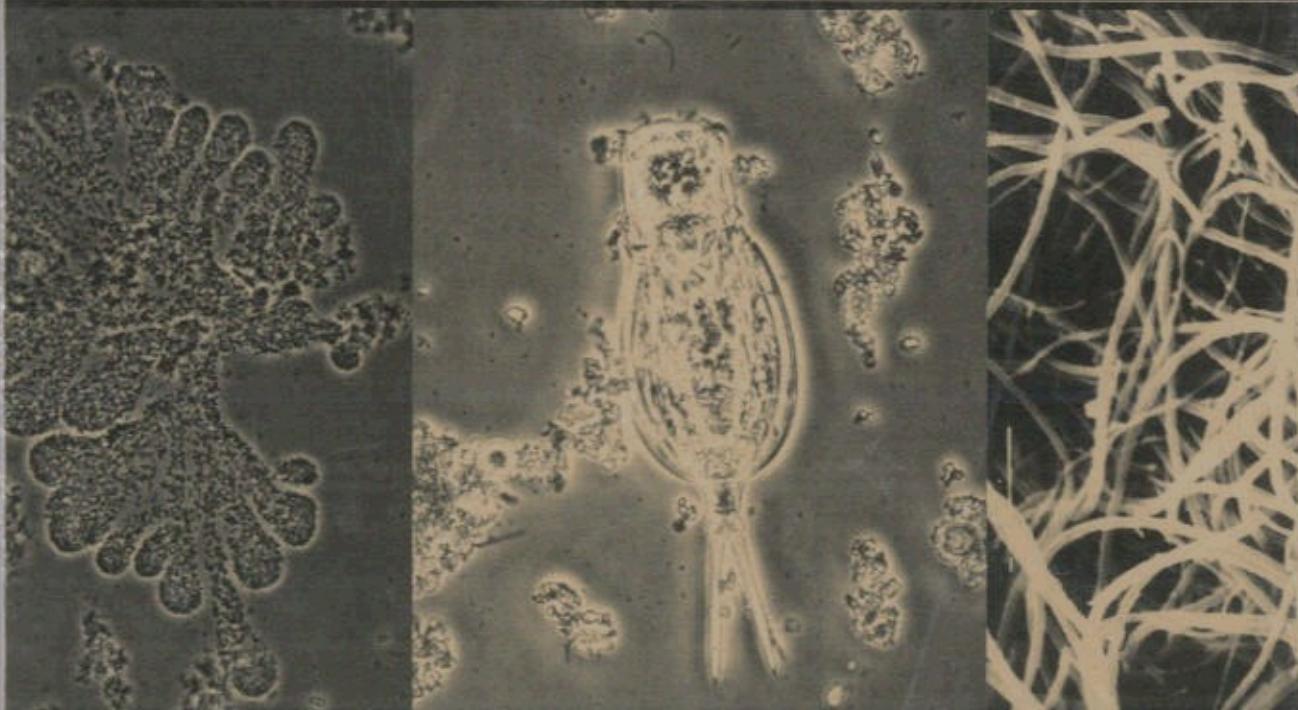


# ENVIRONMENTAL BIOLOGY FOR ENGINEERS AND SCIENTISTS



**David A. Vaccari, Peter F. Strom, James E. Alleman**

# CONTENTS

<b>Preface</b>	<b>xix</b>
<b>1 Perspectives on Biology</b>	<b>1</b>
1.1 Why Environmental Engineers and Scientists Should Study Biology, 1	
1.2 Present Perspectives on Environmental Engineers and Scientists, 2	
1.3 Past Perspectives on Environmental Engineers and Scientists, 5	
1.4 Ambiguity and Complexity in Biology, 6	
1.5 Conservation and Environmental Ethics, 9	
1.6 Guidelines for Study, 13	
Problems, 14	
References, 15	
<b>2 Biology as a Whole</b>	<b>16</b>
2.1 What Is life?, 16	
2.2 The Hierarchy of Life, 18	
2.3 Evolution, 21	
2.4 Taxonomy, 26	
2.5 Interaction of Living Things with the Environment, 30	
2.6 Brief History of Life, 33	
Problems, 34	
References, 34	
<b>3 The Substances of Life</b>	<b>35</b>
3.1 Basic Organic Chemical Structure, 35	
3.2 Chemical Bonding, 36	
3.3 Acid–Base Reactions, 38	
3.4 Physicochemical Interactions, 40	

