

Fourth Edition

ECOLOGY OF FRESHWATERS

A VIEW FOR THE TWENTY-FIRST
CENTURY

Brian Moss

Emeritus Professor, University of Liverpool, UK

©WILEY-BLACKWELL

A John Wiley & Sons, Ltd., Publication

CONTENTS

1 INTRODUCTION, 1

1.1 Why?. 1

Further reading. 8

2 WATER, A REMARKABLE UNREMARKABLE SUBSTANCE, 10

2.1 Introduction. 10

2.2 The molecular properties of water and their physical consequences. 12

2.2.1 Ice and melting. 12

2.2.2 Buffering and evaporation. 13

2.3 How much water is there and where is it?. 13

2.3.1 Turnover and the hydrological cycle. 13

2.3.2 Changes in geological time. 14

2.4 Patterns in hydrology. 15

2.4.1 Temperate regions. 15

2.4.2 Warm-temperate regions. 16

2.4.3 Tropical cycles. 17

2.5 Bodies of water and their temperatures. 18

2.5.1 Lakes and latitude. 18

2.5.2 Deeper lakes. 21

2.5.3 Effects of altitude and oceanicity. 21

2.6 Viscosity of water, fluid dynamics and the diffusion of gases. 22

2.6.1 Diffusion. 24

Further reading. 24

3 WHY THE CHEMISTRY OF WATER IS SO IMPORTANT, 25

3.1 Introduction. 25

3.1.1 Polar and covalent compounds. 25

3.2 The atmosphere. 26

3.2.1 Carbon dioxide. 27

3.3 Major ions. 28

3.3.1 Effects of ionic potential. 28

3.4 Global patterns in major ions: glaciation and endorheism. 30

3.4.1 The water chemistry of ancient landscapes. 31

3.4.2 Volcanic activity. 32

3.5 Open and closed basins. 34

3.6 The big picture. 35

Further reading. 36

4 MORE WATER CHEMISTRY: THE KEY NUTRIENTS, TRACE ELEMENTS AND ORGANIC MATTER, 37

4.1 Introduction. 37

4.2 Concepts of limiting substances. 37

4.3 Nutrients. 42

4.4 Phosphorus. 43

4.5 Nitrogen. 43

4.6 Pristine concentrations. 44

4.7 Trace elements and silicon. 45

4.8 Organic substances. 48

4.8.1 Patterns in DOM availability. 48

4.9 Substance budgets. 50

4.10 Sediment-water relationships. 52

Further reading. 53

5 LIGHT THROWN UPON THE WATERS, 54

5.1 Light. 54

5.1.1 Effects of the atmosphere. 55

5.2 From above to under the water. 56

5.3 From physics and chemistry to biology. 60

Further reading. 60

6 EVOLUTION AND DIVERSITY OF FRESHWATER ORGANISMS, 61

6.1 Introduction. 61

6.2 The ecological theatre and the evolutionary play. 62

6.2.1 The seas form. 62

6.2.2 Eukaryotic cells. 62

- 6.3 The freshwater biota, 64
 - 6.3.1 Flow many phyla and where?. 65
 - 6.3.2 Plants, 66
 - 6.3.3 Animals, 67
- 6.4 Living in freshwaters. 68
 - 6.4.1 Osmoregulation. 69
 - 6.4.2 Reproduction. 70
 - 6.4.3 Restingstages and aestivation, 70
 - 6.4.4 Getting enough oxygen. 72
 - 6.4.5 Insects, 73
 - 6.4.6 Big animals, air breathers and swamps. 73
- 6.5 Dispersal among freshwaters, 75
 - 6.5.1 Small things are the same everywhere?, 76
 - 6.5.2 Or are they?, 76
 - 6.5.3 Vulnerability and dispersal in freshwaters, 76
- 6.6 Patterns in freshwater diversity, 78
 - 6.6.1 Fish faunas. 78
- 6.7 The fish of Lake Victoria. 84
- 6.8 Low diversity freshwater habitats. 84
 - 6.8.1 Caves. 85
- 6.9 A summary of the freshwater biota and its problems, 86
- Further reading, 87

