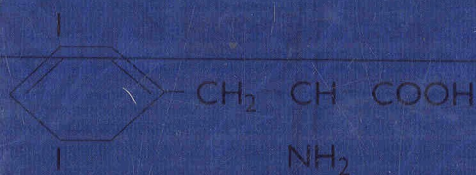


Biology of Fishes

Third Edition

Quentin Bone and Richard H. Moore



SWIM ALL DAY

Contents

Preface

xvii

Chapter 1 The Diversity of Fishes

1.1	Introduction	1
1.2	Fish Classification	5
	Cladistics	8
	Gene and genome duplication	10
	Homeobox diversity	11
1.3	Teleost Classification	11
1.4	Basic Structural Features of Fishes	13
	Body shape, scales, and fins	13
	Internal features	16
1.5	Distribution and Morphology	18
	Myxinoids	18
	Lampreys	19
1.6	Elasmobranchiomorpha	21
	Sarcopterygii	25
1.7	Actinopterygii	26
	Chondrostei	26
	Holostei	28
	Teleostei	29
	Envoi	30
	References	30

Chapter 2 Fishes and their Habitats

2.1	Introduction	35
2.2	Biogeography	35
2.3	Marine Habitats	37
	The open ocean	37
	Shallow seas and coastal regions	44
2.4	Freshwater Fishes	52
	Diversity of freshwater fishes	52
	Lentic systems	54
	Lotic systems	54
2.5	Ostariophysan Success	55
2.6	The Variety and Origin of Some Freshwater Fish Faunas	56
2.7	Lakes and Species Flocks	57
	Envoi	58
	References	58

Chapter 3

Swimming

3.1	The Problem of Analysis	61
3.2	The Myotomal Muscles	64
	Myotomal structure	64
	Myosepta	68
	Muscle fibers	70
	Origin of separate motor systems	73
	Operation of slow and fast fibers	74
3.3	Swimming Speeds	77
	Cruising speed and slow muscle	77
	Sustained swimming	77
	Maximum speeds of fishes	78
	Maximum and sustained speeds are not everything	79
	Not so simple: overlap of the two fiber systems	79
	The development of the slow and fast system in teleosts	80
3.4	Warm Red Muscle	81
3.5	The Generation of Thrust	84
	Caudal fin oscillations	84
	Circulation, lift, and thrust	85
	Body waves, and bulk momentum thrust generation	87
3.6	Drag	88
	Pressure drag	89
	Vortex, induced, or lift (thrust) associated drag and circulation	89
	Skin friction drag, boundary layers, and Reynolds number	91
3.7	Mechanisms for Reducing Skin Friction Drag	93
	Reduction of wetted area	93
	Reduction of lateral movements	93
	Boundary layer control mechanisms	93
	Mucus injection to the boundary layer	94
	Vortex generators, and fluid injection	94
	Drag-reducing behaviors?	95
3.8	Efficiency	96
	Envoi	97
	References	97

Chapter 4

Buoyancy

4.1	Dynamic Lift	101
4.2	Static Lift	101
4.3	Lipid as a Source of Static Lift	103
	Squalene	105
	Wax esters	108
	Insufficient static lift for neutral buoyancy	109

4.4	Gas as a Source of Static Lift	111
	Swimbladder structure	111
	Gas in the swimbladder	113
4.5	The Swimbladder and Vertical Migration	119
4.6	The Swimbladder as a Dynamic Organ: Its Other Functions	121
4.7	Other Sources of Static Lift	122
	Envoi	122
	References	122

Chapter 5 Gas Exchange, Blood, and the Circulatory System

5.1	The Origin of Respiratory Gills	126
5.2	Respiration of Fish Larvae	126
5.3	Respiration in Hagfish, and Lampreys	128
	Hagfish	128
	Lampreys	128
5.4	Gnathostome Fishes	130
	Gill design	130
	Functional gill area	133
	Branchial pumps	136
5.5	Air-breathing Fishes	139
	Lungs and gills	139
	Lungfishes	143
	Estivation	144
5.6	The Circulatory System	145
	Primary and secondary circulations	145
	The heart	147
	White hearts	150
	Accessory pumps	151
5.7	Fish Blood and Gas Transport	152
	Blood properties	152
	Anti-freeze proteins	153
	Fish hemoglobins and oxygen transport	155
	CO ₂ transport	156
	Envoi	156
	References	157

