

Contents

Preface xv

PART I Vertebrate Diversity, Function, and Evolution 1

1 The Diversity, Classification, and Evolution of Vertebrates 2

- 1.1** The Vertebrate Story 2
- 1.2** Classification of Vertebrates 7
- 1.3** Phylogenetic Systematics 8
- 1.4** The Problem with Fossils: Crown and Stem Groups 11
- 1.5** Evolutionary Hypotheses 11
- 1.6** Earth History and Vertebrate Evolution 14
- Summary, Additional Readings 17

2 Vertebrate Relationships and Basic Structure 18

- 2.1** Vertebrates in Relation to Other Animals 18
- 2.2** Definition of a Vertebrate 24
- 2.3** Basic Vertebrate Structure 25
- Summary 45, Additional Readings 46

3 Early Vertebrates: Jawless Vertebrates and the Origin of Jawed Vertebrates 47

- 3.1** Reconstructing the Biology of the Earliest Vertebrates 47
- 3.2** Extant Jawless Fishes 52
- 3.3** The Radiation of Paleozoic Jawless Vertebrates—"Ostracoderms" 59
- 3.4** The Basic Gnathostome Design 59
- 3.5** The Transition from Jawless to Jawed Vertebrates 65
- 3.6** Extinct Paleozoic Jawed Fishes 69
- Summary 74, Additional Readings 75

PART II Non-Amniotic Vertebrates: Fishes and Amphibians 76

4 Living in Water 77

- 4.1** The Aquatic Environment 77
- Box 4-1** Water—A Nice Place to Visit, But Would You Want to Live There? 78
- 4.2** Water and the Sensory World of Fishes 83
- 4.3** The Internal Environment of Vertebrates 90
- 4.4** Exchange of Water and Ions 90
- 4.5** Responses to Temperature 96
- Summary 102, Additional Readings 103

5 Radiation of the Chondrichthyes 104

- 5.1 Chondrichthyes—The Cartilaginous Fishes 104
- 5.2 Evolutionary Specializations of Chondrichthyes 105
- 5.3 The Paleozoic Chondrichthyan Radiation 105
- 5.4 The Early Mesozoic Elasmobranch Radiation 108
- 5.5 The Extant Radiation—Sharks, Skates, and Rays 110
- 5.6 Holocephali—The Bizarre Chondrichthyans 119
- Summary 120, Additional Readings 121

6 Dominating Life in Water: The Major Radiation of Fishes 122

- 6.1 The Appearance of Bony Fishes 122
- 6.2 Extant Sarcopterygii—Lobe-Finned Fishes 125
- 6.3 Evolution of the Actinopterygii 128
- Box 6-1** Brainy Fish 129
- 6.4 Extant Actinopterygii—Ray-Finned Fishes 134
- 6.5 Locomotion in Water 141
- 6.6 Actinopterygian Reproduction 145
- 6.7 The Adaptable Fish—Teleost Communities in Contrasting Environments 146
- Box 6-2** What a Fish's Ears Tell About Its Life 147
- 6.8 Conservation of Fishes 153
- Box 6-3** A Lot is Fishy in Genetic Research 155
- Summary, Additional Readings 159

7 Geography and Ecology of the Paleozoic Era 161

- 7.1 Earth History, Changing Environments, and Vertebrate Evolution 161
- 7.2 Continental Geography of the Paleozoic 163
- 7.3 Paleozoic Climates 166
- 7.4 Paleozoic Terrestrial Ecosystems 167
- 7.5 Paleozoic Extinctions 169
- Additional Readings 170

8 Living on Land 171

- 8.1 Support and Locomotion on Land 171
- 8.2 Eating on Land 178
- Box 8-1** Size and Scaling in Terrestrial Vertebrates 180
- 8.3 Reproduction on Land 183
- 8.4 Breathing Air 183
- 8.5 Pumping Blood Uphill 183
- 8.6 Sensory Systems in Air 187
- Box 8-2** Echolocation in Air and Water 188
- 8.7 Conserving Water in a Dry Environment 190
- 8.8 Controlling Body Temperature in a Changing Environment 191
- Summary 194, Additional Readings 195