7 HEADWATER STREAMS AND RIVERS, 89

- 7.1 Introduction, 89
- 7.2 General models of stream ecosystems. 89
- 7.3 A basic lesson in stream How, 92
- 7.4 Flow and discharge. 92
- 7.5 Laminar and turbulent How, 93
- 7.6 Particles carried. 94
- 7.7 The response of stream organisms to shear stress, 95
- 7.8 Community composition in streams. 96
 - 7.8.1 Algal and plantcommunities, 97
 - 7.8.2 Macroinvertebrates. 98
- 7.9 Streams in cold climates: the polar and alpine zones. 102
 - 7.9.1 Invertebrates of kryal streams, 104
 - 7.9.2 Primary producers. 104
 - 7.9.3 Food webs in cold streams, 105
 - 7.9.4 Fish and birds in polar streams. 107
- 7.10 Stream systems in the cold temperate zone. 109
 - 7.10.1 Allochthonous sources of energy, 111
 - 7.10.2 Shredders, filter-collectors and deposit feeders. 112

- 7.10.3 Stream orders. 113
- 7.10.4 The River Continuum Concept. 113
- 7.10.5 Invertebrates fall in too. 114
- 7.10.6 . . . and emerge, 114
- 7.10.7 Indirectly, wolves are stream animals. 114
- 7.10.8 Scarcity of nutrients. 114
- 7.10.9 Salmon. 115
- 7.11 Warm temperate streams, 117
- 7.12 Desert streams, 119
- 7.13 Tropical streams, 120
- Further reading, 125

8 USES, MISUSES AND RESTORATION OF HEADWATER STREAMS AND RIVERS, 127

- 8.1 Traditional use of headwater river systems. 127
- 8.2 Deforestation. 129
- 8.3 Acidification, 130
- 8.4 Eutrophication. 134
- 8.5 Commercial afforestation. 136
- 8.6 Settlement. 136
- 8.7 Engineering impacts. 138
- 8.8 Alterations of the fish community by man, 139
- 8.9 Sewage, toxic pollution and their treatment. 141
- 8.10 Diffuse pollution. 143
- 8.11 River monitoring, 147
- 8.12 The Water Framework Directive. 148
- 8.13 Implementation of the Directive. 150
- 8.14 Wider considerations: ecosystem services, 151
- 8.15 Restoration, rehabilitation and reconciliation ecology. 151
- 8.16 Reconciliation ecology of river systems. 154
- Further reading. 156

9 MIDDLE STAGE AND DEPOSITIONAL FLOODPLAIN RIVERS, 157

- 9.1 Introduction, 157
- 9.2 Change from an erosive river to a depositional one. 158
- 9.3 Submerged plants, 160
- 9.4 Growth of submerged plants. 162
- 9.5 Methods of measuring the primary productivity of submerged plants. 164.
 - 9.5.1 Whole community methods. 164
 - 9.5.2 Enclosure methods. 165
 - 9.5.3 Other methods, 166
- 9.6 Submerged plants and the river ecosystem, 167

- 9.7 Further downstream-swamps and floodplains. 167
 - 9.7.1 Productivity of swamps and floodplain marshes. 169
 - 9.7.2 Swamp soils and the fate of the high primary production, 170
 - 9.7.3 Oxygen supply and soil chemistry in swamps, 171.
 - 9.7.4 Emergent plants and Hooded soils. 172
- 9.8 Swamp and marsh animals. 173
 - 9.8.1 Whitefish and blacklist!. 174
- 9.9 Latitudinal differences in floodplains, 176
 - 9.9.1 Polarfloodplains. 176
 - 9.9.2 Cold temperate floodplains. 177
 - 9.9.3 Warm temperate floodplains, 179
 - 9.9.4 Tropical floodplains. 180
 - 9.9.5 The Sudd, 183

