

Contents

List of Contributors *XVII*

Foreword *XXI*

Preface *XXIII*

Companion Website *XXV*

Part I: Basics of Life *1*

- 1 Basic Biochemical Roots *3***
Dietrich H. Nies
- 1.1 Chemistry and Physics of Life *3*
- 1.2 Energy and Transport *3*
- 1.3 Basic Biochemistry *4*

- 2 Specialized Plant Metabolites: Diversity and Biosynthesis *15***
Alain Tissier, Jörg Ziegler, and Thomas Vogt
- 2.1 Metabolite Diversity *15*
- 2.2 Major Classes of Plant Specialized Compounds *16*
- 2.2.1 Terpenoids *16*
- 2.2.2 Alkaloid Biosynthesis *20*
- 2.2.2.1 Generation of Metabolic Diversity across Alkaloid Classes *21*
- 2.2.2.2 Generation of Metabolic Diversity within Alkaloid Classes *23*
- 2.2.3 Phenylpropanoid Metabolism *27*
- 2.2.3.1 Hydroxycinnamic Acids and Lignin *27*
- 2.2.3.2 Flavonoids, (Pro)anthocyanins, and other Chromogenic Structures *29*
- 2.2.3.3 Simple C₆-C₁ Phenolics *30*
- 2.2.4 Glucosinolates and Cyanogenic Glucosides *31*
- 2.3 Sites of Biosynthesis and Accumulation *33*
- 2.3.1 Specialized Structures and Storage *33*
- 2.3.1.1 Glandular Trichomes *33*
- 2.3.1.2 Internal Organs *33*
- 2.3.1.3 Vacuoles as Sites of Storage of Specialized Metabolites *34*
- 2.3.2 Alkaloid Biosynthesis: Pathway Trafficking *34*
- 2.4 Evolution of Specialized Pathway Genes *34*
- 2.4.1 Gene Duplication *34*
- 2.4.2 Chromosomal Clusters of Specialized Metabolite Pathway Genes *36*
- 2.4.3 Convergent Evolution *36*
- References *37*
- Further Reading *37*

- 3 Evolution of Secondary Metabolism in Plants *39***
Michael Wink
- 3.1 Origins of Plant Secondary Metabolism *39*
- 3.2 Evolutionary Alternatives *41*

