

CONTENTS

<i>Preface</i>	<i>page ix</i>		
Part I Nature and origins of fungi	1		
1 21st century fungal communities	3		
1.1 What and where are fungi?	4		
1.2 Soil, the essential terrestrial habitat	5		
1.3 How much soil is there and where is it?	5		
1.4 The nature of soil and who made it	5		
1.5 Soil biota are extremely varied and numerous	7		
1.6 Microbial diversity in soil	7		
1.7 Microbial diversity in general	8		
1.8 Geomycology	9		
1.9 The origins of agriculture and our dependence on fungi	10		
1.10 References and further reading	15		
2 Evolutionary origins	18		
2.1 Life, the universe and everything	19		
2.2 Planet Earth: your habitat	21		
2.3 The Goldilocks planet	21		
2.4 The tree of life has three domains	23		
2.5 The Kingdom Fungi	29		
2.6 The opisthokonts	30		
2.7 Fossil fungi	31		
2.8 The fungal phylogeny	35		
2.9 References and further reading	38		
3 Natural classification of fungi	41		
3.1 The members of the Kingdom Fungi	42		
3.2 The chytrids	42		
3.3 More chytrids: the Neocallimastigomycota	45		
3.4 Blastocladiomycota	46		
3.5 Glomeromycota	50		
3.6 The traditional Zygomycota	52		
3.7 Ascomycota	55		
3.8 Basidiomycota	61		
3.9 The species concept in fungi	71		
3.10 The untrue fungi	75		
		3.11 Ecosystem mycology	77
		3.12 References and further reading	79
		Part II Fungal cell biology	83
		4 Hyphal cell biology and growth on solid substrates	85
		4.1 Mycelium: the hyphal mode of growth	86
		4.2 Spore germination and dormancy	86
		4.3 The fungal lifestyle: colony formation	86
		4.4 Mycelium growth kinetics	88
		4.5 Colony growth to maturity	91
		4.6 Morphological differentiation of fungal colonies	92
		4.7 Duplication cycle in moulds	92
		4.8 Regulation of nuclear migration	93
		4.9 Growth kinetics	94
		4.10 Autotrophic reactions	96
		4.11 Hyphal branching	97
		4.12 Septation	99
		4.13 Ecological advantage of mycelial growth in colonising solid substrates	100
		4.14 References and further reading	101
		5 Fungal cell biology	104
		5.1 Mechanisms of mycelial growth	105
		5.2 The fungus as a model eukaryote	105
		5.3 The essentials of cell structure	107
		5.4 Subcellular components of eukaryotic cells: the nucleus	108
		5.5 The nucleolus and nuclear import and export	112
		5.6 Nuclear genetics	114
		5.7 Mitotic nuclear division	115
		5.8 Meiotic nuclear division	117
		5.9 Translation of mRNA and protein sorting	118
		5.10 The endomembrane systems	121
		5.11 Cytoskeletal systems	125
		5.12 Molecular motors	127
		5.13 Plasma membrane and signalling pathways	133
		5.14 Fungal cell wall	136