Further reading, 185

10 FLOODPLAIN ECOSYSTEMS AND HUMAN AFFAIRS, 186

- 10.1 Introduction, 186
- 10.2 Floodplain services, 189
 - 10.2.1 Floodplain fisheries, 192
- 10.3 Floodplain swamps and human diseases. 193
- 10.4 Casestudies. 196
 - 10.4.1 The Florida Everglades. 196
 - 10.4.2 The Pongola river, 200
- 10.5 River and floodplain management and rehabilitation, 204
 - 10.5.1 Plant bed management in rivers. 204
 - 10.5.2 Mitigation and enhancement. 206
 - 10.5.3 Rehabilitation. 209
- 10.6 Interbasin transfers and water needs. 211
 - 10.6.1 Assessment of the water needs, 21.1.

Further reading, 214

11 LAKES AND OTHER STANDING WATERS, 216

- 11.1 Introduction, 216
- 11.2 The origins of lake basins. 217
- 11.3 Lake structure. 219
- 11.4 The importance of the catchment area, 223
- 11.5 Lakes as autotrophic or heterotrophic systems. 224
- 11.6 The continuum of lakes. 227
- 11.7 Lake history, 233
 - 11.7.1 The methods of palaeolimnology, 234

- 11.7.2 Organic remains, 236
- 11.7.3 General problems of interpretation of evidence from sediment cores, 238
- 11.7.4 So what has the history been? Two ancient lakes, 239
 - 11.7.5 Younger lakes, 24.1

11.8 Filling in. 242

11.9 Summing up. 243

Further reading. 244

12 THE COMMUNITIES OF SHALLOW STANDING WATERS: MIRES, SHALLOW LAKES AND THE LITTORAL ZONE, 245

- 12.1 Introduction. 245
- 12.2 The scope of mires and littoral zones. 246
 - 12.2.1 Temperature. 246
 - 12.2.2 Nutrients, 247
 - 12.2.3 Littoral communities in lakes, 250
- 12.3 The structure of littoral communities, 253
- 12.4 Heterotrophs among the plants. 256
 - 12.4.1 Neuston. 260
- 12.5 Linkages, risks and insurances among the littoral communities. 260
- 12.6 Latitude and littorals. 262
- 12.7 The role of the nekton. 262
- 12.8 Further reading. 265

13 PLANKTON COMMUNITIES OF THE PELAGIC ZONE, 267

- 13.1 Kitchens and toilets, 267
- 13.2 Phytoplankton. 268
 - 13.2.1 Photosynthesis and growth of phytoplankton. 271
 - 13.2.2 Net production and growth, 272
 - 13.2.3 Nutrient uptake and growth rates of phytoplankton, 273
 - 13.2.4 Distribution of freshwater phytoplankton, 275
 - 13.2.5 Washout, 275
 - 13.2.6 Cyanobacterial blooms. 276
- 13.3 Heterotrophs in the plankton: viruses and bacteria. 279
- 13.4 Protozoa and fungi. 281
- 13.5 Zooplankton. 283
 - 13.5.1 Grazing. 285
 - 13.5.2 Feeding and grazing rates of zooplankton, 288
 - 13.5.3 Competition among grazers, 288
 - 13.5.4 Predation in the zooplankton, 289

- 13.5.5 Predation on zooplankters by zooplankters, 290
- 13.6 Fish in the open-water community, 293
 - 13.6.1 Predation on the zooplankton and fish production, 293
 - 13.6.2 Avoidance of vertebrate predation by the zooplankton, 296
- 13.7 Piscivores and piscivory, 298
- 13.8 Functioning of the open-water community, 299
 - 13.8.1 Polar lakes, 300
 - 13.8.2 Cold temperate lakes, 301
 - 13.8.3 Warm temperate lakes, 303
 - 13.8.4 Very warm lakes in the tropics, 305
- Further reading, 307