| | | |
|--|--|-----------|
| 3.3 | Endophytes, Symbiotic, and Ectomycorrhizal Fungi | 45 |
| | References | 47 |
| Part II: Ecological Signatures of Life 49 | | |
| 4 | Systematics of Life, Its Early Evolution, and Ecological Diversity | 51 |
| | <i>Dietrich H. Nies</i> | |
| 4.1 | Cellular Life Forms and Subcellular Parasites | 51 |
| 4.2 | Superkingdom Archaea | 51 |
| 4.2.1 | General Features | 51 |
| 4.2.2 | Phylum Euryarchaeota (I. B) | 52 |
| 4.2.3 | Phylum Crenarchaeota (I. A) | 53 |
| 4.2.4 | Phylum Thaumarchaeota (I. E) | 53 |
| 4.2.5 | Other Phylae (I.C, I.D) | 54 |
| 4.3 | Superkingdom Bacteria | 55 |
| 4.3.1 | General Features | 55 |
| 4.3.2 | Phylum Aquificae (II. B) | 56 |
| 4.3.3 | Phylae Thermotogae (II. Z) and Thermodesulfobacteria (II. Y) | 56 |
| 4.3.4 | Chloroflexi (II. G) | 56 |
| 4.3.5 | Crown groups of the Bacteria | 56 |
| 4.3.6 | Phylum Proteobacteria (II.U) | 56 |
| 4.3.7 | Superphylum Bacteroidetes/Chlorobi Group (II. D) | 57 |
| 4.3.8 | Phylum Planctomycetes (II. T) | 57 |
| 4.3.9 | Gram-Positive Bacteria (II.A, II.O, II.X) | 57 |
| 4.3.10 | Phylum Cyanobacteria (II.I) | 58 |
| 4.4 | Superkingdom Eukaryota | 59 |
| 4.4.1 | General Features | 59 |
| 4.4.2 | <i>Excavata</i> : Excavates (III.O, III.P, III.Q) and Discicristates (III.R, III.S, III.T) | 60 |
| 4.4.3 | Chromalveolata: Kingdoms <i>Alveolata</i> (III.K), <i>Stramenopiles</i> (III.N), <i>Cryptophyta</i> (III.L), and <i>Haptophyceae</i> (III.M) | 62 |
| 4.4.4 | Kingdom <i>Rhizaria</i> (III.G) | 64 |
| 4.4.5 | <i>Archaeplastida</i> (III.H, III.I, III.J) | 65 |
| 4.4.6 | Kingdom <i>Amoebozoa</i> (III.A) | 68 |
| 4.4.7 | Kingdom <i>Opisthokonta</i> (III.E) | 70 |
| | Acknowledgment | 74 |
| | References | 74 |
| | Further Reading | 74 |
| 5 | Communities and Ecosystem Functioning | 77 |
| | <i>Heinz Rennenberg</i> | |
| 5.1 | Competition for, and Distribution of, Limiting Resources as a Means of Ecosystem Functioning | 77 |
| 5.1.1 | Light-Capturing Strategies | 78 |
| 5.1.2 | Competition for Nutrients | 79 |
| 5.2 | Joint Exploitation of Limiting Resources by Symbioses | 79 |
| 5.2.1 | Mycorrhiza | 79 |
| 5.2.1.1 | Arbuscular Mycorrhizas (AMs) | 80 |
| 5.2.1.2 | Ectomycorrhizas (ECMs) | 83 |
| 5.2.2 | Symbiotic N ₂ Fixation | 86 |
| 5.2.2.1 | Establishment of Symbiosis and Nodule Formation | 87 |
| 5.2.2.2 | Mechanism of N ₂ Fixation and Plant–Microbial Interactions in N Nutrition | 88 |
| 5.3 | Avoidance of Competition | 89 |
| 5.4 | Facilitation Mechanisms in Communities and Ecosystem Functioning | 90 |
| | References | 91 |
| | Further Reading | 91 |

| | | |
|----------|--|------------|
| 6 | Food Chains and Nutrient Cycles | 93 |
| | <i>Felix Bärlocher and Heinz Rennenberg</i> | |
| 6.1 | Basic Concepts | 93 |
| 6.1.1 | Food Chains and Food Webs | 93 |
| 6.1.2 | Grazing vs. Detritus Food Chains and the Microbial Loop | 94 |
| 6.1.3 | Role of Parasites | 95 |
| 6.1.4 | Metabolic Theory and Ecological Stoichiometry | 95 |
| 6.1.5 | Terrestrial Versus Aquatic Habitats | 95 |
| 6.1.6 | General Principles of Nutrient Cycles | 96 |
| 6.2 | Aquatic Systems | 97 |
| 6.2.1 | Important Physicochemical Properties of Water | 98 |
| 6.2.2 | Marine Systems | 99 |
| 6.2.2.1 | Density Gradients and Pycnoclines | 99 |
| 6.2.2.2 | The Euphotic Zone | 99 |
| 6.2.2.3 | The Pelagial Zone | 99 |
| 6.2.2.4 | Hydrothermal Vents and Methane Seeps | 100 |
| 6.2.2.5 | The Benthic Habitat | 100 |
| 6.2.2.6 | Mangroves | 100 |
| 6.2.2.7 | Salt Marshes | 101 |
| 6.2.2.8 | Coral Reefs | 102 |
| 6.2.3 | Freshwater Systems | 102 |
| 6.2.3.1 | Temperature Gradients and Circulation in Lakes | 102 |
| 6.2.3.2 | Oxygenic and Anoxygenic Photosynthesis | 103 |
| 6.2.3.3 | The Freshwater Pelagial Zone | 103 |
| 6.2.3.4 | The Freshwater Benthic Zone and Freshwater Marshes | 103 |
| 6.2.3.5 | Running Waters | 104 |
| 6.2.4 | Nutrient Cycles | 106 |
| 6.2.4.1 | The Nitrogen Cycle | 106 |
| 6.2.4.2 | The Sulfur Cycle | 107 |
| 6.2.4.3 | The Phosphorus Cycle | 107 |
| 6.2.4.4 | The Carbon Cycle | 109 |
| 6.3 | Terrestrial Systems | 109 |
| 6.3.1 | Trophic Cascades | 109 |
| 6.3.2 | Community Dynamics and Its Regulation | 111 |
| 6.3.3 | Nutrient Cycles | 112 |
| 6.3.3.1 | The Nitrogen Cycle | 113 |
| 6.3.3.2 | The Sulfur Cycle | 116 |
| 6.3.3.3 | The Phosphorus Cycle | 119 |
| 6.3.3.4 | The Carbon Cycle | 120 |
| | References | 120 |
| | Further Reading | 120 |
| | Part III: Biochemical Response to Physicochemical Stress (Abiotic Stress) | 123 |
| 7 | Information Processing and Survival Strategies | 125 |
| | <i>Ingo Heilmann</i> | |
| 7.1 | The Stress Concept—Plants and Their Environment | 125 |
| 7.2 | Plant Signal Transduction and the Induction of Stress Responses | 126 |
| 7.3 | Phytohormones | 130 |
| 7.3.1 | Functionality of Phytohormones | 130 |
| 7.3.2 | Signal Transduction through Nuclear Derepression of Gene Expression | 131 |
| 7.3.2.1 | Auxins | 131 |
| 7.3.2.2 | Jasmonic Acid | 133 |
| 7.3.2.3 | Gibberellins | 135 |
| 7.3.3 | Signal Transduction through Other, Nonmembrane-Associated Receptors | 136 |
| 7.3.3.1 | Abscisic Acid | 136 |

