

21st Century Biology and Agriculture:

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Insect Physiology

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Insect Physiology

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In Memory of

Our Son

Preetham

Of all the precious gifts in our lives

However great or small

To have you as our son

Was the greatest gift of all.

We miss you with every beat

Of our broken Heart.

You have just gone ahead of us.

Hope to see you when we get there!

Acha and Amma

Preface

Studies on insects have interested mankind from time in memorial. Their occurrence in various shapes, sizes and colours have attracted several Naturalists who began studying their behavior, especially those of social insects such as species of wasps, ants, bees and termites. Social insects also served to provide early evidence of the close and evolving association between plants and insects. Naturalists recognized that bees were attracted to flowers because of their fragrances. However, the concept of chemical attraction was rather slowly extended to solitary insects and host plants, especially crops. Studies on host preference of phytophagous insects paved the way for it to become the very centre of agricultural entomology. The secondary plant metabolites served not only as a means of protecting plants from insects, but also facilitated to guide insects for food. The cultivation of food plants on a large scale to meet the burgeoning human population and storage of the subsequent harvest has provided favorable conditions for the emergence of phytophagous and stored product pests respectively. Man's crops are attacked in the field by locusts, an enormous array of Lepidoptera, and by Diptera and Coleoptera among others. Major sources of food and fiber, thus damaged include cereals, rice, vegetables and fruit as well as cotton and timber. This paved the way for a focussed study of insects under the field of economic entomology.

While several generations of pesticides have been used to protect the plants from insect attack, we are still not able to control the insect pests. A better understanding of the physiology of the insects would facilitate fine tuning of our strategies in Insect control. The physiology of all systems functioning in an insect could be used as targets for insect control. Applied entomologists, being confronted with the ravages of insects in agriculture and public health, have begun to recognize the need for thoroughly understanding the physiology of insect nutrition, the laws governing their responses to sensory stimuli, about their reactions to parasites, on the precise way in which insects adapt to diverse climatic conditions, on the reproductive physiology of insects, to name a few, in order to refine

their control strategies. Although several books on insect physiology have been written by several authors, rapid advances in entomological studies and physiology in particular demand the need to provide an up to date account on the subject. With this in view, this textbook contains important, comprehensive and in-depth account of all aspects of insect physiology, providing wherever necessary also the fundamental knowledge of the various systems. Although it is aimed as a resource material for postgraduate students of entomology, it would serve as an essential reference source for invertebrate physiologists and neurologists, entomologists, zoologists and insect biochemists. To achieve this goal, extensive references have been made to several textbooks and reviews, to a few research papers dealing with applied aspects of insect physiology and the resources available over the net.

The first chapter deals with the anatomical and physiological attributes of the integument conferring insect success with a discussion on the use of the chemical properties of the cuticle to design novel molecules to control insect pests. The chapter also indicates that the structural design of the cuticle could itself be applied in the field of material science to develop hard structures which can withstand the harshness of the environment. Chapter two discusses the diversity in growth and life cycle patterns in insects. Chapters three and six deals with the digestive and excretory systems as potential targets for pest management. Aspects of the circulatory system of insects are presented along with an account on the new frontiers in insect immunity in chapter four. This would appraise the reader on the possible improved use of entomopathogens in biological control, in the discovery of antimicrobial molecules that can be exploited by humans, and of new strategies for management of insect vectors of human and animal disease. While the dynamism of the respiratory system (Chapter five) is presented as a key to their success, the use of the knowledge thus gained in fluid dynamics and biomechanical research is mentioned. An up to date account on the insect nervous system is presented in Chapter seven, together with a note on learning, memory and intelligence in insects. Chapter eight deals with the reproductive system of insects while chapter nine deals with hormones and regulation of metabolism, moulting and diapause. General protein, carbohydrate and lipid metabolism and their energetic are presented in chapter ten along with the physiology of regulation in cold hardiness and flight. Chapter eleven deals with muscular coordination while an in depth account on the sensory physiology and behaviour is presented in chapter twelve.

This book has been written with the encouragement and support given to me by Dr. Anantanarayanan Raman, Charles Sturt University, Australia.

He believed that I had the knowledge and potential to undertake this fruitful exercise. His critical review of the manuscript has undoubtedly facilitated in improving the content and presentation. I am deeply indebted to him. Two of my research students- Dr. N. Senthilkumar, Scientist D, Tropical Forest and Tree Breeding Research Institute, Coimbatore and Dr. V.A. Vijayashanthi, Asst. Professor, Agricultural College and Research Institute, Madurai, helped me immensely in providing resource materials which enabled me in writing a few chapters. I thank them for their assistance.

I deem it a privilege to thank Dr. K.G. Sivaramakrishnan, Retd. Professor, Madura College, Dr. R. Varatharajan, Professor, Manipur University, Imphal, Dr. Sabu K Thomas, Associate Professor, St. Xavier's College, Calicut, and Dr. S. Subramanian, Principal Scientist, IARI, New Delhi, for peer reviewing several of the chapters. Their suggestions and critical reading have added to the quality of the book.

I would also like to place on record my sincere thanks to Sardar Manjit Singh Nayar, Secretary and Correspondent and Dr. M. Selvaraj, Principal, Guru Nanak College for their support in all my endeavours at the Guru Nanak College.

Lastly, I would like to thank my family members- my wife Er. Manonmani, K.R, my sons Utham and Preetham for tolerating me and giving me the much needed environment to accomplish this work. Their unstinted support gave me the impetus to sit for several hours into the night working to beat the deadline.

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Series Preface

With great pleasure, the Scientific Publishers (Jodhpur) and I launch the fourth volume of the postgraduate textbook series under the general title *21st Century Biology and Agriculture* for use in the Indian subcontinent.

This series aims at fulfilling the knowledge needs of postgraduate learners in agriculture and biology, focussing on self-directed learning. Keeping this point in full view, these volumes would dilate on contemporary information in chosen themes in a pertinent, but brief backdrop of historical knowledge, with appropriate textual information laced with relevant illustrations. Most importantly, these books aim to cater to the self-learning needs in passionate and committed learners. By self-learning, the teacher's role turns into mentoring rather than tutoring. Vital details have been 'box'ed so that learners can internalize them easily, swiftly, and forever. Care has been exercised to integrate examples from the Indian subcontinent, so that the learners can relate to concepts and principles quickly. The most critical aspect is the inclusion of specific case studies and interactive-mode of learning, so that learners can learn about the day-to-day issues and application of theory that surround the nominated theme effectively. Every effort has been meticulously made to see that the books launched under this series are easily readable and user friendly.

Tanay Sharma of Scientific Publishers (Jodhpur) readily agreed to my demand to identify and recruit an efficient copy editor, who has done a neat job.

This book entitled *Insect Physiology* executed by K.P. Sanjayan is the fourth book of this series. Sanjayan is a well-known entomologist and insect physiologist—ecologist of India. Presently he is working as a professor of Zoology, Guru Nanak College, Chennai. He has contributed to diverse aspects of insect biology, physiology, and ecology. Scientific Publishers (Jodhpur) and I consider his acceptance to write this book a great honour.

Many more similar titles have been enlisted and will be appearing in the near and far future. Scientific Publishers (Jodhpur) and I thank Sanjayan for readily and willingly accepting to our request by executing this task, and importantly doing it speedily.

India is a land of varied landscapes. One of the remarkable natural icons of India is the Great Indian Bustard, the populations of which are restricted to Western India. Because this series is being published from Jodhpur, I thought it will be appropriate to remind ourselves of the uniqueness of this splendid bird and make every effort of conserve its diminishing population. All books slated to appear in the series *21st Century Biology and Agriculture* will celebrate this Indian icon.