14 THE PROFUNDAL ZONE, 308

- 14.1 The end of the line, 308
- 14.2 The importance of oxygen, 309
- 14.3 Profundal communities, 310
- 14.4 Biology of selected benthic invertebrates, 312
 - 14.4.1 *Chironomus tentaculatus*, a detritivore, 312
 - 14.4.2 *Cluwhorus flavicmis*, a predator, 314
- 14.5 What the sediment-living detritivores really eat, 315
- 14.6 Influence of the open water community on the profundal benthos, 316
- Further reading, 321

15 THE USES, ABUSES AND RESTORATION OF STANDING WATERS, 322

- 15.1 Introduction, 322
- 15.2 Services provided by standing waters, 324
- 15.3 Fisheries, 325
 - 15.3.1 Some basic fish biology, 326
 - 15.3.2 Eggs, 326
 - 15.3.3 Feeding, 328
 - 15.3.4 Breeding, 329
 - 15.3.5 Choice of fish for a fishery, 332
 - 15.3.6 Measurement: of fish production, 332
 - 15.3.7 Growth measurement, 333
 - 15.3.8 Fish production and commercial fisheries in lakes, 334
- 15.4 Changes in fisheries: two case studies, 338
 - 15.4.1 The North American Great Lakes, 339
 - 15.4.2 The East African Great Lakes, 340

- 15.5 Fish culture, 346
- 15.6 Stillwater angling, 349
- 15.7 Amenity culture and the aquarium trade, 351
- 15.8 Domestic water supply, eutrophication and reservoirs, 352
 - 15.8.1 Eutrophication-human induced changes in the production of lakes, 353
 - 15.8.2 Dams and reservoirs, 358
 - 15.8.3 Fisheries in new lakes, 359
 - 15.8.4 Effects downstream of the new lake, 360
 - 15.8.5 New tropical lakes and human populations, 360
 - 15.8.6 Man-made tropical lakes, the balance of pros and cons, 361
- 15.9 Amenity and conservation, 363
- 15.10 Restoration approaches for standing waters: symptom treatment, 367
- 15.11 Treatment of proximate causes: nutrient control, 370
 - 15.11.1 Present supplies of phosphorus, their relative contributions and how they are related to the algal crop, 370
 - 15.11.2 Methods available for reducing total phosphorus loads, 371
 - 15.11.3 In-lake methods, 374
 - 15.11.4 Complications for phosphorus control - sediment sources, 374
 - 15.11.5 Nitrogen reduction, 375
- 15.12 Habitat creation, 376
- Further reading, 377

16 CLIMATE CHANGE AND THE FUTURE OF FRESHWATERS, 380

- 16.1 The Merchant of Venice, 380
- 16.2 Climate change, 381
- 16.3 Existing effects of freshwaters, 383
- 16.4 Future effects, 386
 - 16.4.1 Future effects on freshwaters, 389
 - 16.4.2 Switches and feedbacks, 397
- 16.5 Control and mitigation of global warming, 400
- 16.6 The remedy of ultimate causes, 402
- Further reading, 408

17 PROBLEM EXERCISES, 411

- Exercise 1. Stratification, 411
- Exercise 2. Catchments and water chemistry, 412
- Exercise 3. The Vollenweider model, 412

Exercise 4.	Nutrient budgeting. 413	Exercise 14.	The plankton of paddling pools. 423
Exercise 5.	Light penetration. 415	Exercise 15.	Probing the profundal. 427
Exercise 6.	Biodiversity. 416	Exercise 16.	The curse of birds for lake managers. 428
Exercise 7.	Problems with a frog, 416	Exercise 17.	Nutrient problems in tricky situations. 430
Exercise 8.	Predation in streams. 417		
Exercise 9.	Deforestation and tropical streams. 417		
Exercise 10.	Swamp habitats and insect adaptations. 417	References.	432
Exercise 11.	Ecosystem valuation in a floodplain, 420	Index.	454
Exercise 12.	Top down and bottom up control in shallow and deep lakes. 423	Companion website for this book:	www.wiley.com/go/moss/ecology
Exercise 13.	Palatability of aquatic plants to fish, 423		