5.15	Cell biology of the hyphal apex	137	9.4	<i>Aspergillus</i> conidiophores	220
5.16	Hyphal fusions and mycelial interconnections	142	9.5	Conidiation in <i>Neurospora crassa</i>	223
5.17	Cytokinesis and septation	144	9.6	Conidiomata	223
5.18	Yeast–mycelial dimorphism	150	9.7	Linear structures: strands, cords, rhizomorphs and stipes	225
5.19	References and further reading	151	9.8	Globose structures: sclerotia, stromata, ascomata and basidiomata	227
	6 Structure and synthesis of fungal cell walls	156	9.9	References and further reading	231
6.1	The fungal wall as a working organelle	157			
6.2	Fundamentals of wall structure and function	157	Part IV Biochemistry and developmental biology of fungi		235
6.3	Fundamentals of wall architecture	160	10 Fungi in ecosystems		237
6.4	The chitin component	160	10.1	Contributions of fungi to ecosystems	238
6.5	The glucan component	162	10.2	Breakdown of polysaccharide: cellulose	239
6.6	The glycoprotein component	163	10.3	Breakdown of polysaccharide: hemicellulose	240
6.7	Wall synthesis and remodelling	165	10.4	Breakdown of polysaccharide: pectins	241
6.8	On the far side	168	10.5	Breakdown of polysaccharide: chitin	241
6.9	The fungal wall as a clinical target	171	10.6	Breakdown of polysaccharide: starch and glycogen	241
6.10	References and further reading	172	10.7	Lignin degradation	242
	Part III Fungal genetics and diversity	177	10.8	Digestion of protein	246
	7 From the haploid to the functional diploid: homokaryons, heterokaryons, dikaryons and compatibility	179	10.9	Lipases and esterases	247
7.1	Compatibility and the individualistic mycelium	180	10.10	Phosphatases and sulfatases	247
7.2	Formation of heterokaryons	181	10.11	The flow of nutrients: transport and translocation	247
7.3	Breakdown of a heterokaryon	183	10.12	Primary (intermediary) metabolism	251
7.4	The dikaryon	183	10.13	Secondary metabolites, including commercial products like statins and strobilurins	257
7.5	Vegetative compatibility	185	10.14	References and further reading	264
7.6	Biology of incompatibility systems	188			
7.7	Gene segregation during the mitotic division cycle	189	11 Exploiting fungi for food		266
7.8	Parasexual cycle	194	11.1	Fungi as food	267
7.9	Cytoplasmic segregations: mitochondria, plasmids, viruses and prions	194	11.2	Fungi in food webs	267
7.10	References and further reading	197	11.3	Wild harvests: commercial mushroom picking	272
	8 Sexual reproduction: the basis of diversity and taxonomy	198	11.4	Cells and mycelium as human food	274
8.1	The process of sexual reproduction	199	11.5	Fermented foods	274
8.2	Mating in budding yeast	200	11.6	Industrial cultivation methods	275
8.3	Mating type switching in budding yeast	201	11.7	Gardening insects and fungi	279
8.4	Mating types of <i>Neurospora</i>	203	11.8	Development of a fungal fruit body	280
8.5	Mating types in Basidiomycota	205	11.9	References and further reading	280
8.6	Biology of mating type factors	210			
8.7	References and further reading	211	12 Development and morphogenesis		282
	9 Continuing the diversity theme: cell and tissue differentiation	213	12.1	Development and morphogenesis	283
9.1	What is diversity?	214	12.2	The formal terminology of developmental biology	283
9.2	Mycelial differentiation	214	12.3	The observational and experimental basis of fungal developmental biology	285
9.3	Making spores	216	12.4	Ten ways to make a mushroom	286
			12.5	Competence and regional patterning	289

12.6	The <i>Coprinopsis</i> fruit body: making hymenia	291	14 Fungi as pathogens of plants	367
12.7	<i>Coprinopsis</i> and <i>Volvariella</i> making gills (not forgetting how polypores make tubes)	295	14.1 Fungal diseases and loss of world agricultural production	368
12.8	The <i>Coprinopsis</i> fruit body: making stems	301	14.2 A few examples of headline crop diseases	370
12.9	Coordination of cell inflation throughout the maturing fruit body	304	14.3 The rice blast fungus <i>Magnaporthe grisea</i> (Ascomycota)	370
12.10	Mushroom mechanics	305	14.4 <i>Armillaria</i> (Basidiomycota)	370
12.11	Metabolic regulation in relation to morphogenesis	305	14.5 Pathogens that produce haustoria (Ascomycota and Basidiomycota)	371
12.12	Developmental commitment	308	14.6 <i>Cercospora</i> (Ascomycota)	372
12.13	Comparisons with other tissues and other organisms	310	14.7 <i>Ophiostoma</i> (<i>Ceratocystis</i>) <i>novo-ulmi</i> (Dutch elm disease or DED) (Ascomycota)	372
12.14	Classic genetic approaches to study development and the impact of genomic data mining	311	14.8 Black stem rust (<i>Puccinia graminis</i> f. sp. <i>tritici</i>) threatens global wheat harvest	373
12.15	Degeneration, senescence and death	315	14.9 Plant disease basics: the disease triangle	374
12.16	Basic principles of fungal developmental biology	316	14.10 Necrotrophic and biotrophic pathogens of plants	376
12.17	References and further reading	316	14.11 The effects of pathogens on their hosts	376
Part V Fungi as saprotrophs, symbionts and pathogens		323	14.12 How pathogens attack plants	379
13 Ecosystem mycology: saprotrophs, and mutualisms between plants and fungi		325	14.13 Host penetration through stomatal openings	379
13.1	Ecosystem mycology	326	14.14 Direct penetration of the host cell wall	382
13.2	Fungi as recyclers and saprotrophs	326	14.15 Enzymatic penetration of the host	382
13.3	Make the earth move	328	14.16 Preformed and induced defence mechanisms in plants	385
13.4	Fungal toxins: food contamination and deterioration (including mention of statins and strobilurins)	328	14.17 Genetic variation in pathogens and their hosts: co-evolution of disease systems	387
13.5	Decay of structural timber in dwellings	331	14.18 References and further reading	389
13.6	Using fungi to remediate toxic and recalcitrant wastes	334	15 Fungi as symbionts and predators of animals	392
13.7	Release of chlorohydrocarbons into the atmosphere by wood-decay fungi	336	15.1 Fungal co-operative ventures	393
13.8	Introduction to mycorrhizas	336	15.2 Ant agriculture	393
13.9	Types of mycorrhiza	337	15.3 Termite gardeners of Africa	398
13.10	Arbuscular (AM) endomycorrhizas	338	15.4 Agriculture in beetles	399
13.11	Ericoid endomycorrhizas	341	15.5 Anaerobic fungi and the rise of the ruminants	400
13.12	Arbutoid endomycorrhizas	343	15.6 Nematode-trapping fungi	405
13.13	Monotropoid endomycorrhizas	343	15.7 References and further reading	408
13.14	Orchidaceous endomycorrhizas	344	16 Fungi as pathogens of animals, including humans	411
13.15	Ectomycorrhizas	346	16.1 Pathogens of insects	412
13.16	Ectendomycorrhizas	351	16.2 Microsporidia	412
13.17	The effects of mycorrhizas and their commercial applications and the impact of environmental and climate changes	351	16.3 Trichomycetes	414
13.18	Introduction to lichens	356	16.4 Laboulbeniales	416
13.19	Introduction to endophytes	360	16.5 Entomogenous fungi	417
13.20	Epiphytes	361	16.6 Biological control of arthropod pests	421
13.21	References and further reading	361	16.7 Cutaneous chytridiomycosis: an emerging infectious disease of amphibians	422
			16.8 Aspergillosis disease of coral	424
			16.9 Mycoses: the fungus diseases of humans	424
			16.10 Clinical groupings for human fungal infections	426

