

# *Contents*

Preface xiii

## *1 PROLOGUE*

I. Our Freshwater Resources	1
II. Demotechnic Growth	1
III. Human Impact on Freshwater Ecosystems	3
IV. The Study of Limnology	4
V. Scientific Approaches	5
VI. Search for Commonality, Not Only Differences	6
VII. Altered Perspectives	6
VIII. Summary	7

## *2 WATER AS A SUBSTANCE*

I. The Characteristics of Water	9
II. Summary	14

## *3 RIVERS AND LAKES—THEIR DISTRIBUTION, ORIGINS, AND FORMS*

I. Distribution of Fresh Waters	15
II. Running Waters: Lotic Ecosystems	17
III. Morphology and Flow in River Ecosystems	18
IV. Groundwater Fluxes to Lakes	22

V.	Geomorphology of Lake Basins	23
VI.	Morphology of Lake Basins	34
VII.	Reservoirs	37
VIII.	Comparative Geomorphological Characteristics	39
IX.	Summary	40

## 4 *WATER ECONOMY*

I.	Hydrological Cycle	43
II.	Global Water Balance	45
III.	Summary	48

## 5 *LIGHT IN INLAND WATERS*

I.	Light as an Entity	49
II.	Light Impinging on Water	52
III.	Thermal Radiation in Lake Water	55
IV.	Transmission and Absorption of Light by Water	56
V.	Transmission through Ice and Snow	63
VI.	Color of Natural Waters	64
VII.	Transparency of Water to Light	65
VIII.	Utilization and Effects of Solar Radiation	67
IX.	Summary	68

## 6 *FATE OF HEAT*

I.	Distribution of Heat in Rivers	71
II.	Distribution of Heat in Lakes and Reservoirs	72
III.	Thermal Energy Content: Heat Budgets of Lakes	86
IV.	Comparative Analyses: Thermal Characteristics of Rivers, Reservoirs, and Natural Lakes	90
V.	Summary	91

## 7 *WATER MOVEMENTS*

I.	Hydrodynamics of Water Movements	93
II.	Flow of Water	94
III.	In-Stream Hydraulic Movements	96

IV.	Surface Water Movements	102
V.	Internal Water Movements	107
VI.	Water Movements Affecting the Whole Lake	108
VII.	Other Water Movements	113
VIII.	Circulation Caused by Thermal Bars	118
IX.	Currents Generated by River Influents	120
X.	Currents under Ice Cover	122
XI.	Hydrodynamics among Aquatic Ecosystems	124
XII.	Summary	125

## 8 *STRUCTURE AND PRODUCTIVITY OF AQUATIC ECOSYSTEMS*

I.	The Drainage Basin Concept	129
II.	Streams and Rivers	130
III.	Lake Ecosystem Concept	130
IV.	Population Growth and Regulation	134
V.	Community Structure and Interrelationships	136
VI.	Ecosystem Interrelationships	137
VII.	Detritus: Dead Organic Matter and Detrital Dynamic Structure	139
VIII.	Productivity	142
IX.	Summary	149

## 9 *OXYGEN*

I.	The Oxygen Content of Inland Waters	151
II.	Solubility of Oxygen in Water	151
III.	Distribution of Dissolved Oxygen in Running Waters	153
IV.	Distribution of Dissolved Oxygen in Lakes	154
V.	Variations in Oxygen Distributions	158
VI.	Hypolimnetic Oxygen Depletion Rates	164
VII.	Summary	167

## 10 *SALINITY OF INLAND WATERS*

I.	Ionic Composition of Surface Waters	169
II.	Salinity Distribution in World Surface Waters and Control Mechanisms	170

III. Sources of Salinity	173
IV. Distribution of Major Ions in Fresh Waters	176
V. Salinity, Osmoregulation, and Distribution of Biota	184
VI. Summary	186

## 11 *THE INORGANIC CARBON COMPLEX*

I. The Occurrence of Inorganic Carbon in Freshwater Systems	187
II. Hydrogen Ion Activity	192
III. Spatial and Temporal Distribution of Total Inorganic Carbon and pH in Rivers and Lakes	193
IV. Hypolimnetic CO <sub>2</sub> Accumulation in Relation to Lake Metabolism	198
V. Utilization of Carbon by Algae and Macrophytes	200
VI. Summary	203

