Contents

1 Introduction to Mammals 1

1.1 Living Mammals 1
- 1.1.1 *Monotremes, Marsupials, and Placentals* 2
- 1.1.2 *Characteristics of Living Mammals* 7
- 1.1.3 *Phylogeny* 9

1.2 The Mammalian Bauplan in an Evolutionary Context 10
- 1.2.1 *Body Mass* 11
- 1.2.2 *Skin and Fur* 13
- 1.2.3 *Endothermy and Energetics* 14
- 1.2.4 *Respiration* 15
- 1.2.5 *Circulation* 18
- 1.2.6 *Digestion* 21
- 1.2.7 *Locomotion* 21
- 1.2.8 *Excretion* 25
- 1.2.9 *Neurobiology* 27
- 1.2.10 *Reproduction and Development* 30

1.3 Early Mammals 32
- 1.3.1 *Characteristics of Early Mammals* 32
- 1.3.2 *Transition from Mammal-Like Reptiles to Mammals* 35
- 1.3.3 *Mammalian Evolutionary History* 38
- 1.3.4 *Historical Zoogeography* 41

1.4 Ecological and Environmental Diversity of Mammals 45
- 1.4.1 *Climate and Biomes* 45
- 1.4.2 *Zoogeography* 47
- 1.4.3 *Habitats and Diet* 49

1.5 Importance of Mammals 53
- 1.5.1 *Pinnacle Taxon* 53
- 1.5.2 *Conservation* 54
- 1.5.3 *Human Perspective* 56

2 General Physiological Principles 60

2.1 Scaling 60
- 2.1.1 *Isometry and Allometry* 61
- 2.1.2 *Physiological Variables* 63
- 2.1.3 *Life History Variables* 66

2.2 Control Systems 68
2.2.1 *Regulation of Homeostasis* 69
2.2.2 *Neural Control* 72
2.2.3 *Chemical Control* 76
2.2.4 *Glands* 78
2.2.4.1 Exocrine Glands 79
2.2.4.2 Endocrine Glands 82
2.3 Energy Balance 88
2.3.1 *Anaerobic Metabolism* 89
2.3.2 *Aerobic Metabolism* 91
2.3.3 *Joule Equivalents of Food* 93
2.4 Thermal Balance 96
2.4.1 *Temperature* 96
2.4.2 *Thermal Exchange* 96
2.4.3 *Body Temperature Regulation* 100
2.5 Gas Exchange 102
2.5.1 *O_2 and CO_2 Cascades* 104
2.5.2 *Diffusion* 106
2.5.3 *Convection* 107
2.5.4 *Gas Laws* 107
2.5.5 *Flow through Vessels* 109
2.5.6 *Acid-Base Balance* 112
2.6 Digestion 115
2.6.1 *Digestive Tract* 115
2.6.2 *Digestive Function* 118
2.6.3 *Digestibility* 122
2.6.4 *Specific Dynamic Action* 123
2.7 Water and Solute Balance 123
2.7.1 *Water and Solute Intake* 125
2.7.2 *Water and Solute Loss* 127
2.8 Locomotion 132
2.8.1 *Walking and Running* 135
2.8.2 *Gliding and Flying* 136
2.8.3 *Swimming and Diving* 139
2.9 Reproduction and Development 141
2.9.1 *Egg-Laying* 142
2.9.2 *Live Birth* 143

