<i>Vorticella</i> communities attached to cyanobacterial filaments — 295
13.3.2	Communities involving other protists — 295
13.4	Host parasite dynamics — 296
13.5	Conclusion — 298
	Acknowlegments — 299
	References — 300

Sally L. Glockling, Agostina V. Marano, Osu Lilje and Frank H. Gleason

14 Zoosporic parasites of freshwater invertebrates — 305

14.1	Parasites in the Blastocladiomycota and Chytridiomycota — 306
14.2	Parasites in the Oomycota — 307
14.3	Parasites in the Mesomycetozoea — 311
14.4	Parasites of crayfish — 312
14.4.1	Crayfish plague — 312
14.4.2	<i>Psorospermium haekeli</i> — 313
14.5	Parasites of mosquitoes, blackflies and midges — 313
14.5.1	<i>Coelomomyces</i> — 314
14.5.2	<i>Lagenidium giganteum</i> — 315
14.5.3	<i>Pythium</i> — 316
14.5.4	<i>Leptolegnia</i> — 316
14.5.5	<i>Crypticola</i> — 316
14.5.6	<i>Amoebidium</i> and <i>Paramoebidium</i> — 317

14.6	Parasites of <i>Daphnia</i> — 317
14.7	Parasites of rotifers and nematodes — 318
14.7.1	<i>Sommerstorffia spinosa</i> — 320
14.7.2	<i>Aquastella</i> — 321
14.8	Parasites of protozoans — 321
14.9	Discussion — 321
	Acknowledgments — 324
	References — 324

Ecology — 331

Holger Thüs, André Aptroot and Mark R. D. Seaward

15	Freshwater lichens — 333
----	---------------------------------

15.1	Ecology — 336
15.1.1	Habitats and diversity of freshwater lichens — 336
15.1.2	Collecting and identifying freshwater lichens — 338
15.2	Physiological challenges for freshwater lichens — 339
15.2.1	Water saturation and diffusion resistance — 339
15.3	Freshwater lichens as a food source for other organisms — 343
15.4	Biogeography of freshwater lichens — 344
15.5	Zonation — 345
15.6	Lichen trimlines — 348
15.7	Freshwater lichen communities — 349
15.8	Freshwater lichens as bioindicators — 350
15.9	Water quality — 351
15.10	Conservation — 352
	Acknowledgments — 353
	References — 353

Robert W. Lichtwardt

16	Aquatic Trichomycetes — 359
----	------------------------------------

16.1	Trichomycetes, an ecological group — 359
16.2	Phylogenetic considerations — 359
16.3	Distribution and success of Trichomycetes — 364
16.4	Variations in symbiotic associations — 365
16.5	Medical implications — 367
	Acknowledgments — 368
	References — 368

Umpava Pinruan, Aom Pinnoi, Kevin D. Hyde and E. B. Gareth Jones

17	Tropical peat swamp fungi with special reference to palms — 371
----	--

17.1	Material and methods — 373
17.1.1	Sample collection — 373
17.2	Results — 373
17.2.1	Abundance of fungi on four palms (<i>Eleiodoxa conferta</i> , <i>Licuala longicalycata</i> , <i>Metroxylon sagu</i> and <i>Nenga pumila</i>) — 373

17.2.1.1	<i>Eleiodoxa conferta</i> — 379
17.2.1.2	<i>Licuala longicalycata</i> — 380
17.2.1.3	<i>Metroxylon sagu</i> — 380
17.2.1.4	<i>Nenga pumila</i> — 380
17.2.2	Fungal diversity — 381
17.2.3	Percentages overlap in fungal diversity between the four palms — 382
17.3	Conclusion — 383
	Acknowledgments — 385
	References — 386

Verónica Ferreira, Vladislav Gulis, Cláudia Pascoal and Manuel A. S. Graça

18 Stream pollution and fungi — 389

18.1	The importance of aquatic hyphomycetes in woodland streams — 389
18.2	Effects of nutrient enrichment on stream fungi — 391
18.3	Effects of heavy metals and acidification on stream fungi — 394
18.4	Ecological and toxicological effects of engineered nanoparticles on stream fungi — 395
18.5	Effects of organic xenobiotics on stream fungi — 397
18.6	Effects of thermal pollution on stream fungi — 398
18.7	Effects of the interaction among factors on stream fungi — 403
18.8	Conclusions — 404
	Acknowledgments — 404
	References — 405

Felix Bärlocher and Kandikere R. Sridhar

19 Association of animals and fungi in leaf decomposition — 413

19.1	History — 413
19.2	Effects of the leaf-fungus complex on invertebrate consumers — 416
19.2.1	Nutritional value of mycelium vs. leaf substrate — 416
19.2.2	Modifications of leaf substrate — 417
19.2.3	Do invertebrates differ in their feeding strategies? — 420
19.2.4	What factors ultimately determine food choice and feeding selectivity? — 421
19.2.5	Stoichiometric considerations — 423
19.2.6	Stimulation of fungi by invertebrate feeding — 424
19.2.7	Anthropogenic changes — 424
19.2.8	Research outside temperate regions — 426
19.3	Effects of invertebrate consumers on the leaf-fungus complex — 428
19.3.1	Invertebrate ingestion of conidia — 429
19.3.2	Invertebrate ingestion of the leaf-fungus complex — 429
19.4	Conclusions — 431
	Acknowledgments — 432
	References — 432

Diego Libkind, Gabriel Russo and María Rosa van Broock

**20 Yeasts from extreme aquatic environments: hyperacidic
freshwaters — 443**

- 20.1 Introduction — 443
- 20.2 The River Agrio-Lake Caviahue acidic aquatic system — 444
- 20.2.1 Yeast occurrence — 445
- 20.2.2 Yeast diversity — 446
- 20.3 Comparative yeast diversity study between RAC and the acidic environments of the Iberian Pyrite Belt (IPB) — 451
- 20.4 Acidic rock drainage (ARD) yeasts ecoclade — 454
- 20.5 Physiological aspects of acidophilic yeasts — 456
- 20.6 Possible ecological roles of yeasts in acidic aquatic environments — 457
- 20.7 Final remarks — 458
- Acknowledgments — 459
- References — 460

Nattawut Boonyuen, Somsak Sivichai and E. B. Gareth Jones

21 Decomposition of wood in tropical habitats — 465

- 21.1 Review of fungal diversity on wood in freshwater streams — 466
- 21.2 Colonization of 15 timbers exposed at two locations in Thailand — 467
- 21.2.1 Materials and methods — 467
- 21.2.2 Results — 468
- 21.2.3 Rate of decay of selected timbers at two contrasting freshwater ecosystems in Thailand — 472
- 21.2.4 Discussion — 473
- 21.2.4.1 Fungal community — 473
- 21.2.4.2 Decay of wood in freshwater habitats — 474
- Acknowledgments — 476
- References — 477

Ka-Lai Pang, Kevin D. Hyde and E. B. Gareth Jones

22 Epilogue — 481

- 22.1 Introduction — 481
- 22.2 Freshwater fungi — 481
- 22.3 Freshwater fungus-like organisms — 482
- 22.4 Knowledge gaps and future work in freshwater mycology — 482
- 22.5 Conclusions — 486
- References — 486

Index — 489