

# Contents

*Foreword by Lynn Margulis* ix  
*Preface* xi

## Chapter 1

### Introduction 1

- A. *Concepts and Definitions* 1
  - 1. Introduction 1
  - 2. Subdivisions of Symbiosis 2
  - Box Essay: *Anton de Bary: Pioneer in Symbiosis* 3
  - 3. Parasitism and Disease 4
- B. *Symbiosis in All Forms of Life* 6
- C. *Classification of Symbioses* 8
  - 1. Location of the Symbionts 8
  - 2. Persistence of the Symbiosis 8
  - 3. Dependence on the Symbiosis 9
  - 4. Specificity of the Symbionts 9
  - 5. Symbiotic Products 9
- D. *Who Studies Symbiosis?* 9
- E. *Summary and Perspectives* 10
  - Review Questions* 11
  - Further Reading* 11
  - Bibliography* 12

## Chapter 2

### Viral Symbiotic Associations 13

- A. *Introduction* 13
  - 1. Virus Structure 13
  - 2. Classification of Viruses 14
  - 3. Virus Life Cycle 14
- B. *Viruses in Bacteria* 15
- C. *Viruses in Animals* 18
  - 1. Insects 18
  - 2. Other Invertebrates 19
  - 3. Vertebrates 20
  - 4. Cancers: Cellular Transformation 21
- D. *Mycoviruses: Viral Inhabitants of Fungi* 22
- E. *Viruses in Algae* 23
- F. *Viruses in Plants* 23

- G. *Summary and Perspectives* 24
- Review Questions* 26
- Further Reading* 26
- Bibliography* 26

## Chapter 3

### Bacterial Associations: Bacteria as Symbionts of Other Bacteria, Protoctists, and Animals 28

- A. *General Characteristics of Prokaryotes* 28
- B. *Bacterial Symbionts of Bacteria* 28
- C. *Bacterial Symbionts of Protoctists* 31
  - 1. *Paramecium* 31
  - 2. *Amoeba* 33
- D. *Bacterial Symbionts of Animals* 34
  - 1. Bacterial Luminescence 34
  - 2. Bacterial Symbionts of Insects 35
  - 3. Bacterial Symbionts of Ruminants 37
  - 4. Bacterial Symbionts of Tube Worms 39
  - Box Essay: *Life in the Alimentary Canal* 38
- E. *Summary and Perspectives* 40
  - Review Questions* 40
  - Further Reading* 41
  - Bibliography* 41

## Chapter 4

### Bacterial Associations: Bacteria as Symbionts of Plants 43

- A. *Introduction* 43
- B. *Agrobacterium and Crown Gall Disease* 43
- C. *Nitrogen-fixing Symbioses* 46
  - 1. *Rhizobium*-Legume Symbiosis 46
  - 2. Actinorhizal Symbiosis 49
  - 3. Cyanobacteria and Plants 50
- D. *Mycoplasmas: The Smallest of Bacteria* 53
- E. *Summary and Perspectives* 54
  - Review Questions* 55
  - Further Reading* 55
  - Bibliography* 55

**Chapter 5****Symbiosis and the Origin of the Eukaryotic Cell 57**

- A. *Introduction* 57
- B. *Theories on the Origin of Eukaryotic Cells* 57
  - 1. Serial Endosymbiosis Theory 57
  - 2. Autogenous Theory 57
  - 3. Fungal Theory 58
- C. *Origin and Evolution of the Eukaryotic Cell* 59
  - 1. Ancestral Host Cell 59
  - 2. Endomembranous Origin of Cell Organelles 59
  - 3. Endosymbiotic Origin of Mitochondria, Chloroplasts, and Microtubules 59
- Box Essay: *Symbiotic Jumping Genes* 61
- D. *Circadian Rhythms* 63
- E. *Host Cell: An Intracellular Ecosystem* 63
- F. *Symbiosis and Parasexuality* 63
- G. *A New Terminology* 64
- H. *Summary and Perspectives* 64
  - Review Questions* 64
  - Further Reading* 65
  - Bibliography* 65

**Chapter 6****Fungal Associations: Fungi as Symbionts of Protoctists and Animals 67**

- A. *Introduction* 67
- B. *Characteristics of Fungi* 67
- C. *Classification* 68
- D. *Symbionts of Protoctists and Animals* 68
  - 1. Protoctists 68
  - 2. Nematode-trapping Fungi 69
  - 3. Endosymbionts of Nematodes 71
  - 4. Arthropods 73
  - 5. Symbionts of Man and Other Vertebrates 82
  - 6. Mycotoxins 84
- E. *Summary and Perspectives* 84
  - Box Essay: *Roland Thaxter: Pioneer in Insect Mycology* 85
  - Review Questions* 86
  - Further Reading* 86
  - Bibliography* 86