Chapter 6 Osmoregulation and Ion Balance

6.1	The Osmotic Problem: What Fish Have to Cope With	161
6.2	Hagfish, Lampreys and the Origins of the Glomerular Kidney	163
6.3	Teleosts	166
	Marine teleosts	167
	Chloride cells in marine teleosts	168

Freshwater teleosts	171
Freshwater lampreys and ammocoetes	173
6.4 The Kidney and Salt Balance	173
Tubular structure and function	176
6.5 Teleosts in Alkaline Saline Lakes	176
6.6 Teleost Eggs and Larvae	177
6.7 Osmoregulation in Chondrichthyes	177
Urea and energy metabolism: a revision	179
Urea and proteins	179
Extrarenal salt excretion and the rectal gland	180
6.8 Freshwater Elasmobranchs	181
6.9 <i>Latimeria</i>	183
6.10 Which is the More Efficient Way of Coping with Life in Seawater:	
Urea Retention or NaCl Excretion?	183
Plasma ion content and the evolutionary history of different	
groups of fishes	184
Envoi	184
References	185

Chapter 7 Food and Feeding

7.1 Introduction	189
7.2 Techniques for Studying Food Habits and Feeding	191
7.3 Optimal Foraging Theory	192
7.4 Food Choices, Size, and Development	192
7.5 Food Capture	193
7.6 Handling and Ingestion	198
7.7 Anatomy and Physiology of the Digestive Systems	204
Teeth	204
The digestive tract	206
Digestive enzymes	209
Other organs	210
7.8 Food Types, Characteristic Adaptations and Feeding Guilds	210
Carnivorous fishes	210
Plankton filterers	211
Large zooplankton filter-feeders	211
Plankton pickers or particle feeders	211
Bottom feeders, detritivores	212
Herbivorous fishes	212
Unusual food types	213
Envoi	213
References	214

Chapter 8	Reproduction, and Life Histories	
8.1	Types of Life History	217
8.2	Fecundity and Egg Size	222
8.3	Maturation	224
8.4	Intersexes, and Unisexual Species	226
8.5	Fertilization to Hatching (Incubation)	229
8.6	Parental Care	231
	Ovoviviparity	231
	Viviparity	231
	Nest building and brooding	232
8.7	Agnatha	232
8.8	Elasmobranchiomorpha and <i>Latimeria</i>	233
	Reproduction	233
	Ovoviviparity and viviparity	234
	<i>Latimeria</i>	236
8.9	Teleosts	236
	Freshwater species	239
	Marine species	241
8.10	Larval Ecology	245
8.11	Growth	248
	Envoi	249
	References	250

Chapter 9	Endocrine Systems	
9.1	Why Fish Endocrinology is Important	256
9.2	Hormones and Receptors	256
9.3	The Endocrine Organs of Fishes	258
	Origins	259
	The brain–gut axis	263
9.4	The Urophysis	263
9.5	The Pituitary	264
	The pituitary in hagfish and lampreys	267
	The pituitary in elasmobranchiomorpha	268
	The teleost pituitary	269
	Teleost pituitary hormones	270
9.6	The Thyroid	270
9.7	Calcium Homeostasis	272
	The ultimobranchial gland	272
	The corpuscles of Stannius	273
9.8	The Gastro–Entero–Pancreatic Endocrine System	273
	The pancreas	273
	Gut hormones	274