I am confident that learners will benefit from the information and knowledge shared by K.P. Sanjayan; I am also confident that post-graduate teachers of biology and agriculture in the Indian subcontinent would find this material appropriate to prescribe this book as a learning resource.

Anantanarayanan Raman

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Contents

<i>Preface</i>	<i>vii</i>		
<i>Series Preface</i>	<i>xi</i>		
1. The Integument: Anatomical and Physiological Attributes Contributing to Insect Success	1—32		
Introduction	1		
1. Insect Integument Structure	2		
1.1 The Insect Cuticle	3		
1.1.1 The Cuticular Components	4		
1.1.2 Schmidt's Layer	5		
1.1.3 Epidermis	5		
1.1.4 Basement Membrane	6		
1.1.5 Pore Canals	6		
1.2 Chemical Components of Cuticle	7		
1.3 Endoskeleton	13		
1.4 Cuticular Appendages	13		
1.5 Functions of Cuticular Surfaces	15		
1.6 Cuticular Glands	16		
2. Physiology of Moulting	16		
2.1 Steps in Moulting	17		
2.2 Control of Moulting	19		
3. Cuticle Sclerotisation	20		
3.1 Mechanism of Sclerotisation	21		
3.2 The Control of the Sclerotisation Process: Hormones	24		
3.4 Sclerotisation in Larvae and Pupae	25		
4. Colouration and Melanisation	26		
5. Learning from Cuticle	28		
References	29		
2. Diversity in Growth and Life Cycle Patterns in Insects	33—76		
1. Introduction	34		
2. Growth	34		
3. Life history patterns	35		
3.1 Embryonic Development and Hatching	36		
3.2 Larval Development	39		
3.2.1 Types of Larvae	41		
3.2.2 Number of Instars	43		
3.2.3 Larval Growth	43		
3.3 Pupal Development	44		
3.4 Metamorphosis	48		
3.5 The Imaginal or Adult Stage	50		
3.5.1 Emergence	51		
3.5.2 Hormonal Control of Adult Emergence	51		
3.5.3 Maturation	52		
3.5.4 Reproduction	53		
3.5.5 Senescence	55		
4. Hormonal control of metamorphosis	55		
4.1 Hormones in Development of Ametabolous Insects	55		
4.2 Hormones in Nymph to Adult Transformation in Hemimetabolous Insects	56		
4.3 Hormones in Larva to Pupa to Adult Transformation in Holometabolous Insects	58		
5. Voltinism	60		
6. Polymorphism and Polyphenism	62		
6.1 Genetic Polymorphism	62		
6.2 Environmental Polymorphism or Polyphenism	63		
6.3 Phase Dimorphism or Kentromorphism	65		
6.4 Caste or Social Polymorphism	66		
6.5 Polyethism	67		
7. Environmental Effects on Development	69		
7.1 Temperature	69		
7.2 Photoperiod	71		
7.3 Humidity	72		
7.4 Mutagens and Toxins	72		
7.5 Biotic Effects	73		
References	74		
3. Insect Digestive System as a Potential Target for Pest Management	77—148		
Introduction	77		
1. Alimentary Canal Morphology and Function	78		
1.1 Foregut (Stomodaeum)	79		

1.2	Midgut (Mesenteron)	81	6.	Mechanism of Digestive Enzyme Secretion	123
1.3	Hindgut (Proctodaeum)	84	7.	Role of Symbionts in Digestion	125
1.4	Modifications in Alimentary Canal of Insects	87	8.	Physiology of Absorption of Digested Food	128
1.5	Histology of Midgut Epithelium	88	8.1	Process of Absorption	129
1.5.1	The Digestive Epithelial Cells	89	8.2	Absorption of Water	129
1.5.2	Absorptive and Storage Epithelial Cells	89	8.3	Absorption of Digested Carbohydrate	130
1.5.3	Endocrine Cells	89	8.4	Absorption of Protein	130
1.5.4	Regenerative Cells	89	8.5	Absorption of Lipids	130
1.5.5	Goblet Cells	90	9.	Insect Digestive Enzyme Inhibitors in the Control of Insect Pest	131
1.5.6	Cuprophilic Cells	90	9.1	Serine Proteinase Inhibitors	131
2.	Microvillar Membrane-structure and Enzymology	90	9.2	Cysteine Proteinase Inhibitors	132
3.	Peritrophic Membrane-structure, Formation and Function	93	9.3	Aspartic and Metalloproteinase Inhibitors	132
3.1	The Physiological Role of the Peritrophic Membrane	96	9.4	Mechanism of Toxicity	133
4.	Physiology of Digestion	96	References	136	
4.1	Digestive Glands	97	4. The Circulatory System and Immune Responses in Insects	149—206	
4.2	Types of Digestion	99	1.	Introduction	150
4.2.1	Extra-oral/Extra-intestinal Digestion	99	2.	Structural Pattern of the Open Circulatory System	151
4.2.2	Internal/ Intestinal Digestion	100	2.1	Dorsal Diaphragm	152
4.3	Digestion of Carbohydrates	100	2.2	Ventral Diaphragm	153
4.3.1	Amylases	101	2.3	Alary Muscles	154
4.3.2	β -Glucanases	102	2.4	Ostia	154
4.3.3	Xylanases and Pectinases	104	3.	Components of the Circulatory System	155
4.3.4	Chitinases and Lysozymes	104	3.1	Dorsal Vessel: Heart and Aorta	155
4.3.5	α -Glucosidases	106	3.2	Sinuses	155
4.3.6	β -Glucosidases, β -Galactosidases, and Myrosinases	107	3.3	Accessory Pulsatile Organs	156
4.3.7	Trehalases	109	4.	Process of Blood Circulation	158
4.3.8	Acetylhexosaminidases, β -Fructosidases, and α -Galactosidases	109	4.1	Diastole	158
4.4	Digestion of Proteins	110	4.2	Systole	158
4.4.1	Serine Proteinases	111	4.3	Diastasis	158
4.4.2	Cysteine Proteinases	114	4.4	Heartbeat	159
4.4.3	Aspartic Proteinases	115	5.	Path of Circulation	160
4.4.4	Aminopeptidases	116	6.	Extracardiac Pulsations (ExP)	162
4.4.5	Carboxypeptidases and Dipeptidases	118	7.	Autonomic Nervous System for Haemolymph Circulation	163
4.5	Digestion of Lipids and Phosphates	119	8.	Haemolymph	164
4.5.1	Lipases	119	8.1	Functions of Haemolymph	164
4.5.2	Phospholipases	121	8.2	Composition of Haemolymph	165
4.5.3	Phosphatases	121	8.3	Role of Haemolymph in Thermoregulation	167
5.	Evolutionary Trends of Insect Digestive System	122	9.	Haemocytes	168
			9.1	Origin and Types of Haemocytes	170
			9.2	Functions of Haemocytes	172
			10.	Insect Immunity	172