| | | |
|----------|--|------------|
| 7.3.3.2 | Salicylic Acid | 137 |
| 7.3.4 | Signal Transduction through Transmembrane-Receptors | 138 |
| 7.3.4.1 | Cytokinins | 138 |
| 7.3.4.2 | Ethylene | 139 |
| 7.3.4.3 | Brassinosteroids | 141 |
| 7.4 | Other Signaling Molecules | 141 |
| 7.4.1 | Phytochromes and Cryptochromes | 141 |
| 7.4.2 | Strigolactones and Nodulation Factors | 141 |
| 7.4.3 | Reactive Oxygen Species and Nitric Oxide | 142 |
| 7.4.4 | Peptide Signals | 143 |
| 7.4.5 | Volatile Signals | 143 |
| 7.4.6 | Polyamines | 145 |
| 7.4.7 | Phosphoinositides and Inositolpolyphosphates | 145 |
| 7.4.8 | Guanine Nucleotide-Binding Proteins | 146 |
| 7.4.9 | Ion Channels | 148 |
| 7.5 | Signal Transduction by Protein Phosphorylation | 148 |
| 7.6 | The Calcium Signaling Network | 149 |
| 7.7 | Stress-Induced Modulation of Gene Expression by microRNAs | 150 |
| | References | 152 |
| | Further Reading | 152 |
| 8 | Oxygen | 155 |
| | <i>Karl-Josef Dietz</i> | |
| 8.1 | Chemical Nature of Oxygen and Reactive Oxygen Species | 155 |
| 8.2 | Oxygen Metabolism | 156 |
| 8.2.1 | Photosynthesis and Oxygen Metabolism | 156 |
| 8.2.2 | Mitochondrion and Respiration | 158 |
| 8.2.3 | Oxygen Metabolism in Peroxisomes | 159 |
| 8.2.4 | Membrane-Associated Oxygen Metabolism | 159 |
| 8.3 | Oxygen Sensing | 160 |
| 8.4 | Antioxidant Defense | 161 |
| 8.5 | Reactive Oxygen Species in Abiotic Stresses | 162 |
| 8.6 | Reactive Oxygen Species in Biotic Interactions | 164 |
| 8.7 | Cell Signaling Function of Reactive Oxygen Species | 165 |
| | References | 168 |
| | Further Reading | 168 |
| 9 | Light | 171 |
| | <i>Thomas Kretsch</i> | |
| 9.1 | Principles of Light Detection and Photoreceptor Function | 171 |
| 9.1.1 | Modular Domain Structure of Photoreceptors | 171 |
| 9.1.2 | Identification and Classification of Photoreceptor Molecules | 171 |
| 9.1.3 | COP1-Containing E3 Ubiquitin Ligase Complexes: Central Components of Light Signaling in Plants | 173 |
| 9.2 | Sensing of UV-B Light | 175 |
| 9.2.1 | Effects of UV-B Light | 175 |
| 9.2.2 | UV-B Light Reception and Signal Transduction | 175 |
| 9.3 | The LOV Domain: A Variable Molecular Building Block of Many Blue and UV-A Light Sensors | 176 |
| 9.3.1 | LOV Chromophore-Binding Domains | 176 |
| 9.3.2 | Phototropins and Neochromes | 176 |
| 9.3.3 | Zeitlupe-Like Proteins | 176 |
| 9.3.4 | White Collar Light Sensors | 178 |
| 9.4 | Cryptochromes | 179 |
| 9.4.1 | Physiological Functions | 179 |
| 9.4.2 | Cryptochrome Structure and Light Signaling | 179 |