9.9 Chromaffin Tissue, and the Interrenals	275
Chromaffin tissue	275
Interrenals	276
9.10 Kidney Hormones, and the Renin–Angiotensin System	276
Hormones from the heart, natriuretic peptides	277
9.11 Gonadal Hormones and the Regulation of Reproduction	278
Elasmobranchs	279
Teleosts	280
9.12 The Pineal	281
9.13 Origin and Evolution of Fish Hormones	281
Origin	282
Changes in function	284
Envoi	284
References	285

Chapter 10 Sensory Systems, and Communication

10.1 Proprioception	289
10.2 The Acustico-lateralis System	290
The lateral line	292
The inner ear	296
10.3 Sound Reception	296
10.4 Sound Production	301
10.5 Electroreceptors, and Electric Organs	302
Ampullary (tonic) receptors	303
Tuberous (phasic) receptors	305
10.6 Electric Organs	308
10.7 Magnetic Reception	309
10.8 Vision, and Photophores	310
Optics	312
Accommodation	313
Tubular eyes	315
Aerial vision	316
Reflecting tapeta	316
The receptors	318
10.9 Visual Pigments	320
Color vision	323
Sensitivity, and acuity	325
The pineal body	326
10.10 Camouflage	327
Camouflage by reflection	327
Luminescence, and photophores	328
Bacterial photophores	329

Photophores with intrinsic light production	330
Yellow lenses	332
Red headlight fishes	333
10.11 Taste, Olfaction, and Pheromones	334
The chemoreceptors	335
Olfaction	335
Feeding and chemoreception	336
Reproduction and chemoreception	337
Homing and chemoreception	338
Alarm substance	338
Envoi	339
References	339

Chapter 11 The Nervous System

11.1 Glia	348
11.2 Origins	349
11.3 Spinal Cord	350
Spinal nerves	355
Spinal swimming	356
11.4 Cranial Nerves	356
Head segmentation	357
11.5 The Brain	360
Brain size	360
Brain temperature	363
11.6 Elasmobranch Brain Regions and their Connections	363
Telencephalon	364
Diencephalon	365
Mesencephalon	366
Cerebellum	366
Medulla oblongata, brainstem, rhombencephalon	370
11.7 Brains of Other Fishes	371
Telencephalon	371
Mauthner cells	372
The cerebellum in electrolocating teleosts	374
Circuitry of cerebellum-like sensory structures	374
11.8 The Autonomic Nervous System	376
Envoi	379
References	379

Chapter 12 The Immune System

12.1 Why is Knowledge of the Fish Immune System Important?	386
Effects of disease on aquaculture and capture fisheries	386

The immune system of fish is fascinating from a phylogenetic perspective	387
Study of the immune system of fish can yield valuable insights into the human system	387
The use of organismal health in assessing ecosystem health also relies on knowledge about and use of immune system response	387
12.2 Anatomy of the Fish Immune System	387
Epithelial tissues and mucus	388
Gut associated lymphoid tissues (GALTs)	390
Bone marrow analogs	391
12.3 Major Organs of the Lymphoid System	393
The thymus	393
The kidney	393
The spleen	396
12.4 Cells, and Molecules	396
Cells	396
Molecules	399
Envoi	405
References	405

Chapter 13 Behavior and Cognition

13.1 Introduction	409
Behavior	409
Cognition	409
13.2 Behavior as a Discipline	411
How is behavior studied?	411
Categorization of investigators	411
Categorization of behavior	412
Learning	416
13.3 Schooling	418
13.4 Orientation, and Migration	422
Vertical migration	422
Horizontal migration	423
13.5 Symbiosis	428
Envoi	433
References	433

Chapter 14 Fisheries and Aquaculture

14.1 Introduction	437
14.2 Fish and People	438
14.3 Fish as a Source of Food	439
14.4 World Harvests	440

Productive areas and species	441
14.5 Species	442
Deep-water fisheries	448
14.6 The Fisheries, Economics, and Politics	448
14.7 Aquaculture	449
14.8 Ranching	452
14.9 Management	452
Envoi	456
References	456
Further Reading	458
 Subject Index	 459
Systematic Index	469