## 12 *THE NITROGEN CYCLE*

I. Sources and Transformations of Nitrogen in Water	205
II. Inorganic and Organic Nitrogen	212
III. Seasonal Distribution of Nitrogen	220
IV. Carbon-to-Nitrogen Ratios	224
V. Summary of the Nitrogen Cycle	225
VI. Nitrogen Budgets	227
VII. Nitrogen Dynamics in Streams and Rivers	230
VIII. Summary	235

## 13 *THE PHOSPHORUS CYCLE*

I. Phosphorus in Fresh Waters	239
II. The Distribution of Organic and Inorganic Phosphorus in Lakes and Streams	240
III. Phosphorus Cycling in Running Waters	242
IV. Phosphorus and the Sediments: Internal Loading	245
V. Phosphorus Cycling within the Epilimnion	258
VI. Algal Requirements for Phosphorus	266

VII. Humans and the Phosphorus Cycle in Lakes	269
VIII. Phosphorus and Nitrogen Loading and Algal Productivity	279
IX. Summary	286

## 14 *IRON, SULFUR, AND SILICA CYCLES*

I. Biogeochemical Cycling of Essential Micronutrients	289
II. Oxidation-Reduction Potentials in Freshwater Systems	289
III. Iron and Manganese Cycling in Lakes	291
IV. Bacterial Transformations of Iron and Manganese	302
V. Minor Elements	305
VI. The Sulfur Cycle	310
VII. The Silica Cycle	323
VIII. Summary	328

## 15 *PLANKTONIC COMMUNITIES: ALGAE AND CYANOBACTERIA*

I. Composition of the Algae of Phytoplanktonic Associations	332
II. The Importance of Size: Small Is Beautiful and Productive	338
III. Phytoplanktonic Communities	339
IV. Growth Characteristics of Phytoplankton	341
V. Organic Micronutrient Requirements	354
VI. Heterotrophy of Organic Carbon by Algae and Cyanobacteria	356
VII. Other Effects of Dissolved Organic Matter	358
VIII. Seasonal Succession of Phytoplankton	358
IX. Mortality of Phytoplankton	366
X. Competitive Interactions and Successional Diversity	370
XI. Phytoplankton in the Gradient along Rivers, Reservoirs, and Lakes: Diversity and Biomass	371
XII. Vertical Distribution and Maximum Growth in Lakes and Reservoirs	373
XIII. Primary Production of Phytoplankton	375
XIV. Phytoplankton among Aquatic Ecosystems	389
XV. Summary	390

## 16

*PLANKTONIC COMMUNITIES:  
ZOOPLANKTON AND THEIR  
INTERACTIONS WITH FISH*

- I. Zooplankton 396
- II. Protozoa and Other Protists 396
- III. Trophic Relationships of Protists in Pelagic Food Webs 408
- IV. General Characteristics of Rotifers, Cladocera, and Copepods 412
- V. Food, Feeding, and Food Selectivity 416
- VI. Reproduction and Life Histories 428
- VII. Seasonal Population Dynamics 433
- VIII. Rotifer Population Dynamics 436
- IX. Cladoceran Population Dynamics 439
- X. Copepod Population Dynamics 442
- XI. Parasitism and Zooplankton Population Dynamics 446
- XII. Zooplankton Distribution in Reservoirs and in Floodplain Lakes 446
- XIII. Zooplankton Distribution in Tropical Fresh Waters 447
- XIV. Zooplankton Distribution in Flowing Waters 448
- XV. Vertical Migration and Spatial Distribution 448
- XVI. Horizontal Variations in Distribution 455
- XVII. Cyclomorphosis and Predation among the Zooplankton 456
- XVIII. Fish within Aquatic Ecosystems 460
- XIX. Zooplankton Production 468
- XX. Zooplankton among Aquatic Ecosystems 482
- XXI. Summary 484