3.5 Optical Isomers, 41	
3.6 The Composition of Living Things, 44	
3.6.1 Carbohydrates, 44	
3.6.2 Lipids, 47	
3.6.3 Proteins, 51	
3.6.4 Nucleic Acids, 58	
3.6.5 Hybrid and Other Compounds, 61	
3.7 Detection and Purification of Biochemical Compounds, 62	
Problems, 63	
References, 64	
<b>4 The Cell: The Common Denominator of Living Things</b>	<b>65</b>
4.1 Prokaryotes and Eukaryotes, 66	
4.2 The Biological Membrane, 67	
4.3 Membrane Transport, 69	
4.4 Eukaryotic Cell Structure and Function, 72	
4.5 Cell Reproduction, 74	
Problems, 79	
References, 79	
<b>5 Energy and Metabolism</b>	<b>80</b>
5.1 Bioenergetics, 80	
5.1.1 Some Basic Thermodynamics, 80	
5.1.2 Oxidation–Reduction, 85	
5.1.3 Phosphate Compounds and ATP, 86	
5.1.4 Reaction Coupling, 87	
5.2 Elementary Kinetics, 88	
5.3 Enzyme Kinetics, 90	
5.3.1 Single-Substrate Kinetics, 91	
5.3.2 Multiple Substrates, 95	
5.3.3 Effect of pH, 96	
5.3.4 Effect of Temperature, 97	
5.3.5 Other Considerations, 98	
5.4 Biochemical Pathways, 98	
5.4.1 Glycolysis, 98	
5.4.2 Fermentation, 99	
5.4.3 Respiration, 101	
5.4.4 Oxidation of Fats and Amino Acids, 105	
5.4.5 Photosynthesis, 106	
5.4.6 Biosynthesis, 113	
Problems, 114	
References, 115	
<b>6 Genetics</b>	<b>116</b>
6.1 Heredity, 116	
6.1.1 Mendel's Experiments, 118	

6.1.2 Sex Chromosomes, 120	
6.1.3 Genetic Disease, 121	
6.2 Molecular Biology, 122	
6.2.1 Protein Synthesis, 124	
6.2.2 Gene Regulation, 126	
6.2.3 Mutations, 129	
6.2.4 DNA Repair, 130	
6.3 Genetic Engineering, 131	
6.3.1 DNA Analysis and Probes, 132	
6.3.2 Cloning and Recombinant DNA, 135	
6.3.3 Polymerase Chain Reaction, 136	
6.3.4 Genetic Engineering and Society, 137	
6.4 Genetic Variation, 138	
6.5 Sexual Reproduction, 140	
Problems, 141	
References, 142	
<b>7 The Plants</b>	<b>143</b>
7.1 Plant Divisions, 144	
7.2 Structure and Physiology of Angiosperms, 146	
7.2.1 Water and Nutrient Transport, 146	
7.2.2 Plant Growth and Control, 150	
7.2.3 Plant Nutrition, 153	
Problems, 153	
References, 154	
<b>8 The Animals</b>	<b>155</b>
8.1 Reproductive Strategies, 155	
8.2 Invertebrate Phyla Other Than Arthropods, 158	
8.3 Mollusks, Segmented Worms, Arthropods, 160	
8.3.1 Mollusks, 160	
8.3.2 Annelids, 160	
8.3.3 Arthropods, 161	
8.3.4 Lesser Protostomes, 165	
8.4 Deuterostomes (Starfish, Vertebrates, etc.), 166	
8.4.1 Echinoderms, 166	
8.4.2 Chordates, Including the Vertebrates, 166	
Problems, 172	
Reference, 172	
<b>9 The Human Animal</b>	<b>173</b>
9.1 Skin, 174	
9.2 Skeletal System, 175	
9.3 Muscular System, 176	
9.4 Nervous System, 178	
9.4.1 Nerve Signal Transmission, 178	