16.11 Fungi within the home and their effects on health: allergens and toxins	432	18 Molecular biotechnology	511
16.12 Comparison of animal and plant pathogens and the essentials of epidemiology	436	18.1 Antifungal agents that target the membrane	512
16.13 Mycoparasitic and fungicolous fungi	439	18.2 Antifungal agents that target the wall	521
16.14 References and further reading	444	18.3 Clinical control of systemic mycoses at the start of the 21st century: azoles, polyenes and combinatorial therapy	522
Part VI Fungal biotechnology and bioinformatics	449	18.4 Agricultural mycocides at the start of the twenty-first century: strobilurins	526
17 Whole organism biotechnology	451	18.5 Understanding fungal genetic structure	529
17.1 Fungal fermentations in submerged liquid cultures	452	18.6 Sequencing fungal genomes	531
17.2 Culturing fungi	452	18.7 Annotating the genome	535
17.3 Oxygen demand and supply	456	18.8 Fungal genomes and their comparison	540
17.4 Fermenter engineering	458	18.9 Manipulating genomes: targeted gene disruption, transformation and vectors	547
17.5 Fungal growth in liquid cultures	460	18.10 Fungi as cell factories producing heterologous proteins	552
17.6 Fermenter growth kinetics	462	18.11 Recombinant protein production by filamentous fungi	554
17.7 Growth yield	464	18.12 Bioinformatics in mycology: manipulating very large data sets	557
17.8 Stationary phase	465	18.13 Genomic data mining supports the notion that there are different developmental control mechanisms in fungi, animals and plants	560
17.9 Growth as pellets	466	18.14 Effects of climate change on fungi revealed by analysis of large survey data sets	562
17.10 Beyond the batch culture	469	18.15 Cyber fungi: mathematical modelling and computer simulation of hyphal growth	563
17.11 Chemostats and turbidostats	470	18.16 References and further reading	567
17.12 Uses of submerged fermentations	473	Part VII Appendices	573
17.13 Alcoholic fermentations	474	Appendix 1 Outline classification of fungi	575
17.14 Citric acid biotechnology	477	Appendix 2 Mycelial and hyphal differentiation	589
17.15 Penicillin and other pharmaceuticals	478	Index	605
17.16 Enzymes for fabric conditioning and processing, and food processing	483	<i>Plate sections: Section 1 between pages 148 and 149</i>	
17.17 Steroids and use of fungi to make chemical transformations	486	<i>Section 2 between pages 340 and 341</i>	
17.18 The Quorn™ fermentation and evolution in fermenters	487		
17.19 Production of spores and other inocula	492		
17.20 Natural digestive fermentations in herbivores	493		
17.21 Solid state fermentations	494		
17.22 Digestion of lignocellulosic residues	497		
17.23 Bread: the other side of the alcoholic fermentation equation	499		
17.24 Cheese and salami manufacture	501		
17.25 Soy sauce, tempeh and other food products	504		
17.26 References and further reading	506		