| | | |
|----------|---|-----|
| 9.5 | Phytochromes | 180 |
| 9.5.1 | The Light Sensor Module of Phytochromes | 180 |
| 9.5.2 | Physiological Functions of Phytochromes | 181 |
| 9.5.3 | Light Signal Transduction of Phytochromes | 182 |
| 9.5.4 | The Unique Function of Phytochrome A | 183 |
| 9.6 | Other Photoreceptor Systems | 185 |
| 9.7 | Flavonoid Biosynthesis in Plants – a Model for a Light-Regulated Adaptation Process | 185 |
| 9.7.1 | Flavonoids as Light Protectors | 185 |
| 9.7.2 | Light Regulation of the Flavonoid Biosynthesis Pathway | 186 |
| | References | 187 |
| | Further Reading | 188 |
| | | |
| 10 | Water | 191 |
| | <i>Wiebke Zschiesche and Klaus Humbeck</i> | |
| 10.1 | Water: the Essence of Life | 191 |
| 10.2 | Water Balance in Plants | 192 |
| 10.2.1 | Water Flow | 192 |
| 10.2.2 | Loss of Water by Stomatal Transpiration | 193 |
| 10.3 | Drought Stress | 194 |
| 10.3.1 | Drought Stress, a Worldwide Challenge | 194 |
| 10.3.2 | Cellular Disturbances | 194 |
| 10.3.3 | Adaptations to Survive Drought Stress | 194 |
| 10.3.4 | Molecular Mechanism of Drought Stress Tolerance | 197 |
| 10.3.4.1 | Downstream Signal Transduction | 197 |
| 10.3.4.2 | Role of Abscisic acid | 198 |
| 10.3.4.3 | Transcriptional Control Mechanism | 198 |
| 10.3.4.4 | Drought Stress Genes | 199 |
| 10.4 | Cold Stress and Freezing | 200 |
| 10.4.1 | Lowering of Temperature | 200 |
| 10.4.2 | Requirements of Ice Crystal Formation | 200 |
| 10.4.3 | Strategies to Survive Low Temperatures | 200 |
| 10.5 | Salinity | 201 |
| 10.5.1 | Salinity, an Increasing Problem in Agriculture | 201 |
| 10.5.2 | Salt Stress Alters Plant Functions | 201 |
| 10.5.3 | Salinity Tolerance | 202 |
| 10.5.4 | Signal Sensing and Transcriptional and Posttranscriptional Control | 202 |
| 10.5.5 | Target Processes | 203 |
| 10.6 | Flooding-Stress | 205 |
| 10.6.1 | Causes of Flooding | 205 |
| 10.6.2 | Effects on Cellular Energy Status | 205 |
| 10.6.3 | Acclimation to Hypoxia | 205 |
| | References | 206 |
| | Further Reading | 206 |
| | | |
| 11 | Mineral Deficiencies | 209 |
| 11.1 | Mineral Requirement and Insufficiencies | 209 |
| | <i>Edgar Peiter</i> | |
| 11.1.1 | The Essentiality of Mineral Nutrients for Plants | 209 |
| 11.1.2 | The Availability of Mineral Nutrients in the Soil | 211 |
| 11.1.3 | Mineral Nutrient Movement Toward and Uptake by the Plant Root | 212 |
| 11.1.4 | Plant Responses to a Variable Mineral Nutrient Availability | 214 |
| 11.1.4.1 | Nitrogen | 214 |
| 11.1.4.2 | Phosphorus | 215 |
| 11.1.4.3 | Iron | 218 |
| 11.1.4.4 | Zinc | 221 |