9.4.2	Synaptic Transmission, 179	
9.4.3	Nervous System Organization, 180	
9.5	Endocrine System and Homeostasis, 184	
9.5.1	Homeostasis, 184	
9.5.2	Hormones, 186	
9.6	Cardiovascular System, 190	
9.7	Immunity and the Lymphatic System, 193	
9.8	Respiratory System, 196	
9.9	Digestion, 199	
9.10	Nutrition, 203	
9.11	Excretory System, 207	
9.12	Reproduction and Development, 211	
9.12.1	Prenatal Development, 214	
Problems,	216	
References,	216	
<b>10</b>	<b>Microbial Groups</b>	<b>217</b>
10.1	Evolution of Microbial Life, 218	
10.2	Discovery of Microbial Life, 219	
10.2.1	Antonie van Leeuwenhoek, 219	
10.2.2	Spontaneous Generation and the Beginnings of Microbiology, 220	
10.2.3	Virus Discovery, 223	
10.2.4	Discovery of Archaea, 223	
10.3	Diversity of Microbial Activities, 223	
10.3.1	Energy Sources, 224	
10.3.2	Carbon Source, 224	
10.3.3	Environmental Preferences, 225	
10.4	Microbial Taxonomy, 226	
10.4.1	Basis of Identification, 226	
10.4.2	Prokaryotic “Species”, 227	
10.4.3	Naming of Microorganisms, 228	
10.4.4	Characterization of Prokaryotes, 230	
10.5	Bacteria, 241	
10.5.1	Aquaficae, 245	
10.5.2	Xenobacteria, 245	
10.5.3	Thermomicrobia (Including Green Nonsulfur Bacteria), 245	
10.5.4	Cyanobacteria: Blue-Green Bacteria (Formerly, Blue-Green Algae), 246	
10.5.5	Chlorobia: Green Sulfur Bacteria, 246	
10.5.6	Proteobacteria, 248	
10.5.7	Firmicutes: Gram Positives, 258	
10.5.8	Planctomycetacia, 262	
10.5.9	Spirochetes, 263	
10.5.10	Fibrobacter, 264	
10.5.11	Bacteroids, 264	
10.5.12	Flavobacteria, 264	
10.5.13	Sphingobacteria, 265	

10.5.14	Fusobacteria, 265	
10.5.15	Verrucomicrobia, 265	
10.6	Archaea, 265	
10.6.1	Korarchaeota, 265	
10.6.2	Crenarchaeota, 265	
10.6.3	Euryarchaeota (Including Methanogens), 266	
10.7	Eukarya, 267	
10.7.1	Protozoans, 268	
10.7.2	Algae, 271	
10.7.3	Slime Molds, 279	
10.7.4	Fungi, 281	
10.8	Noncellular Infective Agents: Viruses, Viroids, and Prions, 285	
10.8.1	Viruses, 286	
10.8.2	Viroids and Prions, 288	
	Problems, 288	
	References, 288	
<b>11</b>	<b>Quantifying Microorganisms and Their Activity</b>	<b>290</b>
11.1	Microbial Composition and Stoichiometry, 290	
11.1.1	Elemental Makeup, 290	
11.1.2	Growth Factors, 293	
11.1.3	Molecular Makeup, 294	
11.2	Microscopy, 294	
11.2.1	Light Microscopes, 295	
11.2.2	Electron Microscopes, 298	
11.3	Sampling, Storage, and Preparation, 299	
11.3.1	Sampling, 299	
11.3.2	Storage, 299	
11.3.3	Preparation, 300	
11.4	Determining Microbial Biomass, 300	
11.4.1	Measurements of Total Mass, 300	
11.4.2	Measurements of Cell Constituents, 301	
11.5	Counts of Microorganism Numbers, 302	
11.5.1	Direct Counts, 303	
11.5.2	Indirect Methods, 305	
11.5.3	Relationship between Numbers and Mass, 310	
11.5.4	Surface Area/Volume Ratio, 311	
11.6	Measuring Microbial Activity, 311	
11.6.1	Aerobic Respiration, 312	
11.6.2	Anaerobic Systems, 314	
11.6.3	Enzyme Activity, 315	
11.7	Growth, 315	
11.7.1	Exponential Growth, 315	
11.7.2	Batch Growth Curve, 320	
11.7.3	Death, Viability, and Cryptic Growth, 325	
11.7.4	Substrate Utilization, 327	
11.7.5	Continuous Culture and the Chemostat, 329	

