

Contents

1	Introduction	1
2	The Abiotic Frame and Adaptations to Cope with Abiotic Constraints	7
2.1	Introduction	7
2.2	The hydrological cycle	8
2.3	Lake formation	9
2.3.1	<i>Lake basin morphology—and our perception thereof</i>	11
2.3.1.1	Lake zones	12
2.4	Wind and turbulence	13
2.4.1	<i>Positive effects of turbulence</i>	15
2.5	Light	16
2.5.1	<i>Photosynthesis</i>	17
2.5.1.1	Adaptations to optimize light acquisition	18
2.6	Temperature	20
2.6.1	<i>Temperature basics</i>	20
2.6.1.1	The water molecule	20
2.6.1.2	Distribution of heat—temporal and spatial patterns	21
2.6.1.3	Stratification and circulation	22
2.6.2	<i>Adaptations to fluctuations in temperature</i>	25
2.6.2.1	Acclimatization	26
2.6.2.2	Resting stages	27
2.6.2.3	Temperature-induced hatching	28
2.6.2.4	Behavioural thermoregulation	28
2.6.3	<i>Interactions between temperature and other factors</i>	30
2.7	Oxygen	30
2.7.1	<i>Factors affecting the oxygen concentration</i>	30
2.7.1.1	Estimating oxygen production and consumption	31
2.7.2	<i>Spatial and temporal patterns in oxygen availability</i>	31
2.7.2.1	Seasonal stratification	31
2.7.2.2	Oxygen fluctuations in shallow waters	32

2.7.3	<i>Morphological adaptations to obtain oxygen</i>	33
2.7.3.1	Oxygen dissolved in water	33
2.7.3.2	Oxygen from air	35
2.7.4	<i>Oxygen transport in plants</i>	36
2.7.5	<i>Physiological and behavioural adaptations to low oxygen availability</i>	37
2.8	<i>Lakes in their catchment</i>	38
2.8.1	<i>The catchment area</i>	38
2.8.1.1	Water colour	39
2.9	<i>Carbon</i>	41
2.9.1	<i>Lakes and ponds in the global carbon cycle</i>	41
2.9.2	<i>Adaptations to obtain carbon</i>	43
2.9.2.1	Mixotrophy	44
2.9.3	<i>Autotrophic versus heterotrophic systems</i>	45
2.10	<i>pH</i>	46
2.10.1	<i>pH, alkalinity and the carbon dioxide–bicarbonate complex</i>	47
2.11	<i>Nutrients</i>	49
2.11.1	<i>The cycling of nutrients</i>	50
2.11.2	<i>Measuring chemical relations—ecological stoichiometry</i>	50
2.11.2.1	The Redfield ratio	52
2.11.3	<i>Phosphorus</i>	52
2.11.4	<i>Nitrogen</i>	53
2.11.4.1	Nitrogen fixation	54
2.11.4.2	Nitrification and denitrification	55
2.11.5	<i>Micronutrients</i>	55
2.11.6	<i>Limiting nutrients and adaptations to low nutrient availability</i>	56
2.11.6.1	Size	57
2.11.6.2	Luxury uptake	58
2.11.6.3	Occupying a nutrient-rich habitat—the sediment surface	58
2.11.6.4	Remineralization of nutrients: effects of redox potential and pH	58
2.11.7	<i>Bioturbation</i>	60
2.12	<i>Habitat permanence</i>	62
2.12.1	<i>Characteristics of temporary ponds</i>	63
2.12.2	<i>Adaptations</i>	64
2.12.2.1	Adaptations among permanent residents	64
2.12.2.2	Adaptations among temporary residents	64
2.12.2.3	Dispersal modes	66

3	The Organisms: The Actors Within the Abiotic Frame	69
3.1	Introduction	69
3.2	Viruses	72
3.3	Prokaryotic organisms	73
3.3.1	<i>Bacteria</i>	73
3.4	Eukaryotic organisms	74
3.4.1	<i>Fungi</i>	74
3.5	Protozoa	74
3.5.1	<i>Amoebae</i>	75
3.5.2	<i>Ciliates</i>	75
3.5.3	<i>Flagellates</i>	76
3.6	Primary producers	76
3.6.1	<i>Macrophytes</i>	76
3.6.2	<i>Algae</i>	78
3.6.2.1	Phytoplankton	79
3.6.3	<i>Adaptations among algae—how to stay afloat</i>	80
3.6.3.1	Density	80
3.6.3.2	Size and shape	81
3.6.3.3	Flagella	81
3.6.4	<i>Adaptations among algae—avoid being eaten</i>	81
3.6.5	<i>Periphytic algae</i>	85
3.7	Metazoa—animals with differentiated cells	87
3.7.1	<i>Freshwater sponges</i>	87
3.7.2	<i>Hydroids</i>	88
3.7.3	<i>Flatworms</i>	89
3.7.4	<i>Worms</i>	89
3.7.4.1	Oligochaetes	89
3.7.5	<i>Leeches</i>	89
3.7.6	<i>Snails</i>	90
3.7.7	<i>Mussels</i>	91
3.7.8	<i>Rotifers</i>	93
3.7.9	<i>Crustaceans</i>	94
3.7.9.1	Crustacean zooplankton	96
3.7.9.2	Mysids	98
3.7.9.3	Isopods	99
3.7.9.4	Amphipods	99
3.7.9.5	Decapod crayfish	99
3.7.10	<i>Insects</i>	100
3.7.10.1	Mayflies	101
3.7.10.2	Damselflies and dragonflies	102