| | | |
|----------|---|-----|
| 11.1.4.5 | Copper | 222 |
| 11.2 | Carnivorous Plants and Fungi | 224 |
| | <i>Gerd-Joachim Krauss and Gudrun Krauss</i> | |
| 11.2.1 | Habitats, Diversity and Evolution | 224 |
| 11.2.2 | Trapping Devices | 226 |
| 11.2.3 | Prey Digestion and Nutrient Utilization | 229 |
| 11.2.4 | Coevolutionary Strategies of the Carnivorous Life Style: Pitcher Plants | 232 |
| | References | 233 |
| | Further Reading | 234 |
| 12 | Excess of Metals | 237 |
| | <i>Dietrich H. Nies, Eva Freisinger, and Gerd-Joachim Krauss</i> | |
| 12.1 | Properties of Transition Metals | 237 |
| 12.2 | Metal Transport through Cell Membranes | 238 |
| 12.3 | Biochemistry of the Minor Biometals: Essential, Desired, but Also Toxic | 240 |
| 12.3.1 | Oxyanions: Molybdate and Its Neighbors | 240 |
| 12.3.2 | Manganese: the Electron Buffer | 240 |
| 12.3.3 | Transition Metal Cations in Octahedral Complexes | 241 |
| 12.3.4 | Iron: Transmitter of Single Electrons | 241 |
| 12.3.5 | Cobalt and Nickel: between Iron and Zinc | 242 |
| 12.3.6 | Copper: the Oxygen-Handle | 243 |
| 12.3.7 | Zinc (and Exceptionally Cadmium): Non Redox-Active Transition Metals | 244 |
| 12.4 | Biochemistry of Chemical Elements Without Known Biological Functions | 244 |
| 12.4.1 | Cadmium and Lead | 244 |
| 12.4.2 | The Noble Metals Silver and Gold | 245 |
| 12.4.3 | Mercury | 245 |
| 12.4.4 | Arsenate, Arsenite and Antimonite | 246 |
| 12.5 | Metal-Binding Peptides and Proteins Involved in Transition Metal Homeostasis | 246 |
| 12.5.1 | Function of Intracellular Metal-Binding Polypeptides | 246 |
| 12.5.2 | Copper Chaperones | 246 |
| 12.5.3 | COG0523 Metal Chaperones | 246 |
| 12.5.4 | Glutathione and Related Compounds | 247 |
| 12.5.5 | Phytochelatins | 248 |
| 12.5.6 | Metallothioneins and Their Ubiquitous Features | 248 |
| 12.6 | Interaction of Plants and Fungi with Metals | 251 |
| 12.6.1 | Avoidance and Tolerance Mechanisms in Plants | 251 |
| 12.6.2 | Metal Hyperaccumulators | 252 |
| 12.6.3 | Interaction of Plants with Individual Metals | 252 |
| 12.6.4 | Avoidance and Tolerance Mechanisms in Fungi | 254 |
| | References | 256 |
| | Further Reading | 256 |
| 13 | Xenobiotics from Human Impacts | 259 |
| | <i>Magali Solé and Dietmar Schlosser</i> | |
| 13.1 | Xenobiotics: from Emission to Cellular Uptake | 259 |
| 13.1.1 | Emission, Dispersal, Fate Processes, and Bioavailability of Xenobiotics | 259 |
| 13.1.2 | Cellular Uptake of Xenobiotics | 260 |
| 13.2 | Adverse Effects of Xenobiotics: from Cells to Ecosystems | 265 |
| 13.2.1 | Effects at the Level of Individuals and Below | 265 |
| 13.2.2 | Effects at Higher Levels of Biological Organization: Populations, Communities, and Ecosystems | 267 |
| 13.3 | Organismal Responses: Biochemical Elimination of Xenobiotics | 268 |
| 13.3.1 | General Aspects of Biodegradation and Biotransformation Reactions | 268 |
| 13.3.2 | Initial Biochemical Attack on Xenobiotics – Phase I Reactions | 273 |
| 13.3.3 | Conjugate Formation from Functionalized Xenobiotics – Phase II Reactions | 273 |

