

# Contents

Preface — v

Contributing authors — xii

Corien Bakermans

<b>1</b>	<b>Extreme environments as model systems for the study of microbial evolution — 1</b>
1.1	Introduction — 1
1.2	Extreme environments as model systems — 1
1.3	What is known about microbial evolution? — 4
1.3.1	Community diversity as a measure of evolution — 7
1.3.2	Adaptive traits as a measure of evolution — 8
1.4	Themes from extreme environments — 9
1.5	Conclusions and open questions — 11

Francisco J. López de Saro, Héctor Díaz-Maldonado, and Ricardo Amils

<b>2</b>	<b>Microbial evolution: the view from the acidophiles — 19</b>
2.1	Introduction — 19
2.2	Horizontal gene transfer — 20
2.3	The mobilome — 21
2.4	Phages — 22
2.5	Plasmids — 23
2.6	Transposons — 24
2.7	Evolution and ecology: long term studies of genetic variation — 25
2.8	Future directions — 26

R. Eric Collins

<b>3</b>	<b>Microbial Evolution in the Cryosphere — 31</b>
3.1	Overview — 31
3.1.1	Cryospheric environments — 31
3.1.2	Modes of evolution — 34
3.1.3	Adaptations to living with ice — 37
3.2	Focus on sea ice — 38
3.2.1	Sea ice characteristics — 38
3.2.2	Evolutionary modes in sea ice — 42
3.3	Ongoing work and future directions — 43
3.3.1	Field work and experimentation — 43
3.3.2	‘omics’ in the cryosphere — 44
3.3.3	Linking phenotype and genotype — 46

Maximiliano J. Amenabar, Matthew R. Urschel, and Eric S. Boyd

4 **Metabolic and taxonomic diversification in continental magmatic hydrothermal systems — 57**

4.1 **Introduction — 57**

4.2 **Geological drivers of geochemical variation in continental hydrothermal systems — 59**

4.3 **Taxonomic and functional diversity in continental hydrothermal ecosystems — 64**

4.4 **Application of phylogenetic approaches to map taxonomic and functional diversity on spatial geochemical landscapes — 68**

4.5 **Molecular adaptation to high temperature — 72**

4.5.1 **Lipids — 72**

4.5.2 **Protein stability — 73**

4.5.3 **Cytoplasmic osmolytes — 74**

4.5.4 **Motility — 76**

4.6 **Mechanisms of evolution in high temperature environments — 78**

4.7 **Concluding remarks — 81**

Aharon Oren

5 **Halophilic microorganisms and adaptation to life at high salt concentrations – evolutionary aspects — 97**

5.1 **Phylogenetic and physiological diversity of halophilic microorganisms — 97**

5.2 **What adaptations are necessary to become a halophile? — 99**

5.3 **Is an acidic (meta)proteome indeed indicative for halophily and high intracellular ionic concentrations? — 100**

5.4 **Genetic variation and horizontal gene transfer in communities of halophilic Archaea — 101**

5.5 ***Salinibacter*: convergent evolution and the ‘salt-in’ strategy of haloadaptation — 103**

5.6 **High intracellular K<sup>+</sup> concentrations but no acidic proteome? The case of the *Halanaerobiales* — 104**

5.7 **Different modes of haloadaptation in closely related *Halorhodospira* species — 105**

5.8 **Final comments — 105**

John R. Battista

6 **The origin of extreme ionizing radiation resistance — 111**

6.1 **Introduction and background — 111**

6.1.1 **Ionizing radiation — 111**

6.1.2 **Biological damage caused by electromagnetic radiations — 112**

6.1.3	Exposure to ionizing radiation selects for ionizing radiation resistant bacteria — 113
6.1.4	The occurrence of extreme ionizing radiation resistance within the Bacteria and Archaea — 114
6.1.5	Natural sources of ionizing radiation — 115
6.2	The existence of extreme ionizing radiation resistance is difficult to reconcile with the natural history of the Earth — 115
6.3	Proposed explanations for the existence of ionizing radiation resistance — 116
6.3.1	Panspermia: the exchange of bacteria between planets — 116
6.3.2	Man-made sources of ionizing radiation are the source of extreme ionizing radiation resistant microorganisms — 118
6.3.3	Exaptation — 118
6.4	Conclusions — 120