9 Origin and Radiation of Tetrapods 196

9.1 Tetrapod Origins 196

Box 9-1 Early Feet 203

9.2 Radiation and Diversity of Non-amniotic Paleozoic Tetrapods 206

9.3 Amniotes 211

Summary, Additional Readings 218

10 Salamanders, Anurans, and Caecilians 220

10.1 Amphibians 220

10.2 Diversity of Life Histories of Amphibians 232

Box 10-1 The Energy Cost of Vocalization by Frogs 240

10.3 Amphibian Metamorphosis 249

10.4 Exchange of Water and Gases 250

10.5 Poison Glands and Other Defense Mechanisms 255

10.6 Mimicry 258

10.7 Why Are Amphibians Vanishing? 259

Summary 263, Additional Readings 264

PART III Sauropsida: Turtles, Lepidosaurs, and Archosaurs 266

11 Synapsids and Sauropsids: Two Approaches to Terrestrial Life 267

11.1 Taking Advantage of the Opportunity for Sustained Locomotion 268

11.2 Increasing Gas Exchange: The Trachea and Lungs 274

Box 11-1 High-Flying Birds 278

11.3 Transporting Oxygen to the Muscles: Structure of the Heart 279

11.4 Taking Advantage of Wasted Energy: Endothermy 281

11.5 Getting Rid of Wastes: The Kidneys and Bladder 289

11.6 Sensing and Making Sense of the World: Eyes, Ears, Tongues, Noses, and Brains 299

Summary 303, Additional Readings 304

12 Turtles 305

12.1 Everyone Recognizes a Turtle 305

12.2 But What Is a Turtle? Phylogenetic Relationships of Turtles 309

12.3 Turtle Structure and Functions 310

12.4 Ecology and Behavior of Turtles 317

12.5 Conservation of Turtles 325

Box 12-1 Sick Turtles 326

Summary 327, Additional Readings 328

13 The Lepidosaurs: Tuatara, Lizards, and Snakes 330

13.1 The Lepidosaurs 330

13.2 Radiation of Sphenodontids and the Biology of Tuatara 330

13.3 Radiation of Squamates 334

- 13.4** Ecology and Behavior of Squamates 344
- Box 13-1** Caudal Autonomy—Your Tail or Your Life 352
- 13.5** Behavioral Control of Body Temperatures by Ectotherms 360
- 13.6** Temperature and Ecology of Squamates 365
- Summary 369, Additional Readings 370

14 Ectothermy: A Low-Cost Approach to Life 371

- 14.1** Vertebrates and Their Environments 371
- 14.2** Dealing with Dryness—Ectotherms in Deserts 371
- Box 14-1** Doubly Labeled Water 373
- 14.3** Coping with Cold—Ectotherms in Subzero Conditions 381
- 14.4** The Role of Ectothermal Tetrapods in Terrestrial Ecosystems 384
- Summary, Additional Readings 388

15 Geography and Ecology of the Mesozoic Era 389

- 15.1** Mesozoic Continental Geography 389
- 15.2** Mesozoic Terrestrial Ecosystems 391
- Additional Readings 395

16 Mesozoic Diapsids: Dinosaurs, Crocodylians, Birds, and Others 397

- 16.1** Mesozoic Fauna 397
- 16.2** Phylogenetic Relationships Among Diapsids 399
- 16.3** Archosauria 400
- Box 16-1** Marine Diapsids of the Mesozoic Era 402
- 16.4** Dinosaurs 407
- 16.5** The Ornithischian Dinosaurs 409
- 16.6** The Saurischian Dinosaurs 416
- Box 16-2** Dinosaur Eggs and Nests 417
- 16.7** The Origin of Birds: Feathers and Flight 426
- Box 16-3** Pterosaurs: The First Flying Reptiles 426
- Box 16-4** The Evolution of Feathers: Evo-Devo and Fossils 431
- 16.8** *Archaeopteryx* and Other Birds 434
- Summary, Additional Readings 436