**Chapter 7****Fungal Associations: Fungi as Symbionts of Fungi, Algae, and Plants 88**

- A. *Mycosymbionts of Fungi* 88

- 1. Necrotrophic Mycosymbionts 88

- 2. Biotrophic Mycosymbionts 89

- B. *Fungal-Algal Associations* 89

- 1. Mycophycobioses 89

- 2. Lichens 90

- C. *Fungi and Plants* 96

- 1. Mycorrhizas 96

- 2. Plant Diseases: Rusts, Smuts, and Powdery Mildews 101

- 3. Hypovirulence 103

- D. *Summary and Perspectives* 104

- Box Essay: *The Fungal Haustorium* 104

- Review Questions* 106

- Further Reading* 106

- Bibliography* 106

**Chapter 8****Protoctistan Symbiotic Associations: Parasitic and Mutualistic Protozoans 108**

- A. *Introduction* 108
- B. *Kingdom Protoctista* 108
  - 1. Characteristics 108
  - 2. Classification 108
  - 3. A Generalized Life Cycle 109
- C. *Protozoans as Symbionts* 109
  - 1. Amoebae 109
  - Box Essay: *Guests and Hosts* 110
  - 2. Ciliates 112
  - 3. Flagellates 115
  - 4. Apicomplexans 122
- D. *Summary and Perspectives* 127
  - Review Questions* 129
  - Further Reading* 129
  - Bibliography* 130

**Chapter 9****Protoctistan Symbiotic Associations: Algae 131**

- A. *Algae and Marine Invertebrates* 131
  - 1. Introduction 131
  - 2. Sea Anemones and Jellyfish 132
  - 3. Reef-building Corals 132
  - 4. Tridacnid Clams 133
  - 5. Foraminiferans and Radiolarians 133
  - 6. *Convoluta roscoffensis* 134
  - 7. Sponges 134
  - 8. Sea Slugs 135
  - 9. Tunicates 135
- B. *Algae and Freshwater Invertebrates* 136
  - 1. *Hydra* 136
  - 2. *Paramecium* 138

- C. *Parasitic Algae* 139
  - 1. Parasitic Green Algae 139
  - 2. Parasitic Red Algae 139
- D. *Summary and Perspectives* 140
  - Review Questions* 141
  - Further Reading* 141
  - Bibliography* 142

## Chapter 10

### Helminthic Symbiotic Associations: Flukes, Tapeworms, Nematodes 143

- A. *Introduction* 143
- B. *Classification* 144
- C. *Trematodes: The Flukes* 144
  - 1. Some Fluke Symbioses 144
  - 2. Fluke Host-Parasite Relationships 146
- D. *Cestodes: The Tapeworms* 149
  - 1. The Tapeworm Tegument 150
  - 2. Some Tapeworm Symbioses 150
- E. *Nematodes: The Roundworms* 151
  - 1. Parasites of Man and Vertebrates 151
  - Box Essay: *Hormones and Animal Symbioses* 153
  - 2. Nematode-Insect Symbioses 155
  - 3. Nematode-Plant Symbioses 158
- F. *Summary and Perspectives* 162
  - Review Questions* 162
  - Further Reading* 162
  - Bibliography* 163

## Chapter 11

### Plant Symbiotic Associations 164

- A. *Parasitic Plants* 164
  - 1. Mistletoes 164
  - 2. Sandalwoods 166
  - 3. Dodders 166
  - 4. Broomrapes and Figworts 166
  - 5. *Hydnora* 166
  - 6. *Rafflesia* 166
- B. *Plants and Pollinators* 167
  - 1. Coevolution of Insects and Plants 167
  - 2. Floral Features That Attract Pollinators 168
  - 3. Types of Flowers 171
  - 4. Floral Changes after Pollination 171
- C. *Summary and Perspectives* 172
  - Review Questions* 172
  - Further Reading* 173
  - Bibliography* 173

## Chapter 12

### Behavioral and Social Symbioses 174

- A. *Introduction* 174
- B. *Behavioral Symbioses* 174
  - 1. Cleaning Symbioses 174
  - 2. Anemone-Clown Fish Symbiosis 176
  - 3. Behavior of Parasitized Host Animals 178
- C. *Social Symbioses* 179
  - 1. Social Parasitism 179
  - 2. Social Commensalism 181
  - 3. Social Mutualism 181
- D. *Summary and Perspectives* 182
  - Review Questions* 183
  - Further Reading* 183
  - Bibliography* 183

## Chapter 13

### Symbiosis and Evolution 184

- A. *Introduction* 184
- B. *Genetic Interactions in Symbiotic Systems* 185
  - 1. Gene-for-gene Relationships 185
  - 2. Genetic Polymorphism 185
- C. *Nature of Host Resistance* 186
  - 1. Resistance in Animals 186
  - 2. Resistance in Plants 188
- D. *Products of Coevolutionary Symbioses* 189
- E. *Ecological and Evolutionary Perspectives on Symbiosis* 190
  - 1. The Symbiotic Continuum 190
  - 2. Theories of Mutualism 191
  - 3. Categories of Mutualism 191
  - 4. Distribution of Mutualism 192
  - 5. r and K Selection: Life History Patterns and Symbiosis 193
  - 6. Evolution in a Symbiotic Environment 193
- F. *Symbiosis and Human Affairs* 194
- G. *Summary and Perspectives* 195
  - Review Questions* 196
  - Further Reading* 196
  - Bibliography* 197

## Appendix: Historical Landmarks in Symbiology 199

## Glossary 202

## Index 206