

Contents

Preface	xiii
Acknowledgments	xvii

1. Sex Determination

1.1 Introduction	1
1.2 Modes of Sex Determination	2
1.2.1 Genetic Sex Determination	2
1.2.2 Polygenic Sex Determination	10
1.3 Sex Determination in Clamp Shrimp	12
1.4 Sex-Linked Genes and Sex Determination in <i>Artemia salina</i>	15
1.5 Epigenetic Factors on Sex Determination	16
1.5.1 Influence of Environmental Factors on Sex Determination	16
1.5.2 Influence of Cytoplasmic Sex Factors on Sex Determination	19
1.6 Evolution of Sex-Determining Mechanism in Isopods	19
1.6.1 Genetic Sex Determination	19
1.6.2 Cytoplasmic Sex Determination in Isopods	21
1.6.3 Intragenomic Conflicts in Isopods	24
1.7 Amphipods	25
1.8 Decapods	26
1.9 Hormonal Regulation of Sex Determination in Crustacea	27

2. Sex Differentiation

2.1 Introduction	29
2.2 Gonad Differentiation	29
2.3 Female Differentiation in <i>Orchestia gammarellus</i>	31
2.3.1 Secondary Sexual Characteristics	32
2.4 Male Sex Differentiation in <i>Orchestia gammarellus</i>	32
2.4.1 External Male Characteristics	33
2.5 Sexual Differentiation in Isopods	33
2.6 Sexual Differentiation in Decapoda	34
2.7 Discovery of Androgenic Gland	37
2.8 Role of Androgenic Gland in Male Sex Differentiation	42

2.9	Androgenic Gland Hormone	44
2.9.1	Chemical Nature	44
2.9.2	Isolation of Insulin-like Androgenic Gland Hormone	45
2.9.3	Silencing of Mr-IAG	48
2.10	Molecular Basis of Sex Differentiation	48
2.10.1	<i>dmrt</i> Gene Expression	51
2.10.2	Doublesex (<i>Dsx</i>) Gene	52
2.10.3	Tra Homologue Genes	53
3.	Sexual Systems	
3.1	Introduction	57
3.2	Gonochorism	58
3.3	Hermaphroditism	58
3.3.1	Nonfunctional Hermaphroditism	59
3.3.2	Sequential Hermaphroditism	59
3.3.3	Protandric Hermaphroditism	59
3.4	Protandric Simultaneous Hermaphroditism	80
3.5	Protogyny	84
3.6	Ecological and Evolutionary Importance of Sequential Hermaphroditism	85
3.7	Androdioecy	87
3.8	Intersexuality in Crustacea	88
3.8.1	Copepods	89
3.8.2	Amphipods	90
3.8.3	Decapods	94
3.9	Gynandromorphism in Crustacea	95
3.9.1	Gynandromorphism in Decapods	95
3.9.2	Branchiopoda: Anostracans	98
3.9.3	Methyl Farnesoate Control of Gynandromorphism	100
3.10	Parthenogenesis	101
3.10.1	Parthenogenesis in <i>Artemia salina</i>	101
3.10.2	Parthenogenesis in <i>Daphnia</i> Species	102
3.10.3	Facultative Parthenogenesis in the Crayfish <i>Orconectes limosus</i>	102
3.10.4	Parthenogenesis in Marbled Crayfish	103
4.	Mating Systems	
4.1	Introduction	105
4.2	Factors Influencing Mating System	106
4.2.1	Anisogamy	106
4.2.2	Availability of Breeding Females	107
4.2.3	Female Receptivity	107
4.3	Influence of Molting on Mating System	107
4.4	Life History Variation and Mating System	109
4.5	Types of Mating Systems	109
4.5.1	Monogamy	112