- 13.3.4 Further Modification, Excretion, and Deposition of Xenobiotics and Their Metabolites – Phase III
 Reactions 274
 References 274
 Further Reading 274

Part IV: Organismal Interactions (Biotic Stress) 277

- 14 **The Biofilm Mode of Life 279**
Hans-Curt Flemming
- 14.1 What are Biofilms? 279
 14.2 Environmental Roles of Biofilms 280
 14.3 Life Cycle of Biofilms 281
 14.4 Investigation of Biofilms 283
 14.5 The Matrix: Extracellular Polymeric Substances 284
 14.5.1 The Extracellular Polymeric Substances (EPS) 284
 14.5.2 Predation and Antagonism 285
 14.5.3 VBNC Forms and Persisters 285
 14.5.4 Motility within Biofilms 285
 14.5.5 Matrix Stability 286
 14.5.6 Gradients and Heterogeneity in the Biofilm Matrix 287
 14.6 Communication in Biofilms 287
 14.7 Enhanced Resistance of Biofilm Organisms 288
 14.8 Emergent Properties of the Biofilm Mode of Life 290
 References 291
 Further Reading 291
- 15 **Rhizosphere Interactions 293**
Silvia D. Schrey, Anton Hartmann, and Rüdiger Hampp
- 15.1 Bacterial Communities in the Rhizosphere 294
 15.1.1 Plant Growth Promoting Rhizobacteria 294
 15.1.2 Plant Disease Suppression by Rhizobacteria – Indirect Plant Growth Promotion 297
 15.1.3 Nitrogen-Fixing Plant–Bacterium Symbiosis 299
 15.1.4 Actinobacteria: Prolific Producers of Natural Compounds 300
 15.1.5 Plant Pathogenic Soil Bacteria 300
 15.1.6 Plant-Associated Bacteria as (Opportunistic) Human Pathogens 301
 15.2 Fungi of the Rhizosphere 303
 15.2.1 Mycorrhiza: Chemical Dialogue between Plants and Mycorrhizal Fungi 303
 15.2.2 Chemical Cross Talk between Plant Roots and Pathogenic Fungi: Signaling Involved in Recognition 304
 15.2.3 Fungus–Bacterium Interactions 305
 15.2.3.1 Mycorrhiza Helper Bacteria 306
 15.2.3.2 Bacterial Mycophagy 306
 15.3 Plant–Plant Interactions 306
 15.3.1 Plant–Plant Interaction via Fungal Networks 307
 15.3.2 Parasitic Plants 307
 15.3.3 Allelopathy 308
 References 310
 Further Reading 310
- 16 **Plant-Animal Dialogues 313**
Susanne Preiß, Jörg Degenhardt, and Jonathan Gershenzon
- 16.1 The Flower Pollinator System 313
 16.1.1 General Aspects 313
 16.1.2 Flower Color 313
 16.1.3 Nectar 317
 16.1.4 Floral Scent 317