3.7.10.3	Alderflies	103
3.7.10.4	Caddisflies	103
3.7.11	Bugs	104
3.7.11.1	Beetles	104
3.7.11.2	Flies and midges	106
3.7.12	Fish	107
3.7.13	Amphibians	109
3.7.14	Birds	110
4	Biotics: Competition, Herbivory, Predation, Parasitism and Symbiosis	114
4.1	Introduction	114
4.1.1	<i>The niche</i>	115
4.2	Competition	116
4.2.1	<i>Competitive ability</i>	120
4.2.1.1	Size	120
4.2.1.2	'Luxury uptake'	120
4.2.2	<i>Mathematical models of competition</i>	122
4.2.2.1	The Lotka-Volterra model	122
4.2.2.2	The 'two species-two resources model'	124
4.2.2.3	'Paradox of the plankton'	126
4.2.3	<i>Examples of competitive interactions in lakes and ponds</i>	127
4.2.3.1	Periphyton versus phytoplankton: bidirectional resource supply	127
4.2.3.2	Depth distribution of macrophytes	128
4.2.3.3	Snails and tadpoles	131
4.2.3.4	Intra- and interspecific competition in fish	132
4.2.4	<i>Apparent competition</i>	134
4.3	Predation and herbivory	136
4.3.1	<i>Principles of predation and herbivory</i>	136
4.3.2	<i>The predation cycle</i>	137
4.3.3	<i>Feeding modes of herbivores</i>	138
4.3.3.1	Filter-feeding	138
4.3.3.2	Surface-feeding	138
4.3.3.3	Raptorial feeding	139
4.3.4	<i>Grazing on aquatic macrophytes</i>	139
4.3.5	<i>Feeding modes of predators</i>	140
4.3.6	<i>Adaptations for prey detection</i>	140
4.3.7	<i>Morphological adaptations for foraging</i>	142
4.3.8	<i>Selective feeding</i>	143
4.3.8.1	Measurements of selective feeding—stable isotopes and gut content	143
4.3.8.2	Optimal diet choice	146
4.3.8.3	Patch use	147
4.3.8.4	Trade-offs—foraging or avoiding predators?	148

4.3.9	<i>Functional response of consumers</i>	149
4.3.10	<i>Consumption rate of small organisms</i>	151
4.3.11	<i>Defence</i>	152
4.3.12	<i>Primary defences</i>	153
4.3.12.1	<i>Avoiding encounters</i>	153
4.3.12.2	<i>Spatial refugia</i>	154
4.3.12.3	<i>Temporal refugia</i>	155
4.3.13	<i>Secondary defences</i>	160
4.3.14	<i>Consumer resistance among smaller organisms</i>	162
4.3.14.1	<i>Chemical warfare—the cyanobacteria versus Daphnia arms race</i>	163
4.3.15	<i>Constitutive or inducible defences?</i>	164
4.3.16	<i>Costs of defences</i>	167
4.3.17	<i>Inducible offences</i>	168
4.3.18	<i>Consumptive versus non-consumptive effects</i>	169
4.4	<i>Parasitism</i>	169
4.4.1	<i>Parasites causing biodiversity loss and 'zombification'</i>	171
4.4.2	<i>Impact of freshwater parasites on humans</i>	173
4.4.3	<i>Epibionts</i>	175
4.5	<i>Symbiosis</i>	175
5	Food Web Interactions in Freshwater Ecosystems	180
5.1	<i>Introduction</i>	180
5.2	<i>The evolution of an ecosystem approach</i>	181
5.2.1	<i>The theoretical take-off</i>	182
5.2.2	<i>The empirical beginning</i>	183
5.3	<i>Cascading trophic interactions</i>	183
5.3.1	<i>Experimental illustrations of trophic cascades</i>	185
5.3.1.1	<i>Small-scale experiments</i>	185
5.3.1.2	<i>Large-scale experiments</i>	186
5.3.1.3	<i>Natural experiments on trophic cascades</i>	187
5.3.2	<i>'Bottom-up/top-down' theory</i>	187
5.3.3	<i>Further theoretical developments</i>	188
5.3.3.1	<i>Alternation between competition and predation along productivity gradients</i>	190
5.3.4	<i>Complex interactions in benthic food chains</i>	193
5.3.4.1	<i>Direct and indirect effects of benthic omnivores</i>	193
5.3.5	<i>Trait-mediated indirect effects</i>	195
5.4	<i>Alternative stable states</i>	196
5.4.1	<i>Alternative states in shallow, eutrophic lakes</i>	198
5.4.2	<i>What causes the transitions?</i>	199
5.4.3	<i>The marble-in-a-cup model</i>	200
5.5	<i>Microbial components</i>	201