10.1 The Cellular (hemocytic) Immune Response	173	6.1 Gas exchange pattern	220
10.2 The Systemic Immune Response (Humoral response)	175	6.2 Discontinuous gas exchange cycles	221
10.3 The Local Immune Response	176	6.2.1 Internal and external factors that influence the DGC	222
10.4 Physical Barriers to Invasion	176	6.2.2 Evolution of the DGC	223
11. Recognition of Non-self by Insect Immune System	177	7. Gas exchange in aquatic insects	225
11.1 Pattern Recognition Receptors	178	7.1 Oxygen intake from air	226
11.2 Signalling Pathways	179	7.2 Oxygen intake from water	227
11.3 Antiviral Defence	180	7.3 Physics of bubble gas exchange in collapsible gas gill	228
12. Synthesis of Antifungal and Antibacterial Peptides	181	8. Respiration in endoparasitic insects	230
12.1 Toll Pathway for Synthesis of Antimicrobial Peptides	181	9. Respiratory pigments in insects	230
12.2 IMD Pathway for Synthesis of Antimicrobial Peptides	182	10. Respiration in eggs and water conservation	231
12.3 JAK/STAT Pathway	185	11. Control of respiratory patterns	233
12.4 The RNA Interference (RNAi) Pathway	187	11.1 Spiracle control and innervations	234
12.5 Pathway Crosstalk	189	11.2 Metabolic rate determines patterns of respiration	236
13. C-Type Lectins	190	12. Using the knowledge gained from the insect's tracheal system	238
14. Serpins	191	References	239
15. Evolutionary Ecology of Insect Immune Defences	191		
16. Autoimmune Consequences of Some Defence Reactions	192	6. Insect Excretory System and Mechanism of Homeostasis	245
17. Gender Differences in Immune Responses	193	1. Introduction	246
18. Comparison of the Immune System of Insects vis-a-vis the Vertebrates	194	2. Excretory organs of insects	247
19. Insect Immunity and Global Warming	195	2.1 Malpighian tubule	248
20. New Frontiers in Insect Immunity	196	2.2 Integument	250
References	197	2.3 Tracheal system	250
		2.4 Alimentary canal	250
		2.5 Nephrocytes	250
		2.6 Oenocytes	250
		2.7 Urate cells	250
		2.8 Labial glands	251
		2.9 Chloride cells	251
5. Dynamics of the Respiratory System as a Key to Insects' Success	207—243	3. Morphology and Ultrastructure of Malpighian Tubules (MT)	251
Introduction	207	3.1 Cell types	251
1. Structure and Diversity of the Tracheal System	208	3.2 The Basal Lamella	254
1.1 Spiracles	209	3.3 Basal Infolds	254
1.2 Tracheae	210	3.4 Junctions	254
1.3 Tracheoles	211	3.5 Intracellular storage granules	255
1.4 Air sacs, aeriferous trachea and tracheal lungs	212	3.6 Microvilli	255
1.5 The tracheal system in Locusts—A case study	213	3.7 Secondary Specialisations in Malpighian Tubules	256
2. Classification of the tracheal system	215	4. Anatomical Specialisation of Hindgut Epithelial Cells	257
3. Other types of Respiration	216	5. Formation of primary urine in Malpighian tubules	259
4. Development of the tracheal system	217	6. The basic transepithelial transport system	260
5. Plasticity in tracheal organisation as a key trait for insect's success	218		
6. Gaseous exchange in insects	219		

7. Proton Pump is the Driving Mechanism for Urine Formation and Homeostasis	262	5. The Peripheral Nervous System	311
8. Selective reabsorption in the hind gut	263	6. Basic structure of ganglia	312
8.1 Reabsorption in the Ileum	264	7. Morphology of neurons in the insect brain	313
8.2 Reabsorption in the Rectum	265	8. Organisation of Glial cells	314
9. Role of the Excretory System in Maintaining Homeostasis	266	8.1 Role of the Glial cells	316
9.1 Electrolyte Homeostasis	267	9. Synapses	317
9.2 Water Homeostasis	267	10. Neuromuscular junction	318
9.3 Acid-Base Homeostasis	268	11. Physiology of impulse transmission	318
9.4 Nitrogen Homeostasis	269	11.1 Generation and Conduction of Nerve Impulse	319
9.4.1 Ammonia Excretion	270	11.2 Transmission of Impulse	321
9.4.2 Uric Acid Synthesis and Excretion	271	12. Neuropeptides and neurotransmitters	322
10. Hormonal Control of Urine Formation	272	12.1 Classical neurotransmitters	323
10.1 Diuretic hormones	273	12.2 Biogenic amine neurotransmitters	325
10.2 Antidiuretic Hormones	274	14. Learning, Memory and Intelligence in Insects	328
10.3 Hormonal Regulation of Malpighian Tubule Transport	275	15. Hormonal control on the development of the Nervous System	331
10.4 Hormonal Regulation of Midgut Transport	278	16. Nerve repair and regeneration in insects	332
10.5 Hormonal Regulation of Hindgut Transport	278	16.1 Degenerative responses	332
11. Cryptonephridial Systems	279	16.2 Regenerative responses	333
12. The insect excretory system as a target for novel pest control strategies	281	17. Nervous control of locomotion	334
12.1 Peptide analogs of diuretic or antidiuretic factors	281	17.1 Walking and Running	334
12.2 Interference with membrane transporters for inorganic ions or toxins	282	17.2 Flight	335
12.3 Microbial and plant-derived natural compounds	283	17.3 Swimming and skating	337
References	283	References	338
7. Insect Nervous Coordination and Integration	291	8. Physiology of Insect Reproduction	343
1. Introduction	292	Introduction	344
2. Basic plan of the insect nervous system	293	1. The Male reproductive system	344
3. The Central Nervous system	294	1.1 Structure of testis follicle	346
3.1 Brain structure and function	296	1.2 Accessory glands of the male tract	347
3.1.1 Protocerebrum	297	1.3 Structure of Insect Spermatozoa	348
3.1.2 Deutocerebrum	304	1.4 Production of Spermatozoa (Spermatogenesis)	350
3.1.3 Tritocerebrum	305	1.4.1 Spermatogenesis in Postembryonic Development	351
3.2 The suboesophageal ganglion and its function	306	1.5 Spermatohores	351
3.3 Thoracic and abdominal ganglia	307	1.6 Seminal fluid	352
4. Visceral Nervous system/ Sympathetic nervous system	308	1.7 The Male external genitalia	353
4.1 The Stomodaeal Nervous system	308	1.8 Male courtship behaviour and insemination	355
		1.8.1 Role of pheromones	356
		1.8.2 Insemination	356
		1.8.3 Traumatic insemination	357
		1.9 Endocrine Control of the Male Reproductive System and Spermatogenesis	358

2. The Female Reproductive System	360	2. Anatomy of the endocrine system	416
2.1 Structure of ovariole	362	2.1 The Prothoracic glands	416
2.1.1 Types of ovarioles	362	2.2 The Corpora Allata	418
2.2 The Spermatheca	365	2.3 Ring gland	420
2.3 Other accessory glands	366	2.4 Epitracacheal glands	420
2.4 The female external genitalia	367	2.5 The Neurosecretory System	420
3. Oogenesis	369	2.5.1 Distribution of neurosecretory cells in the brain	422
3.1 Formation of oocytes and nurse cells	369	2.5.2 Corpora Cardiaca	425
3.2 The follicle cells	370	2.6 Other endocrine organs	427
3.3 Alimentary aspects of oogenesis	371	2.7 Neuroendocrine System in the Ventral Nervous System	427
3.4 Vitellogenesis	374	2.8 The Nervous and Endocrine System	428
3.5 Formation of Egg Polarity	379	2.9 The Midgut Endocrine System	429
3.6 Formation of egg membranes and specialised chorionic structures	380	3. Insect Hormones	430
3.6 Oosorption	382	3.1 Lipid Hormones	430
3.7 Development of ovarian structure in <i>Drosophila</i>	383	3.1.1 Ecdysteroid	432
3.7.1 Egg chamber development in <i>Drosophila</i>	385	3.1.2 Juvenile Hormones	433
4. Oviposition	386	3.2 Peptide Hormones	434
5. Structure and physiology of eggs and eggshells in insects	389	3.2.1 Prothoracicotropic Hormone	435
5.1 Eggshell layers	389	3.2.2 Diuretic and anti-diuretic hormones	435
5.2 Physiological function of eggshell	390	3.2.3 Muscle stimulating neuropeptides	436
5.2.1 Spermatozoon Entry: Micropyle Apparatus	390	3.2.4 Adipokinetic hormones	437
5.2.2 Oxygen Entry: Aeropyles and Plastron	391	3.2.5 Chloride transport stimulating hormone (CTSH)	438
5.2.3 Eggshell Structures for larval Hatching	392	3.2.6 Neurohormone D	438
6. Modes of Reproduction	392	3.2.7 Neurohormones that activate ecdysis and sclerotisation	439
6.1 Oviparity	393	3.2.8 Neurohormones acting as neurotransmitters	440
6.2 Viviparity	393	3.2.9 Bursicon - the insect cuticle sclerotisation hormone	440
6.3 Parthenogenesis	394	3.2.10 Hormones and carbohydrate metabolism	446
6.4 Paedogenesis and Neoteny	396	4. Ecdysteroid Biosynthesis	448
6.5 Polyembryony	397	5. Mode of action of Ecdysteroids at the gene level	451
6.6 Hermaphroditism	397	5.1 Ecdysone Pulses During <i>Drosophila</i> Development	452
6.7 Castration	398	5.2 Ecdysone Regulation of Primary-Response Genes	453
6.8 Alternation of generation (Heterogony)	398	5.3 Regulation of Ecdysone Secondary-Response Genes	455
6.9 Sex determination	399	5.4 Cross-Regulation among Ecdysone-Induced Transcription Factors	456
7. Endocrinology of female reproduction	403	5.5 From Gene Regulation to Biological Responses	457
8. Physiological and reproductive effects of <i>Wolbachia</i>	403	6. Biosynthesis of JH	457
References	405	7. Pheromones	459
9. Insect Endocrine System and Regulatory Mechanisms	413		
Introduction	413		
1. Insect endocrine system	414		