4.6	Social Monogamy	115
4.6.1	Symbiotic Shrimp <i>Pontonia margarita</i>	116
4.6.2	Snapping Shrimp	116
4.6.3	Crab <i>Planes major</i>	118
4.7	Eusociality in Sponge-Dwelling Snapping Shrimp <i>Synalpheus</i>	118
4.8	Social Monogamy to Eusociality	119
4.9	Bromeliad Crabs	122
4.10	Polygamy	123
4.11	Polygyny	126
4.11.1	Scramble-Competition Polygyny	126
4.11.2	Host Defense Polygyny	126
4.11.3	Female-Centered Polygyny	127
4.12	Polyandry	127
4.13	Polygynandry	128
4.14	Aggregational Mating in Sand Crabs	129
4.15	Mating Systems in Hermaphrodites	130
5.	Mating Behavior	
5.1	Introduction	131
5.2	Pure Searching	135
5.2.1	Female-Centered Competition	136
5.2.2	Resource-Centered Competition	138
5.3	Mate Guarding	139
5.3.1	Mate Guarding in Decapoda	145
5.3.2	Mate Guarding in Amphipods	147
5.3.3	Mate Guarding in Isopods	148
5.4	Alternative Mating Strategy	152
5.5	Male Morphotypes and Alternative Mating Tactics	152
5.6	Mating Contests	155
5.6.1	Intersexual Conflict of Reproductive Interests	155
5.6.2	Female Mate Choice	157
6.	Sex Pheromones	
6.1	Introduction	159
6.2	Types of Pheromone	160
6.2.1	Sex Pheromones in Brachyuran Crabs	163
6.2.2	Lobsters and Crayfishes	166
6.2.3	Caridean Shrimps	167
6.2.4	Amphipods	172
6.3	Concluding Remarks	172
7.	Reproductive Cycle and Environmental Control	
7.1	Introduction	175
7.2	Patterns of Reproductive Cycle	176
7.3	Continuous Reproduction	176

7.4	Semiannual Reproductive Cycle	179
7.5	Annual Reproduction	180
7.6	Impact of Climate Change on Reproductive Cycle	183
7.7	Environmental Contamination Affecting Reproduction	184
8.	Oogenesis	
8.1	Introduction	187
8.1.1	Morphology of Female Reproductive System	187
8.1.2	Structure of the Ovary	189
8.2	Chelicerate and Mandibulate Type of Ovary	195
8.3	Oogenesis	197
8.3.1	Oocyte Proliferation	197
8.3.2	Follicle Cells	198
8.3.3	Nurse Cells	199
8.4	Oocyte Differentiation	200
8.5	Biogenesis of Yolk	205
8.6	Endogenous Yolk Synthesis	205
8.7	Exogenous Yolk Synthesis	208
8.8	Vitellogenin	210
8.8.1	Phylogenetic Analysis of Vg	211
8.8.2	Vg Gene Expression and Yolk Synthesis	218
8.8.3	Vitellogenin Receptor and Yolk Protein Uptake	219
8.9	Yolk Processing	223
8.10	Crustacean Lipovitellin	224
8.11	Cortical Rod Formation	229
9.	Endocrine Regulation of Vitellogenesis	
9.1	Introduction	231
9.2	Eyestalk Inhibitory Hormones	231
9.3	Vitellogenesis-Inhibiting Hormone	232
9.4	Androgenic Hormone	241
9.5	Gonad-Stimulating Hormones	242
9.5.1	Vitellogenesis-Stimulating Hormones	242
9.5.2	Stimulatory Action of CHH Peptides	243
9.5.3	Biogenic Amines and Opioid Peptides	244
9.5.4	Gonadotropin-Releasing Hormone	248
9.5.5	Vertebrate-Type Gonadotropins	250
9.5.6	Bursicon	250
9.5.7	Prostaglandins	251
9.5.8	Vg-Stimulating Ovarian Hormone	251
9.5.9	Methyl Farnesoate	252
9.5.10	Steroid Control of Vitellogenesis	254
9.6	Future Perspectives on Application of Endocrine Research to Crustacean Aquaculture	265