5.5.1	<i>The microbial loop</i>	201
5.5.2	<i>Interactions among microbial components</i>	203
5.5.3	<i>Regeneration of nutrients</i>	204
5.5.3.1	<i>Bacteria</i>	204
5.5.3.2	<i>Consumer release of nutrients—indirect 'bottom-up' effects</i>	205
5.6	<i>Interaction strength in freshwater food chains</i>	205
5.6.1	<i>Do trophic levels exist?</i>	206
5.6.2	<i>Predator identity and multiple predators</i>	209
5.6.3	<i>Omnivory</i>	211
5.6.4	<i>Ontogenetic niche shifts and size-structured populations</i>	213
5.6.4.1	<i>Examples of ontogenetic niche shifts</i>	213
5.6.5	<i>Subsidized consumers and food chain coupling</i>	215
5.6.5.1	<i>Land to water subsidies</i>	215
5.6.5.2	<i>Marine to freshwater subsidies</i>	216
5.6.5.3	<i>Water to land subsidies</i>	216
5.6.5.4	<i>Within lake subsidies</i>	217
5.6.6	<i>Defence adaptations against consumers</i>	219
5.6.6.1	<i>Algae</i>	219
5.6.6.2	<i>Grazer-resistant bacteria</i>	219
5.6.6.3	<i>Gape-limited predatory fish</i>	221
5.6.7	<i>Structural complexity</i>	222
5.7	<i>Succession</i>	222
5.7.1	<i>Factors behind algal succession patterns</i>	223
5.7.1.1	<i>The PEG model</i>	224
5.7.2	<i>Relative strength of factors behind succession patterns</i>	225
5.8	<i>Impact of organisms on the abiotic frame</i>	225
5.8.1	<i>Effects of organisms on the water temperature</i>	227
5.8.2	<i>Organism interactions affecting carbon input from the atmosphere</i>	227
5.9	<i>Eco-evolutionary dynamics</i>	228
6	Biodiversity and Environmental Threats	232
6.1	<i>Introduction</i>	232
6.2	<i>Biodiversity in lakes and ponds</i>	233
6.2.1	<i>Definition</i>	233
6.2.2	<i>Measures of biodiversity</i>	234
6.2.3	<i>What determines biodiversity in ponds and lakes?</i>	235
6.2.4	<i>Patterns in biodiversity</i>	240
6.2.4.1	<i>Latitudinal gradients</i>	240
6.2.5	<i>Biodiversity versus productivity</i>	240
6.2.6	<i>Biodiversity and ecosystem function</i>	242
6.2.7	<i>Restoration—to what?</i>	245
6.3	<i>Paleolimnology as a tool to understand history</i>	245

6.4	Eutrophication	247
6.4.1	<i>The eutrophication process</i>	248
6.4.1.1	Phosphorus reduction	249
6.4.2	<i>Lake restoration</i>	249
6.4.2.1	Dredging	249
6.4.2.2	The 'Riplox method'	250
6.4.2.3	Biomanipulation	250
6.4.2.4	Wetlands as nutrient traps	251
6.5	Acidification	251
6.5.1	<i>Effects of acid rain in freshwaters</i>	252
6.5.1.1	Changes in community composition due to reduced pH	252
6.5.1.2	Mechanisms behind changes in community structure	254
6.5.2	<i>Actions against acidification</i>	254
6.5.2.1	Reduced emissions	254
6.5.2.2	Liming	256
6.6	Contamination	256
6.6.1	Heavy metals	257
6.6.2	Organochlorines	257
6.6.3	Endocrine disruptors and pharmaceutical drugs	259
6.6.4	Micro-plastics	260
6.6.5	The nano-scale threat	260
6.7	Global climate change	261
6.7.1	Physical effects of global warming	261
6.7.2	Global warming effects on organism distributions	262
6.7.3	Global warming effects on organism interactions	263
6.7.3.1	Food web composition modulates global warming effects	264
6.7.3.2	Match/mismatch scenarios	264
6.7.3.3	Global warming affects the rate of invasions and diseases	265
6.8	Brownification	266
6.8.1	CO ₂ and acidification	267
6.9	Solar ultraviolet radiation	267
6.10	Combined effects of environmental hazards	269
6.11	Environmental change and rapid evolution	270
6.12	Invasive species	272
6.12.1	<i>Freshwater weeds</i>	275
6.12.1.1	Control methods for freshwater weeds	276
6.12.2	<i>The zebra mussel</i>	277
6.12.3	<i>The golden apple snail</i>	279
6.12.4	<i>Nile perch</i>	281
6.12.4.1	Secondary effects of Nile perch introduction	283
6.13	Genetically modified organisms	284

6.14	Global differentiation	284
6.15	Actions taken against environmental threats	286
6.15.1	<i>Light in the tunnel—ecosystem adaptations and international agreements?</i>	287
	Glossary	289
	Further Reading	295
	References	299
	Index	323