| | | |
|--------|---|-----|
| 16.1.5 | Flower Pollinator Interactions Are Guided by Complex Patterns of Biochemical Cues | 318 |
| 16.2 | Ant–Plant–Fungus Mutualism, a Three-Way Interaction | 319 |
| 16.3 | Phenolics in the Interaction between Plant and Animals | 320 |
| 16.3.1 | Salicin – a Defense Compound in <i>Salix</i> Species | 320 |
| 16.3.2 | Flavonoid Signals Modulate Herbivore Behavior | 321 |
| 16.4 | Alkaloids in the Interaction between Plants and Animals | 321 |
| 16.4.1 | The Monarch Butterfly | 321 |
| 16.4.2 | Optimal Defense in the Wild Ragwort <i>Senecia jacobea</i> | 322 |
| 16.4.3 | Endophytes and Plant Parasitic Nematodes Mediate Plant–Herbivore Interactions | 323 |
| 16.4.4 | Glucosinolates Are Pungent Antiherbivore Defenses of Mustards and Related Plant Species | 324 |
| 16.5 | Terpenes in Plant Defense | 325 |
| 16.5.1 | Monoterpene-Based Defenses of Thyme | 325 |
| 16.5.2 | Mammals, Wood Ants, and Scots Pine Trees | 326 |
| 16.5.3 | Ecological Role of Herbivore-Induced Plant Volatiles | 326 |
| 16.5.4 | Tritrophic Interactions with Herbivores and Herbivore Enemies | 326 |
| 16.5.5 | Interference of Plant Volatile Terpenes with Insect Pheromones | 328 |
| 16.5.6 | Terpene-Mediated Interactions between Plants Affect Herbivores | 329 |
| | References | 330 |
| | Further Reading | 330 |

Part V: The Methodological Platform 331

| | | |
|----------|--|-----|
| 17 | Sensing of Pollutant Effects and Bioremediation | 333 |
| | <i>Gerd-Joachim Krauss and Dietmar Schlosser</i> | |
| 17.1 | Pollutant Effect and Approaches to Characterize Exposure | 333 |
| 17.2 | Ecological Restoration and Bioremediation | 335 |
| 17.2.1 | Biological Ecosystem Components Mitigating Environmental Pollution | 335 |
| 17.2.2 | Present and Future Directions | 338 |
| | References | 339 |
| | Further Reading | 340 |
| 18 | The -Omics Tool Box | 343 |
| | <i>Dirk Schaumlöffel</i> | |
| 18.1 | Genomics | 343 |
| 18.1.1 | First-Generation Sequencing | 343 |
| 18.1.2 | Next-Generation Sequencing (NGS) | 344 |
| 18.1.2.1 | Pyrosequencing: 454/Roche FLX™ Pyrosequencer | 344 |
| 18.1.2.2 | Reversible Dye Terminator Technology: Illumina Genome Analyzer™ | 344 |
| 18.1.2.3 | Sequencing by Ligation: Applied Biosystems SOLiD™ Sequencer | 345 |
| 18.1.3 | Understanding the Genome: Genes and Their Functions | 345 |
| 18.2 | Transcriptomics | 345 |
| 18.2.1 | DNA Microarrays | 346 |
| 18.2.2 | Transcriptome Sequencing by NGS Platforms | 346 |
| 18.3 | Proteomics | 346 |
| 18.3.1 | Proteomic Strategies | 347 |
| 18.3.1.1 | Sample Preparation for Proteomics | 347 |
| 18.3.1.2 | Protein Separation | 347 |
| 18.3.1.3 | Differential Proteome Analysis | 348 |
| 18.3.1.4 | Identification of Proteins | 348 |
| 18.3.1.5 | Analytical Protein Microarrays | 348 |
| 18.3.1.6 | Bottom-Up Proteomics | 348 |
| 18.3.1.7 | Shotgun Proteomics | 349 |
| 18.3.1.8 | Top-Down Proteomics | 350 |
| 18.3.1.9 | <i>De novo</i> Sequencing of Proteins | 350 |
| 18.3.2 | Protein Mass Spectrometry | 350 |