8. Hormonal control of Diapause	463	2.5.2 Production of Malony CoA: The Initiation Phase	526
8.1 Hormonal basis for embryonic diapauses	466	2.5.3 The Fatty Acid Synthase Complex	527
8.2 Hormonal basis for larval and pupal diapauses	467	2.5.4 Priming of the Fatty Acid Synthesis by Acetyl-CoA : The Priming Phase	528
8.3 Hormones in adult diapauses	468	2.5.5 Growth of the Fatty Acyl Chain by Two Carbons : The Elongation Phase	528
9. Hormonal regulation of moulting	469	3. Amino acid and protein metabolism	531
9.1 Peptides of the epitracheal endo- crine system implicated in ecdysis	471	3.1 Steps in protein synthesis	532
9.2 Roles of rising and falling ecdysteroids in signalling	472	3.2 Aminoacid metabolism in general	534
9.3 Phases of peptide release from Inka cells	472	3.3 Formation of Ammonia from Glutamate	536
9.4 Ecdysis Sequence by Peptide Signalling Cascade	473	3.4 Storage proteins	536
9.5 Mechanistic model for endocrine control of the ecdysis	475	3.5 Glycoprotein and lipoprotein	538
References	477	4. Energy storage and release- Role of fat body	540
10. Metabolism in Insects	489	4.1 Fat body cell types	540
Introduction	489	4.2 Accumulation of energy reserves	541
1. Carbohydrate metabolism	491	4.3 Mobilisation of carbohydrate reserves	542
1.1 Glycogen	491	4.4 Mobilisation of lipid reserves	542
1.1.1 Glycogen metabolism pathway	492	4.4.1 Utilisation of Lipids	542
1.1.2 Conversion of glycogen to glycerol and sorbitol	503	4.5 Hormonal Regulation of Fat body energy metabolism	544
1.2 Trehalose	505	5. Metabolic regulation in insect cold hardiness	545
1.2.1 Metabolic pathway of Insect trehalose	505	5.5 Control of Polyol Metabolism	547
1.2.2 Biological role of insect trehalase	507	5.6 Metabolic rate depression	548
1.2.3 Insect trehalase: Target for insect pest control	510	5.7 AMPK and metabolic poise over the winter	549
1.3 Chitin metabolism	511	5.8 Mitochondrial metabolism	550
1.3.1 Chitin structure	511	6. Fuels for flight and control of Flight Metabolism	551
1.3.2 Chitin formation	512	6.1 Energy substrates for flight	551
1.3.1 Chitin degradation	514	6.2 Metabolic pathways of proline during insect flight	553
1.3.4 Chitin synthase	515	6.3 Regulation of flight metabolism	555
1.3.5 Hormonal regulation of chitin metabolism	516	6.3.1 Regulation of flight metabolism at physiological level	555
1.3.6 Inhibition of chitin metabo- lism as a strategy for insect control	517	6.3.2 Regulation of flight metabolism at the cellular and sub-cellular level	557
2. Lipid Metabolism	519	References	559
2.1 Lipids for storage and liberation of metabolic energy	519	11. Muscular Co-ordination System	571
2.2 Structural lipids	520	1. Introduction	571
2.3 Oxidation of fatty acids	521		
2.4 Ketone Bodies	524		
2.5 Biosynthesis of fatty acids	525		
2.5.1 Acetyl-CoA Transport into the Cytosol	525		

2. Types of muscles	573	7.5 Interleg co-ordination	619
2.1 Skeletal muscles	574	7.6 Negotiating obstacles	619
2.1.1 Cephalic muscles	574	8. Tymbal muscles: Sound production	621
2.1.2 Thoracic muscle	575	8.1 The mechanism of tymbal action	625
2.1.3 Abdominal muscles	575	8.2 The action of the tensor muscle	627
2.1.4 Muscles of flight	576	References	627
2.2 Visceral muscles	581		
2.3 Cardiac muscles	582	12. Insect Sensory Physiology and Behaviour	631
3. Muscle Ultrastructure	582	1. Introduction	631
3.1 Muscle Fibre Bundles	582	2. Classification of insect sense organs	633
3.2 Filaments and Fibrils	583	3. Mechanoreceptors	633
3.3 Other Components	587	3.1 The tactile organs or trichoid sensilla	634
3.4 Contractile Proteins of Myofibrils	588	3.1.1 Structure of tactile organ	634
3.4.1 Myosin- Structure and function	588	3.1.2 Location and function of tactile organ	635
3.4.2 Paramyosin and Miniparamyosin	592	3.2 Proprioceptors	636
3.4.3 Novel Myosin Associated Proteins	593	3.2.1 The hair plate	636
3.4.4 Actin and Arthrin	594	3.2.2 The stretch receptors	637
3.4.5 Troponin, Tropomyosin and GST-2	595	3.2.3 The Campaniform sensilla	637
3.4.6 Z -Band Proteins	599	3.3 Chordotonal organs	638
4. Muscle Attachments	602	3.3.1 Subgenual organs	639
5. Innervation and Activation	603	3.3.2 Johnston's organ	639
6. Muscle Mechanics	604	3.3.3 Auditory or tympanal organ	640
6.1 Muscle Force and Muscle Length	604	3.3.4 Non-tympanal sound perception	645
6.2 Force, Shortening Velocity, and Power	605	3.3.5 Sound-producing mechanisms in insects	647
6.3 Determinants of muscle power	608	3.3.6 Behaviours associated with insect sound	652
6.3.1 Force-length relationship	608	4. Chemoreceptors	654
6.3.2 Force-velocity relationship	608	4.1 Olfactory (odorant) receptor	659
6.3.3 Phase of activation	609	4.2 Gustatory receptors	661
6.4 Functional diversity of muscles	610	4.3 Ionotropic receptors (IRs)	662
6.4.1 Muscles that function as motors	610	4.4 Common chemical sense	663
6.4.2 Muscles that function as brakes	610	4.5 Olfaction in insects	663
6.4.3 Muscles that function as springs	611	4.5.1 Transduction mechanism of odour reception	664
6.4.4 Muscles that function as struts	611	5. Temperature and Humidity Receptors	665
7. Muscles involved in walking and jumping	612	5.1 Mechanism of hygroreception	669
7.1 Movements of the legs and their constituent joints	612	5.2 Thermoregulatory behaviour in insects	669
7.2 Neuromuscular System	614	5.2.1 Endothermy	670
7.3 Control of Basic leg movements: Central Pattern Generation	615	5.2.2 Ectothermy	671
7.4 Leg sensors	616	5.2.3 Heat Loss Mechanisms	672
		6. Photoreceptors	675
		6.1 Compound Eyes	675
		6.2 Ocelli - Simple eyes	678