17 Avian Specializations 439

- 17.1** Early Birds and Extant Birds 439
- 17.2** The Structure of Birds 443
- 17.3** The Avian Wing 448
- 17.4** The Hind Limbs 455
- 17.5** Feeding and Digestion 458
- 17.6** Sensory Systems 463
- Box 17-1** Chaucer the Ornithologist 464
- 17.7** Mating Systems, Reproduction, and Parental Care 467

- 17.8** Migration and Navigation 479
Summary 483, Additional Readings 484

PART IV Synapsida: The Mammals 485

18 The Synapsida and the Evolution of Mammals 486

- 18.1** The Origin of Synapsids 486
18.2 Diversity of Nonmammalian Synapsids 488
18.3 Evolutionary Trends in Synapsids 494
Box 18-1 Evolution of the Mammalian Middle Ear 499
18.4 The First Mammals 501
Summary 506, Additional Readings 508

19 Geography and Ecology of the Cenozoic Era 509

- 19.1** Cenozoic Continental Geography 509
19.2 Cenozoic Terrestrial Ecosystems 510
19.3 Cenozoic Climates 513
19.4 Cenozoic Extinctions 517
Additional Readings 518

20 Mammalian Diversity and Characteristics 519

- 20.1** Major Lineages of Mammals 519
20.2 Features Shared by All Mammals 530
Box 20-1 the Evolution of Tribosphenic Molars 532
20.3 Features that Differ Between Mammal Groups 540
20.4 Cenozoic Mammal Evolution 543
Summary, Additional Readings 551

21 Mammalian Specializations 553

- 21.1** Mammalian Reproduction 553
21.2 Some Extreme Placental Mammal Reproductive Specializations 560
21.3 Are Placental Mammals Reproductively Superior to Marsupials? 560
21.4 Specializations for Feeding 562
21.5 Specializations for Locomotion 569
21.6 Evolution of Aquatic Mammals 573
Box 21-1 Comparison of Different Types of Fully Aquatic Mammals 574
Summary 578, Additional Readings 579

22 Endothermy: A High-Energy Approach to Life 580

- 22.1** Endothermal Thermoregulation 580
Box 22-1 Energy Budgets of Vampire Bats 583
22.2 Endotherms in the Arctic 585

- 22.3** Migration to Avoid Difficult Conditions 588
- 22.4** Torpor as a Response to Low Temperatures and Limited Food 590
- 22.5** Endotherms in Hot Deserts 595
- Box 22-2** How Hot Is It? 600
- Summary 604, Additional Readings 605

23 Body Size, Ecology, and Sociality of Mammals 606

- 23.1** Social Behavior 606
- 23.2** Population Structure and the Distribution of Resources 607
- 23.3** Advantages of Sociality 611
- 23.4** Body Size, Diet, and the Structure of Social Systems 612
- Box 23-1** Altruism or Taunting? 618
- 23.5** Horns and Antlers 619
- 23.6** Primate Societies 621
- Box 23-2** Sociality and Survival 625
- Summary 627, Additional Readings 628

24 Primate Evolution and the Emergence of Humans 629

- 24.1** Primate Origins and Diversification 629
- 24.2** Origin and Evolution of the Hominoidea 638
- 24.3** Origin and Evolution of Humans 641
- Box 24-1** Controversial New Finds of the Genus *Homo* 649
- 24.4** Ecological and Biogeographical Aspects of Early Hominid Evolution 652
- 24.5** Evolution of Human Characteristics 653
- Box 24-2** The Genus *Homo* and the Evolution of Running 655
- Summary 659, Additional Readings 660

25 The Impact of Humans on Other Species of Vertebrates 663

- 25.1** Humans and the Pleistocene Extinctions 664
- 25.2** Humans and Recent Extinctions 666
- Box 25-1** Fish Farming 668
- 25.3** Organismal Biology and Conservation 671
- Box 25-2** Subtle Elements of Critical Habitats 672
- 25.4** Captive Breeding 676
- Box 25-3** Adolescent Elephants 677
- 25.5** Global Issues in Conservation Biology 684
- Box 25-4** Endocrine Disruptors 685
- 25.6** The Paradoxes of Conservation 686
- Summary, Additional Readings 687

Glossary G-1

Credits C-1

Subject Index SI-1

Name Index NI-1