3 Physiological Characteristics of Mammals 146

3.1 Energetics 146
3.1.1 *Basal Metabolic Rate* 147
3.1.2 *Incremental Metabolic Rate* 152
3.1.2.1 Locomotion 153

3.1.2.2 Digestion 155
3.1.2.3 Summit Metabolism 158
3.1.3 *Field Metabolic Rate* 158
3.2 Thermoregulation 161
3.2.1 *Body Temperature* 161
3.2.2 *Evolution of Endothermy* 165
3.2.3 *Thermogenesis* 166
3.2.3.1 Shivering Thermogenesis 168
3.2.3.2 Non-shivering Thermogenesis 170
3.2.3.3 Brown Adipose Tissue 171
3.2.3.4 Insulation 174
3.2.4 *Heterothermy* 180
3.2.4.1 Regional Heterothermy 180
3.2.4.2 Temporal Heterothermy 184
3.2.5 *Heat loss* 192
3.2.5.1 Non-evaporative Heat Loss 192
3.2.5.2 Evaporative Heat Loss 194
3.2.6 *Fever* 195
3.2.7 *Development* 197
3.2.8 *Bergmann's and Other 'Rules'* 198
3.3 Ventilation 201
3.3.1 *Airways and Lungs* 201
3.3.2 *Ventilatory Mechanics* 202
3.3.3 *Ventilatory Control* 205
3.3.4 *Fetal and Newborn Ventilation* 206
3.4 Circulation 207
3.4.1 *Blood* 209
3.4.2 *The Heart* 214
3.4.3 *Lymphatic System* 215
3.4.4 *Gas and Heat Transport* 216
3.4.5 *Fetal and Newborn Circulation* 219
3.5 Feeding and Digestion 221
3.5.1 *Foods and Consumers* 222
3.5.1.1 Insectivores and Carnivores 227
3.5.1.2 Omnivores 229
3.5.1.3 Herbivores 230
3.5.2 *Digestive Function and Flexibility* 233
3.5.3 *Lactation* 237
3.6 Water and Solutes 240
3.6.1 *Water and Solute Balance* 240
3.6.2 *Evaporative Water Loss* 244
3.6.3 *The Kidney* 249
3.6.3.1 Vasopressin 256
3.6.3.2 Aquaporins 256
3.6.4 *Nitrogenous Wastes* 258
3.6.4.1 Ammonia 258

3.6.4.2 Urea 260
3.6.4.3 Purines 261
3.7 Neurobiology 261
3.7.1 *Central Nervous System* 262
3.7.2 *Sensory Systems* 264
3.7.2.1 Chemoreception 265
3.7.2.2 Mechanoreception 267
3.7.2.3 Thermoreception 267
3.7.2.4 Pain Reception 268
3.7.2.5 Audition 268
3.7.2.6 Electroreception 269
3.7.2.7 Magnetoreception 270
3.7.2.8 Baroreception 271
3.7.2.9 Humidity 271
3.7.2.10 Vision 272
3.8 Reproduction 275
3.8.1 *The Monotreme 'Strategy': Egg-Laying* 279
3.8.2 *The Marsupial 'Strategy': Short Gestation* 282
3.8.3 *The Placental 'Strategy': Prolonged Gestation* 286

4 Physiological Adaptations to Extreme Environments 290

4.1 Cold Environments 290
4.1.1 *Endurers* 291
4.1.2 *Avoiders* 303
4.2 Hot Environments 312
4.2.1 *Endurers* 313
4.2.2 *Avoiders* 320
4.3 Underground Environments 323
4.3.1 *Hypercapnic Hypoxia* 323
4.3.2 *Temperature and Energetics* 325
4.4 High Altitude Environments 328
4.4.1 *Hypoxic Hypoxia* 329
4.4.2 *Thermal Balance* 335
4.5 Aquatic Environments 336
4.5.1 *Diving Response* 338
4.5.2 *O_2 Stores and Aerobic Dive Limit* 341
4.5.3 *Hyperbaria: Diving under Pressure* 343
4.5.4 *Vision and Echolocation* 347
4.6 Extreme Terrestrial Locomotion 349
4.6.1 *Cursorial Locomotion* 350
4.6.2 *Brachiation and Climbing* 354
4.6.3 *Migration* 355
4.7 Flying Mammals 358
4.7.1 *Metabolic Cost of Flight* 363

4.7.2 *Thermal Balance* 367
4.7.3 *Digestion, Respiration, and Circulation* 369
4.7.4 *Echolocation* 376
4.8 Difficult Digestion 377
4.8.1 *Keratin, Bone, Wax, and Chitin* 378
4.8.2 *Plant Fermentation* 381

5 Concepts, Approaches, Techniques, and Applications 393

5.1 The Comparative Method 393
5.1.1 *Phylogenies* 394
5.1.2 *Phylogenetic Methods* 399
5.1.3 *Allometry and Scaling* 403
5.2 Mass, Temperature, and Humidity 405
5.2.1 *Mass* 405
5.2.2 *Temperature* 407
5.2.3 *Humidity* 411
5.3 Energetics 413
5.3.1 *Laboratory Energetics* 413
5.3.2 *Field Energetics* 420
5.4 Remote Sensing and Thermal Logging 425
5.5 Circulatory Systems 430
5.6 Molecular Biology 432
5.7 Isotopes 437
5.7.1 *Isotope Turnover* 439
5.7.2 *Isotope Ratios* 440
5.7.3 *Radioisotopes in Nuclear Medicine* 443
5.8 Species Geographic Range 444

6 Conclusions and Future Directions 448

6.1 Future Directions 449
6.2 Climate Change 450
6.3 Phenotypic Plasticity and Epigenetics 452
6.4 Conservation Physiology and Ecology 455
6.5 Medicine, Veterinary Science, and Agriculture 457

Appendix 459
References 479
Index 571