6.3	Extra-ocular Photoreception	679	7.1.4	Visual navigation in insects	688
6.4	The mechanism of image formation	679	7.1.5	Sound orientation in crickets	689
6.5	Mechanism of vision	680	7.2	Robot control	689
6.5.1	Visual acuity	680	7.2.1	A visually guided robot inspired by fly	689
6.5.2	Visual cascade	681	7.2.2	A flight-stabilising device based on ocelli	691
6.5.3	Dark Adaptation	681	7.2.3	Robots using insect design principle	691
6.5.4	Flicker-fusion Frequency	682	7.2.4	An insect-based flying robot	691
6.5.5	Colour Vision	683	7.2.5	Insect walking and a walking-controlled robot	692
6.5.6	Perception of polarised light by insects	684	7.3	Controlling insect behaviours	693
7.	Industrial application of knowledge of insect sensory system	685	7.3.1	Remote control of insect behaviours	693
7.1	Sensory system application	686	7.3.2	Architectural insecticide method	694
7.1.1	Odour sensors	686	References	694	
7.1.2	Odour source localisation robot	687			
7.1.3	A flow sensor using an artificial sensory hair	687			

21st Century Biology and Agriculture

Wildlife Ecology and Conservation

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Wildlife Ecology and Conservation

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Cover illustration: This textbook series *21st Century Biology and Agriculture* launched by Scientific Publications, Jodhpur (India), celebrates the native, but critically-threatened bird of the western semi-arid grasslands and scrubs of India, the great Indian bustard *Ardeotis nigriceps* (Gruiformes: Otidae). The great Indian bustard has been a part of Indian culture and tradition, known as *gonādh* (*Sanskrit*), because the male call closely resembles the mooing of cows. Artist: Urvashi Sharma.

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Foreword

The year 2015 is a landmark year in international development. It marks the transition from Millennium Development Goals to a new post-2015 agenda for sustainable development, with new Sustainable Development Goals as pillars of this new development agenda, and for advancing international efforts to cope with global climate change.

Sustainable development and wildlife as defined by Mundanthra Balakrishnan in *Wildlife Ecology and Conservation* are closely interlinked. At the same time, as we address our development challenges, we are at the mid-way mark in the process of trying to achieve the goals and targets of the Strategic Plan for Biodiversity 2011–2020. All these efforts are aimed at meeting the challenges of alleviating poverty, improving human health and providing clean water, food and energy for all. It has become ever clearer that conserving our biological diversity is *sine qua non* not only for making sustainable development become reality but for the well-being of humankind itself.

How does all this relate to Prof. Balakrishnan's book *Wildlife Ecology and Conservation*?

Education for all and capacity building are key elements in the processes discussed above. This is where the book by Prof. Balakrishnan comes into play. It serves as an element in these contexts and, more specifically, at its target clientele, the college and university students and teachers in the Indian subcontinent. The book uses the right approach, viz. a connotation of wildlife as encompassing all organisms not directly under human control and which build the fabric of our "natural ecosystems". The latter term is however discussed controversially: there are virtually no ecosystems, which have not been influenced by humans to various extents. Again, wildlife traditionally refers to non-domesticated animal species, but has come to include all animals, plants, fungi and other organisms, which grow or live wild in an area and have not been introduced by humans. As a matter of fact, the distinction between wildlife and biodiversity, not even in contexts such as agro-ecosystems or urban ecosystems ("urban wildlife"), may not be as straight forward as commonly thought.

Loss of wildlife and biodiversity has been a serious issue and challenge at all levels, from local to international. Bringing biodiversity loss to a complete halt, as repeatedly requested and currently aimed at in the international "Vision 2050" for biodiversity, may be too lofty a goal to

be achievable in the coming decades, or it may be even impossible to be achieved in its entirety, lastly a result of continued growth of the human population and concomitant rising pressure on natural resources.

Wildlife has experienced enormous losses. According to a recent report of the World Wide Fund for Nature (WWF), between 1970 and 2014 wildlife has been globally reduced by over 50%. Severely affected have been the tropical realms, in particular the Neotropical and Indo-Pacific Realms. Global species extinction rates are generally estimated 1,000 times or even more than the normal or background extinction rate.

India, a mega diverse country, contains two of the 34 global hotspots of biodiversity. Neighbouring countries in South Asia have two more biological hotspots, which are partially contiguous to India. Special efforts have been taken to conserve biodiversity and wildlife in India. For instance, in line with the Aichi Targets, India has defined its specific targets to address the different facets of biodiversity. In international debates, India has been a forerunner in stressing the need for a global change in our production and consumption patterns. In view of the continued human population growth and increasing pressure on natural resources and ecosystems, this change may be needed ever more for the conservation of biodiversity for our future generations.

I have known Mundanthra Balakrishnan for a long time. We first met when he still worked in southern India, at the Department of Zoology, University of Kerala, and I carried out research on the biogeography of India and Sri Lanka. Since then we have been in regular contact.

Wildlife Ecology and Conservation is not just another book on wildlife ecology and conservation. Its primary focus is on education. Accordingly, its design reflects the series focus on “self-directed learning”, as pointed out in the series preface at the beginning of the book. *Wildlife Ecology and Conservation* is targeted at college and university students and teachers in the Indian subcontinent. A major add-on is the 13 text boxes in which specific aspects are highlighted. These include species-specific situations, examples of ecosystems, major institutions working on wildlife issues in India, butterfly farming, and specific methodology used in wildlife research.

Depth and breadth of discussing wildlife and conservation issues is a major feature and strength of Prof. Balakrishnan’s book. This holistic approach is reflected *inter alia* in the introduction which sets the scene, an overview of the biogeography of India and major ecological aspects of wildlife, followed by chapters on habitats, predator–prey interactions, ecological principles, conservation with emphasis on India and the South

Asian subregion, human–wildlife conflicts, economic aspects related to wildlife, protected areas and wildlife conservation, conservation biology, and international instruments. The book concludes with two chapters on methods used in ecological studies of wildlife. Each chapter ends with content-related questions posed to the reader. Both theoretical and practical aspects of wildlife ecology and conservation are, therefore, presented.

With rapid population growth and development in India, conservation of biodiversity and wildlife and related education efforts have become ever more pressing an issue. Specifically with regard to this situation, I hope that this book will make a difference. Moreover, I do hope that *Wildlife Ecology and Conservation* will become a standard textbook for education about wildlife and its conservation, not only for current and future generations of students and teachers of India, but also at regional and international levels.



Mechernich,
June 11, 2015

Prof. Dr. Walter R. Erdelen
Former Assistant Director-General for Natural Sciences
UNESCO

Series Preface

With great pleasure, the Scientific Publishers (Jodhpur) and I launch the third volume of the postgraduate textbook series under the general title *21st Century Biology and Agriculture* for use in the Indian subcontinent.

This series aims at fulfilling the knowledge needs of postgraduate learners in agriculture and biology, focussing on self-directed learning. Keeping this point in full view, these volumes would dilate on contemporary information in chosen themes in a pertinent, but brief backdrop of historical knowledge, with appropriate textual information laced with relevant illustrations. Most importantly, these books aim to cater to the self-learning needs in passionate and committed learners. By self-learning, the teacher's role turns into mentoring rather than tutoring. Vital details have been 'box'ed so that learners can internalize them easily, swiftly, and forever. Care has been exercised to integrate examples from the Indian subcontinent, so that the learners can relate to concepts and principles quickly. The most critical aspect is the inclusion of specific case studies and interactive-mode of learning, so that learners can learn about the day-to-day issues and application of theory that surround the nominated theme effectively. Every effort has been meticulously made to see that the books launched under this series are easily readable and user friendly.