11.7.6	Environmental Factors, 336
11.7.7	Inhibition, 338
Problems,	340
References,	340
<b>12 Effect of Microbes on Human Health</b>	<b>342</b>
12.1	Microbial Colonization of Humans, 342
12.1.1	Abnormal Microbial Infection, 343
12.2	Waterborne Diseases, 354
12.2.1	Types of Water, 355
12.2.2	Sources of Contamination, 355
12.2.3	Routes of Infection, 356
12.2.4	Fecal-Oral Route, 357
12.2.5	Modern and Recent Outbreaks, 362
12.3	Foodborne Diseases, 364
12.3.1	Bacterial Food Poisoning, 365
12.3.2	Bacterial Infections, 366
12.3.3	Other Agents, 367
12.4	Air-Transmitted Diseases, 368
12.4.1	Pneumonia, 368
12.4.2	Other Streptococcal Infections, 368
12.4.3	Tuberculosis, 369
12.4.4	Influenza, 370
12.4.5	Diphtheria and Whooping Cough (Pertussis), 370
12.4.6	Meningococcal Meningitis, 371
12.4.7	Histoplasmosis, San Joaquin Valley Fever, and Aspergillosis (Respiratory Mycoses), 371
12.4.8	Hantavirus Pulmonary Syndrome, 371
12.5	Vector-Transmitted Diseases, 371
12.5.1	Malaria, 372
12.5.2	Trypanosomiasis (African Sleeping Sickness), 372
12.5.3	Plague, 373
12.5.4	Typhus Fever, 373
12.5.5	Rocky Mountain Spotted Fever, 373
12.5.6	Lyme Disease, 373
12.5.7	Dengue, 374
12.5.8	Yellow Fever, 374
12.5.9	Rabies, 374
12.5.10	West Nile Encephalitis, 374
12.6	Sexually Transmitted Diseases, 374
12.6.1	Syphilis, 375
12.6.2	Gonorrhea, 375
12.6.3	Chlamydial Infections, 375
12.6.4	AIDS, 375
12.6.5	Genital Herpes and Warts, 376
12.6.6	Trichomoniasis, 376
12.6.7	Yeast Infections, 376

12.7	Other Diseases Transmitted by Contact, 376	
12.7.1	Tetanus, 376	
12.7.2	Gangrene, 376	
12.7.3	Trachoma, 377	
12.7.4	Bacterial Conjunctivitis, 377	
12.7.5	Anthrax, 377	
12.7.6	Leprosy, 377	
12.7.7	Athlete's Foot and Ringworm, 377	
12.7.8	Hepatitis B, 378	
12.7.9	Ebola, 378	
12.8	Control of Infection, 378	
12.8.1	Physical Steps to Prevent Transmission, 378	
12.8.2	Immunity and Vaccination, 379	
12.8.3	Antibiotics and Antitoxins, 381	
12.9	Indicator Organisms, 382	
12.9.1	Physical-Chemical Indicators, 382	
12.9.2	Microbiological Indicators, 382	
	Problems, 385	
	References, 385	
<b>13</b>	<b>Microbial Transformations</b>	<b>387</b>
13.1	Carbon, 389	
13.1.1	Carbon Reduction, 391	
13.1.2	Carbon Oxidation, 396	
13.1.3	Carbon in Environmental Engineering and Science, 397	
13.2	Nitrogen, 414	
13.2.1	Nitrogen Reduction, 417	
13.2.2	Nitrogen Oxidation, 421	
13.2.3	Nitrogen in Environmental Engineering and Science, 424	
13.3	Sulfur, 429	
13.3.1	Sulfur Reduction, 430	
13.3.2	Sulfur Oxidation, 432	
13.3.3	Sulfur in Environmental Engineering and Science, 432	
13.4	Iron, 435	
13.4.1	Iron Reduction, 436	
13.4.2	Iron Oxidation, 436	
13.4.3	Iron in Environmental Engineering and Science, 437	
13.5	Manganese, 439	
13.5.1	Manganese Reduction, 439	
13.5.2	Manganese Oxidation, 439	
13.5.3	Manganese in Environmental Engineering and Science, 439	
	Problems, 441	
	References, 441	
<b>14</b>	<b>Ecology: The Global View of Life</b>	<b>442</b>
14.1	Flow of Energy in the Ecosystem, 443	
14.1.1	Primary Productivity, 444	