Jennifer B. Glass, Cecilia Batmalle Kretz, Melissa J. Warren, and Claire S. Ting

7	Current perspectives on microbial strategies for survival under extreme nutrient starvation: evolution and ecophysiology — 127
7.1	Introduction — 127
7.2	Carbon — 128
7.3	Nitrogen — 133
7.4	Phosphorus — 136
7.5	Iron — 137
7.6	Other micronutrients — 138
7.7	Conclusions — 139

Joseph Seckbach and Pabulo Henrique Rampelotto

8	Polyextremophiles — 153
8.1	Introduction — 153
8.2	Bacteria — 154
8.2.1	<i>Deinococcus radiodurans</i> : Conan the bacterium — 154
8.2.2	<i>Chroococcidiopsis</i> — 156
8.3	Archaea — 157
8.3.1	<i>Halobacterium salinarum</i> NRC-1: a model organism — 157
8.4	Eukaryota — 158
8.4.1	<i>Cyanidiophyceae</i> — 158
8.4.2	Lichens — 159
8.4.3	Tardigrades: nature's toughest animal — 161
8.5	Conclusion — 162

William F. Martin, Sinje Neukirchen, and Filipa L. Sousa

9 Early life — 171

Cene Gostinčar, Nina Gunde-Cimerman, and Martin Grube

10 Polyextremotolerance as the fungal answer to changing environments — 185

10.1 Introduction — 185

10.2 Extremes in nature — 185

10.3 Anthropogenic extremes: indoor habitats — 190

10.4 Coincidental opportunities: opportunistic infections — 192

10.5 Conclusions: polyextremotolerance — 197

Alexander I. Culley, Migun Shakya, and Andrew S. Lang

11 Viral evolution at the limits — 209

11.1 Introduction — 209

11.2 Acidic hot springs and hypersaline environments — 209

11.3 The deep sea — 212

11.4 Polar environments — 213

11.5 Viruses and their effects on host organisms and communities — 214

11.6 Future perspectives — 216

Eva C. M. Nowack and Arthur R. Grossman

12 Evolutionary pressures and the establishment of endosymbiotic associations — 223

12.1 Introduction — 223

12.2 Diversity, evolution, and stability of endosymbiotic relationships — 227

12.2.1 Diversity of endosymbionts and their physiological functions — 227

12.2.2 Evolutionary routes to establish and maintain endosymbiosis — 228

12.2.3 Stability and the age of endosymbioses — 230

12.3 Genome evolution in endosymbiotic bacteria — 230

12.3.1 Reductive genome evolution in endosymbionts — 230

12.3.2 Evolution toward an organelle and beyond — 232

12.4 Evolution of the host genome as shaped by endosymbiosis — 235

12.4.1 Complementarity of host and endosymbiont metabolic abilities — 235

12.4.2 Acquisition of symbiotic potential — 236

12.4.3 Redefinition of immune functions — 238

12.5 Conclusions and future directions — 239

Fabia U. Battistuzzi and Anais Brown

13 Rates of evolution under extreme and mesophilic conditions — 247

13.1 Overview — 247

13.2	How do we estimate rates of genetic change? — 253
13.2.1	Relative rate estimation — 254
13.2.2	Absolute rate estimation — 255
13.3	How do we model evolutionary rates? — 257
13.4	Environments and evolutionary rates — 257
13.4.1	Evolutionary rates of pathogens — 258
13.5	Large-scale genomic changes: duplications/loss and horizontal gene acquisition — 259
13.5.1	Rates of gene duplication and loss — 259
13.5.2	Highways of horizontal gene transfers — 261
13.6	Conclusions — 263
	<b>Index — 269</b>