Tanay Sharma of Scientific Publishers (Jodhpur) readily agreed to my demand to identify and recruit an efficient copy editor, who has done a neat job.

This book entitled *Wildlife Ecology and Conservation* executed by M. Balakrishnan is the third book of this series. Balakrishnan is a well-known wildlife ecologist of India. Presently he is working as professor of Zoology, Addis Ababa University in Ethiopia. He has contributed to diverse aspects of wildlife biology, ethology and ecology. Scientific Publishers (Jodhpur) and I consider his acceptance to write this book a great honour.

Many more similar titles have been enlisted and will be appearing in the near and far future. Scientific Publishers (Jodhpur) and I thank Balakrishnan for readily and willingly accepting to our request by executing this task, and importantly doing it speedily.

India is a land of varied landscapes. One of the remarkable natural icons of India is the Great Indian Bustard, the populations of which are

restricted to Western India. Because this series is being published from Jodhpur, I thought it will be appropriate to remind ourselves of the uniqueness of this splendid bird and make every effort of conserve its diminishing population.

All books slated to appear in the series *21st Century Biology and Agriculture* will celebrate this Indian icon.

I am confident that learners will benefit from the information and knowledge shared by M. Balakrishnan; I am also confident that post-graduate teachers of biology and agriculture in the Indian subcontinent would find this material appropriate to prescribe this book as a learning resource.

Anantanarayanan Raman

Editor-in-Chief, Textbook Series
21st Century Biology and Agriculture
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Preface

This textbook on Wildlife Ecology and Conservation is prepared as requested by Scientific Publishers, Jodhpur, for the use of students of College and University students and teachers in India. My long-term experience of over 40 years at the University of Kerala, Agricultural University of Norway and Addis Ababa University, Ethiopia, where I have been dealing with this subject area in teaching and research have helped me to put in all essential information with suitable examples to introduce the subject matter in a simple way, and I hope our students can easily grasp and understand the basic concepts of wildlife ecology and conservation biology using this book. For a better understanding of the subject, I have drawn more examples from India with additional examples from Africa and elsewhere in the tropics.

As a deviation from routine textbooks, I have included 13 special boxes in this book. Some of these boxes are case studies, some are typical examples and others are details of techniques. These boxes are prepared by eminent scientists having long-term experience in the respective subject areas. I expect that these boxes will serve for details of the subject with first hand elaborations by well-known scientists, which will be of high use for the student community to know at least some of the scientists in their own fields of interest. Contributors of these boxes have also agreed that anyone who may read these boxes can contact them for further information and ideas, if required, and all of them have given their full postal address and e mail IDs for this purpose. I am extremely thankful to each of these contributors for devoting their time in response to my request and providing me their text and figures on time.

I thank Dr. S. Anilkumar (one of my former post-graduate and doctoral students at the University of Kerala, India), now at Jawaharlal Nehru Tropical Botanic Garden and Research Institute, Thiruvananthapuram, Kerala for helping me in the preparation of the drawings used in this book. My son, Sharon M. Balakrishnan is thanked for his help in final editing of figures and photos included in this book. He has also supported me on computer technical problems during the final editing of the text, figures and photos. I am also thankful to a number of my post-graduate and doctoral students whom not only I taught, but from whom I also learned various issues of wildlife ecology, conservation and management I have presented in this book. I am also thankful to them for

their valuable feedback on my ecology, biodiversity and other wildlife related courses.

The text of this book was prepared using my spare time in Addis Ababa. In this context, I am indebted to Addis Ababa University, particularly to the Department of Zoological Sciences for giving me excellent working facilities and comfortable working atmosphere. Professor Afework Bekele, former Dean, Faculty of Science has been supporting me throughout my over 13 years of career with Addis Ababa University, which made me to continue here for such a long time even beyond my expectations. I sincerely thank my other Ethiopian colleagues, Dr. Kifle Dagne, Dr. Dawit Abate, Dr. Gurja Belay, Dr. Ababe Getahun and Dr. Tilaye Wube, under whom I have worked from time to time, for their support.

I take this opportunity to thank Professor Anantanarayanan Raman, Charles Sturt University, Australia, for inviting me to write this book. Mr. Tanay Sharma, Scientific Publishers (India) and his team of officials are thanked for their immediate and efficient responses on all my clarifications, particularly during the final stage of the preparation of this book.

I have reproduced parts of my publications appeared in few of the scientific journals as part of student review, exercise and case study for which I thank the Society of Photo-Optical Instrumentation Engineers (SPIE); National Institute of Ecology, New Delhi; International Scientific Publications, New Delhi; International Society for Tropical Ecology; Blackwell Publishing Ltd; Indian Academy of Sciences; Elsevier; Association for Tropical Biology and Conservation; Bombay Natural History Society; and the International Union for Conservation of Nature and Natural Resources.

I will fail in my attempt if I do not thank my parent institution, the Department of Zoology, University of Kerala, Thiruvananthapuram, where I started my academic career as a doctoral student and retired as a full Professor. This institution was responsible for my academic advancements and success, with its limited facilities and funding just like any of the other Indian State Universities. The earlier experience I had with the Kerala Forest Research Institute, Peechi as a staff of its Division of Wildlife made me to advance as a wildlife ecologist, for which I thank my then senior colleague, Dr VS Vijayan, who introduced me to the field of wildlife ecology. It was with him that I first made wildlife field observations in the famous Silent Valley forests of Kerala.

I have made my wife, Mrs. P.C. Roopa to suffer for a long time during the preparation of this text, as I have been spending much of my time at home to complete this task. I take this opportunity to thank her for her patience.

M. Balakrishnan

Addis Ababa,
March 30, 2015.

List of Boxes

Box 1.1.	Caecilians – The Elusive Limbless Amphibians by <i>K Ramachandran and OV Oommen</i>	2
Box 1.2	Glimpses of the Indian Barbets by <i>HSA Yahya</i>	6
Box 1.3.	Mountain Nyala by <i>B Afework</i>	12
Box 1.4.	Mutualism – A Case Study in the Western Ghats of Kerala, India by <i>S Anilkumar</i>	29
Box 2.1.	Wetland Ecosystems, Wildlife and Conservation by <i>B Gopal</i>	42
Box 2.2.	Mountain Lakes of Norway – Heavily Influenced by Human Activities by <i>Reidar Borgstrøm</i>	50
Box 2.3.	The Lion-tailed Macaque: A Case Study on the Impacts of Forest Fragmentation by <i>A Kumar and G Umapathy</i>	57
Box 4.1.	Biology and Behaviour of Bats by <i>G Marimuthu</i>	107
Box 5.1.	Wildlife Research in India in Two and Half Decades by the Wildlife Institute of India – Achievements at a Glance by <i>K Sankar</i>	158
Box 5.2	Bombay Natural History Society – Conservation Activities and Recent Achievements by <i>AR Rahmani</i>	167
Box 7.1.	Butterfly Farming for Conservation and Awareness Creation by <i>G Mathew and E George</i>	211
Box 13.1.	Camera-Trapping by <i>HV Goldman</i>	363
Box 13.2.	Remote Sensing and Geographic Information System in Wildlife Habitat Analysis by <i>PS Roy and S Nandy</i>	374