10. Yolk Utilization and Embryonic Nutrition

10.1 Introduction	269
10.2 Embryonic Development	269
10.3 Biochemical Composition and Analysis	270
10.4 Lipid Utilization in Embryos and Larvae	273
10.5 Yolk Proteins	275
10.5.1 Breakdown of Lipovitellin	276
10.5.2 Yolk Utilization in <i>Emerita asiatica</i>	276
10.6 Energy Utilization	277
10.7 Enzyme Activity During Yolk Protein Degradation	279
10.8 Carotenoid Metabolism	281
10.9 Embryonic Ecdysteroids	285
10.10 Vertebrate Steroids	291

11. Spermatogenesis

11.1 Introduction	293
11.2 Male Reproductive System	293
11.2.1 Morphology of the Testis	295
11.3 Spermatogenesis	297
11.3.1 Spermatogenesis in Brachyuran Crabs	298
11.4 Spermiogenesis	299
11.4.1 Acrosome Formation in the Shrimp <i>Sicyonia ingentis</i>	301
11.5 Sperm Morphology	303
11.5.1 Decapod Spermatozoa	304
11.5.2 Reptantian Spermatozoa	305
11.5.3 Natantian Sperm	315
11.6 Sperm Morphology in Thalassinidea	317
11.7 Flagellate Spermatozoa of Cirripedes	318
11.8 Motile Spermatozoa of the Ostracod <i>Cypridopsis</i>	319
11.9 Nonmotile Spermatozoa of <i>Artemia</i>	319
11.10 Sperm Structure and Spermatogenesis in Copepoda	321
11.11 Remipede Sperm	322
11.12 Endocrine Regulation of Sperm Production	322

12. Spermatophore and Sperm Transfer Mechanisms

12.1 Introduction	325
12.2 Spermatophore Morphology	326
12.2.1 Spermatophore Morphology and Diversity in Decapods	330
12.2.2 Anomura	336
12.2.3 Macrura	351
12.2.4 Penaeoid Shrimps	358
12.2.5 Caridean Shrimp	361
12.2.6 Copepoda	362

12.2.7	Peracarids	365
12.2.8	Spermatophores in Other Crustaceans	366
12.3	Functional Attributes and Evolutionary Perspectives	366
13.	Accessory Reproductive Glands	
13.1	Introduction	369
13.2	Female Ductal Glands	369
13.3	Oviductal Glands of Cirripedes	370
13.4	Nature of Ovisac Secretion	371
13.5	Disintegration of Sac Wall	373
13.6	Spermatheca	374
13.6.1	Spermatheca of Primitive Brachyurans	374
13.6.2	Spermatheca of Higher Brachyuran Crabs	375
13.6.3	Secretory Activity of Spermatheca	377
13.6.4	Spermatheca in Nonmalacostracans	379
13.7	Shell Glands in Anostraca	379
13.7.1	Egg Shell Formation in <i>Streptocephalus dichotomus</i>	381
13.8	Integumental Glands	383
13.9	Cement Glands of Crayfish	384
13.9.1	Cement Gland of Stomatopods	385
13.10	Male Accessory Sex Glands	385
13.10.1	Male Accessory Glands in Brachyuran Crabs	386
13.10.2	Male Accessory Gland of Stomatopods	387
13.11	Accessory Gland Secretions: A Functional Evaluation	389
14.	Fertilization	
14.1	Introduction	391
14.2	Resumption of Meiotic Maturation	391
14.3	Molecular Mechanisms of Meiotic Maturation	395
14.4	Hormonal Control of Meiotic Maturation	396
14.5	Egg Activation	398
14.5.1	Cortical Reaction	398
14.6	Electrical Events at Egg Activation	404
14.6.1	Electrical Response to Egg Activation in Crab	404
14.6.2	Electrical Response in Lobster Eggs	406
14.6.3	Electrical Response in the Prawn <i>P. serratus</i>	406
14.7	Sperm Activation	407
14.7.1	Sperm Capacitation	407
14.7.2	Acrosome Reaction	410
14.8	Sperm-Egg Interaction and Pronuclear Fusion	415
	Glossary	419
	References	429
	Index	499