14.1.2	Trophic Levels, and Food Chains and Webs, 446
14.2	Flow of Matter in Ecosystems, 451
14.2.1	Sedimentary Cycles, 453
14.2.2	Carbon Cycle, 454
14.2.3	Hydrologic Cycle, 456
14.2.4	Nitrogen Cycle, 457
14.2.5	Sulfur Cycle, 460
14.2.6	Phosphorus Cycle, 462
14.2.7	Cycles of Other Minerals, 463
14.2.8	System Models of Cycles, 464
14.3	Factors that Control Populations, 466
14.3.1	Limiting Factors and Interactions, 466
14.3.2	Resources and Environmental Conditions, 468
14.3.3	Tolerated Range of Factors, 469
14.3.4	Species Interactions, 470
14.4	Populations and Communities, 472
14.4.1	Growth Models: Temporal Structure of Populations, 472
14.4.2	Species Richness and Diversity: Synoptic Structure of Communities, 484
14.4.3	Development and Succession: Temporal Structure of Communities, 486
14.4.4	Distribution vs. Abundance: Spatial Structure of Communities, 488
14.5	Humans in the Balance, 490
14.6	Conclusion, 492
	Problems, 492
	References, 494

## 15 Ecosystems and Applications 496

15.1	Terrestrial Ecosystems, 496
15.1.1	Forest Nutrient Cycles, 499
15.1.2	Soil Ecology, 500
15.2	Freshwater Ecosystems, 506
15.2.1	Aquatic Environments, 507
15.2.2	Biota, 508
15.2.3	Succession in Lakes, 520
15.2.4	Microbial Loop, 522
15.2.5	River Productivity, 523
15.2.6	Nutrients and Eutrophication in Lakes, 526
15.2.7	Organic Pollution of Streams, 530
15.3	Wetlands, 536
15.3.1	Hydric Soils, 538
15.3.2	Hydrophytic Vegetation, 540
15.3.3	Wetlands Animals, 543
15.3.4	Hydrology and Wetlands Ecology, 545
15.3.5	Wetlands Nutrient Relationships, 546
15.3.6	Major Wetland Types, 546

15.3.7	Wetland Law and Management, 549	
15.4	Marine and Estuarine Ecosystems, 552	
15.4.1	Productivity and Nutrients, 553	
15.4.2	Marine Adaptations, 557	
15.4.3	Marine Communities, 558	
15.4.4	Adverse Impacts on Marine Ecosystems, 562	
15.5	Microbial Ecology, 564	
15.6	Biological Effects of Greenhouse Gases and Climate Change, 567	
15.7	Acid Deposition, 569	
15.8	Endangered Species Protection, 571	
Problems,	574	
References,	575	
<b>16</b>	<b>Biological Applications for Environmental Control</b>	<b>577</b>
16.1	Wastewater Treatment, 580	
16.1.1	Process Fundamentals, 582	
16.1.2	Attached-Growth Systems, 586	
16.1.3	Suspended-Growth Systems, 600	
16.1.4	Stabilization Lagoon Systems, 618	
16.1.5	Constructed Wetland Systems, 623	
16.2	Sludge Treatment, 633	
16.2.1	Anaerobic Digestion, 636	
16.2.2	Aerobic Digestion, 646	
16.2.3	Composting, 652	
16.3	Potable Water Treatment, 659	
16.4	Water and Wastewater Disinfection Treatment, 662	
16.5	Solid Waste Treatment, 668	
16.6	Air Treatment, 671	
16.7	Soil and Groundwater Treatment, 675	
16.7.1	Phytoremediation, 675	
16.7.2	Bioremediation, 684	
Problems,	699	
References,	702	
<b>17</b>	<b>The Science of Poisons</b>	<b>704</b>
17.1	Mechanisms of Toxicity, 705	
17.2	Abiotic Factors That Affect Toxicity, 708	
17.3	Individual Variability, 711	
17.4	Toxic Effects, 712	
17.4.1	Biochemical and Physiological Effects, 713	
17.4.2	Genotoxicity, 714	
17.4.3	Mutagenesis, 714	
17.4.4	Teratogenesis, 714	
17.4.5	Carcinogenesis, 715	
17.4.6	Histological Effects, 720	
17.4.7	Effects on Particular Organs or Organ Systems, 721	
17.4.8	Effects at the Individual Level, 729	