Contents

1. Introduction	1-40
1.1. Wildlife – Definition and Scope.....	1
1.2. Wildlife Ecology and Management	14
1.3. Biomes of the World.....	15
1.4. Biogeographic Zones of India.....	16
1.5. Ecology of Natural Communities	21
1.6. Niche in Wildlife Ecology	25
1.7. Ecological Succession	26
1.8. Association between Species.....	28
1.9. Diversity, Stability and Resilience.....	37
2. Wildlife Populations and Habitats	41-81
2.1. Types of Habitats.....	41
2.2. Habitat and Food Resources for Wildlife	49
2.3. Habitat Association of Wildlife	56
2.4. Disturbances in Natural Habitats	65
2.5. Climate Change and its Effects on Wildlife.....	70
2.6. Ozone Depletion	75
3. Predator–Prey Interactions	82-99
3.1. Behavioural Ecology	82
3.2. Food and Feeding	85
3.3. Foraging as a Major Activity of Animals	85
3.4. Predation and Predator–Prey Interactions	86
3.5. Lotka-Volterra Model of Predator–Prey Interactions	89
3.6. Optimal Foraging Theory (OFT).....	90
3.7. Aggregation in Response to the Availability of Food.....	91
3.8. Food as a Factor Responsible for Distribution of Animals.....	93
3.9. Mammalian Foraging and Seed Dispersal	93
3.10. Feeding Behaviour of Animals as a Factor Responsible for Maintaining Healthy Habitats	94

4. Ecological Principles in Wildlife Management and Conservation.....	100-133
4.1. Introduction	100
4.2. Goal of Wildlife Management	101
4.3. Human Interactions in Natural Habitats.....	102
4.4. Habitat Loss and Fragmentation	102
4.5. Habitat Restoration	103
4.6. Population Structure and Regulation	103
4.7. Wildlife Stocking.....	104
4.8. Competition between Wildlife and Livestock.....	104
4.9. Wildlife Harvest	104
4.10. Reintroduction	105
4.11. Wildlife Conservation and Management	106
4.12. Behavioural Biology and Wildlife Management	106
4.13. Communication	114
4.14. Scent-Marking	115
4.15. Problems and Prospects in Wildlife Management	118
4.16. Urban Wildlife.....	120
5 Conservation of Threatened Wildlife in India and Neighbouring Countries.....	134-179
5.1. Introduction	134
5.2. India.....	135
5.3. Nepal	172
5.4. Sri Lanka	175
5.5. Pakistan	176
5.6. Future Prospects	177
6. Human–Wildlife Conflict	180-208
6.1. Human–Wildlife Conflicts (HWCs).....	180
6.2. Cattle Lifting and Crop Raiding by Wildlife	187
6.3. Case studies	188
6.4. Wildlife-related Conflicts in African Wildlife Foundation (AWF) Heartlands.....	193
6.5. Measures to Mitigate HWCs	194
6.6. Physical Barriers.....	197
6.7. Visual, Auditory and Olfactory Stimuli to Scare Wild Animals.....	198
6.8. Compensation and Benefit Sharing	202

6.9. Highway Traffic through Forests.....	203
7. Wildlife Farming and Hunting.....	209-228
7.1. Farming Wild Animals.....	209
7.2. Crocodile Farming.....	218
7.3. Ostrich Farming.....	220
7.4. Deer Farming.....	220
7.5. Rangelands.....	222
7.6. Behaviour of Farm Animals and Farm Management.....	223
7.7. Game Hunting.....	225
8. Economic Benefits of Wildlife.....	229-244
8.1. Introduction.....	229
8.2. Assessing Economic Benefits of Wildlife.....	230
8.3. Non-consumptive Value of Wildlife.....	231
8.4. Consumptive Value of Wildlife.....	232
8.5. Wildlife as Pests.....	232
8.6. Civet as Economically-important Wildlife.....	234
8.7. Economics of Wildlife Conservation.....	236
8.8. Hidden and Unknown Features of Wildlife and Wildlife Habitats.....	236
8.9. Carbon Sequestration.....	238
9. Protected Areas and Wildlife Conservation.....	245-277
9.1. Wildlife Conservation and Protected Areas.....	245
9.2. History of Protected Area System.....	246
9.3. World Coverage of PAs.....	248
9.4. Megadiversity Countries and Hotspots.....	250
9.5. Protected Areas and Conservation Initiatives.....	250
9.6. Features of Areas to be Conserved.....	253
9.7. Categories of Protected Areas.....	256
9.8. IUCN revised categories of PAs – 1994.....	259
9.9. <i>In-situ</i> Gene banks: A New Category of PA.....	261
9.10. Types of Utilization.....	262
9.11. Criteria for the Selection of PAs.....	262
9.12. Protected Area Management/Park Management.....	268
9.13. Local People and Protected Area Management.....	273

10	Conservation Biology	278-307
10.1.	Conservation Biology as a New Discipline in Biology	279
10.2.	Aims of Conservation Biology	281
10.3.	An Overview of Extinction.....	283
10.4.	A Major Extinction Spasm	288
10.5.	IUCN Threatened Species Categories.....	291
10.6.	Concept of Keystone Species, Umbrella Species and Flagship Species	294
10.7.	Conservation Perspectives for the Future	297
10.8.	Conservation Strategies	299
10.9.	Conservation Agenda	300
10.10.	Application of Conservation Activities.....	301
10.11.	The World Conservation Strategy 1980 and Since Then	303
11.	International Conventions on Wildlife and Nature Conservation	308-319
11.1.	Reasons for International Collaboration	309
11.2.	Organizations and Institutions	310
11.3.	Conventions (Treaties and Agreements).....	311
12.	Traditional Methods in Wildlife Ecology.....	320-360
12.1.	Ecological Monitoring	321
12.2.	Species–Area Curve	325
12.3.	Population Studies	326
12.4.	Population Estimation.....	342
12.5.	Population Indices	344
12.6.	Estimating Biodiversity	348
12.7.	Trapping Wild Animals	355
13	Modern Techniques in Wildlife Ecology and Habitat Analysis	361-394
13.1.	Camera-Trapping.....	362
13.2.	Biotelemetry and Radio-tracking.....	368
13.3.	Remote Sensing and Geographic Information System.....	373
13.4.	Ecological and Conservation Genetics	384
13.5.	DNA Fingerprinting	386
	References	395-411
	Subject Index	412-441
	Author Index.....	442-446

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Growth and Development in Plants

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Cover illustration: This textbook series *Biology and agriculture for the twenty-first century* launched by Scientific Publishers, Jodhpur (India), celebrates the native, but critically threatened bird of the western semi-arid grasslands and scrubs of India, the great Indian bustard (GIB) *Ardeotis nigriceps* (Gruiformes: Otididae). GIB has been a part of Indian culture and tradition, known as *gonādh* (Sanskrit), because the male GIB's call closely resembles the mooing of cows. Artist: Urvashi Sharma.

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Series Preface

With great pleasure, the Scientific Publishers (Jodhpur) and I launch the second volume of the postgraduate textbook series under the general title *21st Century Biology and Agriculture* for use in the Indian subcontinent.

This series aims at fulfilling the knowledge needs of postgraduate learners in agriculture and biology, focussing on self-directed learning. Keeping this point in full view, these volumes would dilate on contemporary information in chosen themes in a pertinent, but brief backdrop of historical knowledge, with appropriate textual information laced with relevant illustrations. Most importantly, these books aim to cater to the self-learning needs in passionate and committed learners. By self-learning, the teacher's role turns into mentoring rather than tutoring. Vital details have been 'box'ed so that learners can internalize them easily, swiftly, and forever. Care has been exercised to integrate examples from the Indian subcontinent, so that the learners can relate to concepts and integrate principles quickly. The most critical aspect is the inclusion of specific-case studies and interactive-mode of learning so that learners can learn about the day-today issues and application of theory that surround the nominated theme effectively. Every effort has been meticulously made to see that the books launched under this series are easily readable and user-friendly. Tanay Sharma of Scientific Publishers (Jodhpur) readily agreed to my demand to identify and recruit an efficient copy editor, who has done a neat job.

