

Contents

<i>List of Abbreviations</i>	<i>page xi</i>
<i>Preface</i>	<i>xiii</i>
1 Introduction	01
1.1 Historical background	01
1.2 Definitions	02
1.2.1 Responses of motile microorganisms to environmental stimuli	04
1.2.2 Behavioral responses of sessile plants to environmental stimuli	08
1.2.3 "Microgravity" and hypergravity	10
1.3 Ecological significance	10
2 Methods in Gravitational Biology	12
2.1 Horizontal microscopes and clinostats	14
2.2 Free-fall machine	18
2.3 Drop facilities: towers, shafts, and balloons	19
2.4 Parabolic flights	19
2.4.1 Aircraft	19
2.4.2 Sounding rockets	20
2.5 Centrifuges	23
2.6 Shuttles, satellites, and space stations	25
2.7 Direct manipulation of gravisensors	26
3 Image Analysis	28
3.1 Introduction	29
3.2 Hardware	29

3.3	Software	33
3.3.1	Identification of objects	34
3.3.2	Cell counting and area determination	36
3.3.3	Organism tracking	37
3.3.4	3D tracking	42
3.4	Fluorescence imaging	43
4	Ciliates	51
4.1	<i>Paramecium</i>	51
4.1.1	Morphological aspects	51
4.1.2	<i>Paramecium</i> – a swimming sensory cell	53
4.1.3	Ion channels	53
4.1.4	Regulation of the ciliary beat pattern	54
4.1.5	<i>Paramecium</i> mutants	57
4.1.6	Graviresponses of <i>Paramecium</i>	58
4.2	<i>Loxodes</i>	67
4.2.1	Müller organelles of <i>Loxodes</i> – cellular gravisensors	69
4.2.2	Graviresponses of <i>Loxodes</i>	70
4.2.3	Graviperception in <i>Loxodes</i> – conclusion	72
4.3	Other ciliates	72
5	Flagellates	75
5.1	Introduction	76
5.2	<i>Euglena</i>	78
5.2.1	Gravitaxis in <i>Euglena</i> – the phenomenon	80
5.2.2	Passive orientation vs. active sensing	83
5.2.3	Sensor for gravity perception	87
5.2.4	Sensory transduction chain of gravitaxis	96
5.3	Gravitaxis in <i>Chlamydomonas</i>	97
5.4	Other flagellates	100
5.5	Circadian rhythm of gravitaxis	104
6	Other Organisms	106
6.1	Amoeba	106
6.2	Slime molds	106
6.2.1	<i>Dictyostelium</i>	106
6.2.2	<i>Physarum</i>	107
6.3	Reproductive unicellular stages	110
6.3.1	Fungal zoospores	110
6.3.2	Sperm cells	111
6.4	Bacteria	111

7 Responses to Other Stimuli	113
7.1 Introduction	113
7.2 Photoorientation	114
7.2.1 Photokinesis	115
7.2.2 Photophobic responses	115
7.2.3 Phototaxis	118
7.2.4 Other light-induced responses	129
7.3 Orientation in chemical gradients	130
7.4 Orientation in thermal gradients	134
7.5 Guidance by the Earth's magnetic field	136
7.6 Galvanotaxis	138
7.7 Interaction between different stimuli and responses	139
8 Energetics	141
8.1 Gravity is a small power that applies a force to a mass	142
8.2 Displacement of masses or work has to be done	150
8.3 The potential role of membranes in graviperception	151
8.3.1 Membrane compressibility	152
8.3.2 Membrane expansion	152
8.3.3 Membrane thickness elasticity	154
8.3.4 Membrane shearing	155
8.3.5 Membrane bending and curvature	156
8.4 The hearing process as a model for graviperception in single cells	158
9 Models for Graviperception	165
9.1 Gravity-buoyancy model	167
9.2 Drag-gravity model	173
9.3 Propulsion-gravity model	174
9.4 Physiological models – statocyst model	175
9.4.1 Gravitaxis	175
9.4.2 Gravikinesis	182
10 Evolutionary Aspects of Gravisensing: From Bacteria to Men	184
10.1 Development of gravisensing during evolution	184
10.2 Primary receptor for gravity	186
10.3 Graviorientation in microorganisms	188
10.4 Gravitropism in lower and higher plants	189
10.4.1 Gravitropism in fungi	189
10.4.2 Gravitropism in <i>Chara</i> rhizoids	191
10.4.3 Gravitropism in higher plants	193
11 Perspectives	197
<i>References</i>	205
<i>Index</i>	251