| | | |
|-----------|--|------------|
| 18.3.2.1 | Ion Sources for Biomolecules | 350 |
| 18.3.2.2 | Mass Analyzers | 351 |
| 18.3.2.3 | Tandem Mass Spectrometry | 352 |
| 18.3.2.4 | Element Mass Spectrometry: ICP MS | 353 |
| 18.3.3 | Quantitative Proteomics | 354 |
| 18.3.3.1 | Label-Free Relative Quantification | 354 |
| 18.3.3.2 | Chemical and Metabolic Labeling with Stable Isotopes and Metals for Relative Quantification | 354 |
| 18.3.3.3 | Absolute Quantification Strategies | 354 |
| 18.3.4 | Determination of the 3D Protein Structure and Functional Evaluation | 355 |
| 18.3.4.1 | X-Ray Crystallography and Protein NMR | 355 |
| 18.3.4.2 | Functional Protein Microarrays | 355 |
| 18.3.5 | Meta-Omics Approaches | 355 |
| 18.4 | Metabolomics | 356 |
| 18.4.1 | Analytical Strategies | 356 |
| 18.4.2 | Metabolomics in Single Cells | 358 |
| 18.4.3 | Integrating -Omics Techniques | 360 |
| 18.5 | Metallomics | 360 |
| 18.5.1 | Analytical Strategies | 361 |
| 18.5.1.1 | Element Mass Spectrometry (ICP MS) | 361 |
| 18.5.1.2 | Coupling Techniques | 361 |
| 18.5.1.3 | Elemental Imaging Techniques | 361 |
| 18.5.1.4 | Bioinformatic Approaches | 362 |
| 18.5.2 | Functional Connections between DNA, Proteins, Metabolites, and Metals | 362 |
| 18.5.3 | Metallothiolomics | 362 |
| | References | 365 |
| | Further Reading | 365 |
| 19 | Microscope Techniques and Single Cell Analysis | 367 |
| | <i>Bettina Hause and Gerd Hause</i> | |
| 19.1 | Visualization Principles | 367 |
| 19.1.1 | Light Microscopy | 367 |
| 19.1.1.1 | Bright Field Microscopy | 367 |
| 19.1.1.2 | Dark Field Microscopy | 370 |
| 19.1.1.3 | Fluorescence Microscopy | 370 |
| 19.1.2 | Advanced Fluorescence Techniques/Generation of Optical Sections | 370 |
| 19.1.2.1 | Confocal Laser Scanning Microscopy (CLSM) | 370 |
| 19.1.2.2 | Multiphoton Microscopy | 371 |
| 19.1.2.3 | Spinning Disk Microscopy | 371 |
| 19.1.2.4 | Stimulated Emission Depletion (STED), 4Pi Microscopy, and 4Pi-STED-Microscopy | 371 |
| 19.1.2.5 | Photo-Activated Localization Microscopy (PAL-M)/Stochastic Optical Reconstruction Microscopy (STORM) | 371 |
| 19.1.2.6 | Structured Illumination Microscopy (SIM) | 372 |
| 19.1.3 | Electron Microscopy | 372 |
| 19.1.3.1 | Transmission Electron Microscopy (TEM) | 372 |
| 19.1.3.2 | Scanning Electron Microscopy (SEM) | 373 |
| 19.1.4 | Scanning Probe Microscopy | 373 |
| 19.2 | Preparation of Biological Materials | 373 |
| 19.2.1 | Chemical Fixation | 373 |
| 19.2.2 | Physical Fixation/Cryofixation | 374 |
| 19.3 | Detection Methods – from Macromolecules to Ions | 375 |
| 19.3.1 | Histological Staining | 375 |
| 19.3.2 | Autoradiography | 375 |
| 19.3.3 | Immunocytochemistry (IC) | 376 |

| | | |
|--------|---|------------|
| 19.3.4 | <i>In situ</i> Hybridization (ISH) | 377 |
| 19.3.5 | Reporter Molecules in Transgenic Approaches | 378 |
| 19.4 | Single Cell Technologies | 380 |
| | References | 382 |
| | Further Reading | 382 |
| | Glossary | 383 |
| | Index | 397 |