17.4.9	Effects at the Ecological Level,	730
17.4.10	Microbial Toxicity,	731
Problems,	732	
References,	732	
<b>18</b>	<b>Fate and Transport of Toxins</b>	<b>734</b>
18.1	Physicochemical Properties,	734
18.2	Uptake Mechanisms,	742
18.3	Absorption and Routes of Exposure,	743
18.4	Distribution and Storage,	746
18.5	Biotransformation,	747
18.5.1	Phase I Reactions,	748
18.5.2	Phase II Reactions,	750
18.6	Excretion,	753
18.7	Pharmakokinetic Models,	755
18.7.1	Dynamic Model and the Half-Life,	758
18.7.2	Steady-State Model and Bioaccumulation,	760
18.7.3	Equilibrium Model and Bioconcentration,	761
18.7.4	Food Chain Transfer and Biomagnification,	763
18.7.5	Multicompartment Models,	764
18.8	Effect of Exposure Time and Mode of Exposure,	765
Problems,	767	
References,	768	
<b>19</b>	<b>Dose–Response Relationships</b>	<b>770</b>
19.1	Tolerance Distribution and Dose–Response Relationships,	772
19.2	Mechanistic Dose–Response Models,	776
19.3	Background Response,	777
19.3.1	Low-Dose Extrapolation,	777
19.3.2	Thresholds,	780
19.4	Interactions,	780
19.4.1	Nonadditive Interactions,	783
19.5	Time–Response Relationship,	785
19.6	Other Measures of Toxic Effect,	785
Problems,	786	
References,	787	
<b>20</b>	<b>Field and Laboratory Toxicology</b>	<b>788</b>
20.1	Toxicity Testing,	788
20.1.1	Design of Conventional Toxicity Tests,	789
20.1.2	Test Duration,	789
20.1.3	Selecting Organisms,	790
20.1.4	Toxic Endpoint and Other Observations,	792
20.1.5	Route of Administration and Dosage,	792
20.1.6	Number of Organisms Per Test,	793
20.1.7	Other Experimental Variables,	793

20.1.8	Conventional Toxicity Tests, 794	
20.1.9	In Situ Measurement of Conventional Toxicity, 796	
20.1.10	Occupational Monitoring, 797	
20.1.11	Population and Community Parameters, 797	
20.1.12	Testing for Carcinogenicity and Teratogenicity, 797	
20.1.13	Mutagenicity Testing and In Vitro Tests, 798	
20.1.14	Extrapolation from Animals to Humans, 799	
20.2	Epidemiology, 800	
	Problems, 802	
	References, 802	
<b>21</b>	<b>Toxicity of Specific Substances</b>	<b>803</b>
21.1	Metals, 803	
21.2	Pesticides, 807	
21.2.1	Toxic Effects, 808	
21.2.2	Ecosystem Effects, 811	
21.3	Hydrocarbons, Solvents, PAHs, and Similar Compounds, 813	
21.4	Halogenated Organics, 819	
21.5	Air Pollutants, 824	
21.6	Water Pollutants, 827	
21.7	Toxicity to Microbes, 829	
21.8	Ionizing Radiation, 831	
21.8.1	Dosimetry, 834	
21.8.2	Radiation Exposure and Risks, 837	
	Problems, 840	
	References, 840	
<b>22</b>	<b>Applications of Toxicology</b>	<b>842</b>
22.1	Risk Assessment, 842	
22.1.1	Human Health Risk Assessment, 843	
22.1.2	Ecological Risk Assessment, 847	
22.2	Toxicity Reduction Evaluation, 850	
	Problems, 852	
	References, 853	
<b>Appendices</b>		<b>855</b>
<b>A</b>	Physicochemical Properties of Common Pollutants, 856	
<b>B</b>	Biodegradability of Common Pollutants, 862	
<b>C</b>	Toxicological Properties of Common Pollutants, 867	
<b>D</b>	Standards for Exposure to Common Toxic Pollutants, 876	
<b>E</b>	Ambient Air Quality Standards, 878	
<b>F</b>	Unit Conversions and Physical Constants, 879	

**xviii** CONTENTS

**G** The Elements, 883

**H** Periodic Table of the Elements, 884

**Index**

**885**