## 17

*BACTERIOPLANKTON*

- I. The Organic Carbon Cycle 490
- II. Distribution of Bacterioplankton 491
- III. Control of Bacterioplankton by Resource Availability and Environmental Factors 498
- IV. Decomposition of Dissolved Organic Matter 500
- V. Control of Bacterioplankton by Biota 508
- VI. Biotically Released Dissolved Organic Matter 510
- VII. Decomposition of Particulate Organic Detritus 513
- VIII. Productivity of Bacterioplankton 519
- IX. Comparison of Bacterioplankton among Aquatic Ecosystems 522
- X. Summary 524

## 18

*LAND-WATER INTERFACES:  
LARGER PLANTS*

- I. Aquatic Macrophytes of the Littoral Zone and Wetlands 528
- II. Aquatic Plant Characteristics 529
- III. Metabolism by Aquatic Macrophytes 535
- IV. Rates of Photosynthesis and Depth Distribution of Macrophytes 549
- V. Primary Productivity of Macrophytes 553
- VI. Summary 572

## 19

*LAND-WATER INTERFACES: ATTACHED  
MICROORGANISMS, LITTORAL ALGAE,  
AND ZOOPLANKTON*

- I. Attached Microbes and Algae of Littoral Regions 578
- II. Metabolic Interactions in the Littoral Regions 602
- III. Productivity of Littoral Algae 605
- IV. Periphyton among Aquatic Ecosystems 617
- V. Littoral Zooplankton Communities 619
- VI. Summary 621

## 20

*SHALLOW LAKES AND PONDS*

- I. Origins and Distribution 625
- II. Characteristics 625
- III. Invasion and Growth of Macrophytes 626
- IV. Shifts between Macrophyte and Phytoplankton Dominance 626
- V. Temporary Ponds, Pools, and Streams 628
- VI. Summary 630

## 21

*SEDIMENTS AND MICROFLORA*

- I. General Composition of Sediments 631
- II. Resuspension and Redeposition of Sediments 633
- III. Microflora of Sediments and Rates of Decomposition 635
- IV. Anaerobic Decomposition in Sediments 639

V. Littoral Decomposition and Microbial Metabolism	651
VI. Degradation of Particulate Organic Matter in Sediments of Running Waters	657
VII. Degradation of Dissolved Organic Matter in Sediments of Running Waters	660
VIII. Summary	662

## 22

*BENTHIC ANIMALS AND FISH COMMUNITIES*

I. Benthic Animal Communities	665
II. Aquatic Insects	695
III. Littoral and Profundal Benthic Communities of Lakes	702
IV. Stream Benthic Communities	710
V. Reservoir Benthic Communities	714
VI. Production of Invertebrate Benthic Fauna	715
VII. Fish Predation and Other Mortality of Benthic Fauna	721
VIII. Fish Production Rates	724
IX. Invertebrates and Fish among Aquatic Ecosystems	724
X. Summary	725

## 23

*DETRITUS: ORGANIC CARBON CYCLING AND ECOSYSTEM METABOLISM*

I. Overview of Organic Transfers and Uses	731
II. Dead Organic Matter: The Central Role of Detritus	732
III. Allochthonous Organic Matter	737
IV. Distribution of Organic Carbon	751
V. Detritus: Organic Matter as a Component of the Ecosystem	759
VI. Net Ecosystem Production	775
VII. Biotic Stability and Succession of Productivity	775

VIII. Synergies among Dissolved Organic Matter, Sunlight, Climatic Warming, Enhanced Atmospheric CO <sub>2</sub> , and Acidification	779
IX. Summary	780

## 24

*PAST PRODUCTIVITY: PALEOLIMNOLOGY*

I. Stratigraphy and Geochemistry	786
II. Biological Indicators	792
III. Sedimentary Record and Lake Ontogeny	802
IV. Summary	802

## 25

*THE ONTOGENY OF INLAND AQUATIC ECOSYSTEMS*

I. Successional Development of Aquatic Ecosystems	806
II. Dystrophy and Bog Ecosystems	812
III. Summary	821

## 26

*INLAND WATERS: UNDERSTANDING IS ESSENTIAL FOR THE FUTURE*

I. Water Quality Is Essential; Water Quality Is Biological	825
II. Biodiversity of Inland Waters	826
III. River Regulation	832
IV. Restoration of Aquatic Ecosystems	836
V. Summary	841

References	843
Appendix	981
Index	985