This book entitled *Growth and Development in Plants*, executed by K.V. Krishnamurthy, a distinguished plant biologist, and was a professor at Bharathidasan University, Tiruchirapalli, Tamil Nadu, of India is the second in this series. Many more similar titles have been enlisted and will be appearing in the near and far future. Scientific Publishers (Jodhpur) and I thank Krishnamurthy for readily and willingly accepting to our request by executing this task, and importantly doing it speedily.

India is a land of varied landscapes. One of the remarkable natural icons of India is the Great Indian Bustard, the populations of which are restricted to Western India. Because this series is being published from Jodhpur, I thought it will be appropriate to remind ourselves of the uniqueness of this splendid bird and make every effort of conserve its diminishing population.

All books to appear in the series *21st Century Biology and Agriculture* will celebrate this Indian icon.

I am confident that learners will benefit from the information and knowledge shared by Krishnamurthy; I am also confident that post-graduate class teachers of biology and agriculture in the Indian subcontinent would find this material appropriate to prescribe this book as a learning resource.

Anantanarayanan Raman

Editor-in-Chief, Textbook Series

21st Century Biology and Agriculture

School of Agricultural & Wine Sciences

Charles Sturt University

Orange, NSW 2800, Australia

Preface

The purpose of the book is to provide a broad explanation on growth and development in plants from seed germination to vegetative growth, maturation and flowering, fruiting and seeding. The book presents the principles and results of previous and ongoing research on plant growth and development throughout the world. Researchers have been interested in plant growth and development for at least the past two centuries. However, their interests have been largely reductionistic and not holistic. They have concentrated their attention all along exclusively on addressing the problem of growth and development from morphological, anatomical, biochemical, physiological, molecular, environmental or genetical angles but not trying to make an integrated study. Also they focused their attention on studying growth and development by exclusively laying emphasis on different hierarchical levels of plant organization i.e. at the cellular, tissue and organ levels, again not attempting to integrate the information obtained from all these hierarchical levels. Some concentrated on in vivo approaches, others on in vitro approaches, some focusing on normal growth and development and yet others on abnormal growth and development. This book tries to integrate all the information drawn from these reductionistic approaches and provides a holistic account on plant growth and development. This is done first through detailed accounts on the various concepts and definitions, on cell division, cell cycle and cell enlargement which form the basis of growth and development, on growth regulators and signaling molecules, and on the attainment of form (morphogenesis) as related to function, at all hierarchical levels of plant organization. A detailed account on vegetative and reproductive growth and development, growth movements and rhythmic growth phenomena is provided. The role of alternative growth strategies and abnormal growth phenomena in the understanding of normal growth and development is also emphasized.

Because of space limitations, the author has concentrated his attention on flowering plants with very little focus on other groups of plants. The author also has not covered the entire gamut of the subject of plant growth and development but has summarized what he has as felt as very important. This book is meant for all those students, researchers and teachers who are curious about how plants grow and develop and what biotic and abiotic factors control growth and development. They will find

this book useful in their careers in plant biology, biotechnology, forestry, horticulture and seed science.

I am very grateful to Dr. A. Raman, Editor-in-Chief, Text book Series 21st Century Biology and Agriculture School of Agricultural and Wine Sciences Charles Sturt University Orange, NSW 2800, Australia and Mr. Tanay Sharma, Scientific Publishers, India for inviting me to write this book. I am very indebted to my wife Brindha, who has gracefully and patiently tolerated my negligence of the family during the writing of this book and who has constantly been the strongest pillar of support to me. I am also indebted to my son Arvind, daughter-in-law Anusha and grandson Sundar for foregoing the time they would have otherwise spent with me. My thanks are also to Sri Darshan Shankar, Dr. Padma Venkat and John Adams for their support and constant encouragement. I am also thankful to those people who have allowed me to use their illustrations in this book.

K.V. Krishnamurthy

17-02-2015
Bangalore

Contents

1. Basic Concepts and Definitions.....	1
1.1. Introduction.....	1
1.2. Levels of Structural Organization in Higher Plants.....	3
1.3. DEVELOPMENT.....	4
1.3.1. Formal Methods of Representing Development.....	5
1.3.2. Controls in Development.....	6
1.4. GROWTH.....	7
1.4.1. Types of Growth.....	8
1.4.2. Growth Kinetics.....	9
1.5. Ontogeny.....	10
1.6. Differentiation, Dedifferentiation, Redifferentiation and Transdifferentiation.....	11
1.7. Meristems.....	13
1.7.1. Types of Meristems.....	13
1.8. Initials and Stem Cells.....	14
1.9. Determination, Commitment, Competence and Position Effect.....	16
1.10. Pattern Formation.....	17
1.11. Polarity.....	17
1.12. Morphology and Morphogenesis.....	19
1.13. Plant Growth Regulators.....	22
1.14. Abnormal Growth.....	22
1.15. Evolution and Plant Development.....	23
2. Signalling Molecules and Growth Regulators.....	24
2.1. Introduction.....	24
2.2. Signalling.....	25
2.2.1. Concept of Target Cells.....	26
2.2.2. Receptors of Signals.....	27
2.2.3. Second Messengers, Calcium and Protein Kinases.....	29
2.3. Growth Regulators.....	30
2.3.1. Differential Sensitivity to Hormones.....	31
2.3.2. Hormones and Gene Activity.....	32
2.3.3. Sites of Hormonal Activity.....	33
2.3.4. Different Kinds of Growth Regulators.....	33
2.3.5. Interaction between Growth Regulators.....	58
2.3.6. Morphactins.....	58
3. Cell Division and Enlargement.....	60
3.1. Introduction.....	60
3.2. Nuclear and Cell Divisions.....	61
3.3. Cell Cycle.....	62
3.3.1. Cell Cycle Phases.....	62
3.3.2. Control and Regulation of Cell Cycle.....	63

3.3.3. Modifications of Cell Cycle.....	66
3.4. Mitotic Cycle and Index.....	68
3.5. Laws of Cell Division.....	68
3.6. Planes of Cell Division.....	69
3.6.1. Anticlinal Division.....	70
3.6.2. Periclinal Division.....	72
3.6.3. Transverse Division.....	73
3.6.4. Diffuse Division.....	73
3.7. Asymmetric Cell Divisions.....	74
3.7.1. Zygotic Division.....	74
3.7.2. Formation of Root Hair.....	75
3.7.3. Formation of Stomata.....	77
3.7.4. Pollen Formation.....	78
3.7.5. Endodermis Formation.....	79
3.8. Meiotic Division.....	79
3.9. Cell Enlargement.....	83
3.9.1. Types of Cell Enlargement.....	83
3.9.2. Water Uptake and Cell Growth.....	84
3.9.3. Intercellular Adjustments during Cell Growth.....	86
3.9.4. Growth of Pollen Tube.....	88
3.9.5. Growth of Root Hair.....	89
3.9.6. Growth of Seed Hairs.....	90
3.10. Role of Genome on Cell Size and Cell Division Rate.....	91
3.11. Relative Importance of Cell Division and Enlargement in Growth and Development.....	92
4. Morphogenesis.....	97
4.1. Introduction.....	97
4.2. Diffusion Reaction Theory and Positional Theory of Morphogenesis.....	98
4.3. Morphogenesis at Cell Level.....	99
4.3.1. Role of Cell Wall in Cell Morphogenesis.....	100
4.3.2. Role of Cell Shape in Morphogenesis.....	117
4.4. Morphogenesis at Tissue Level.....	119
4.4.1. Intercellular Spaces.....	120
4.4.2. Symplastic Domains.....	122
4.4.3. Morphogenesis of Epidermal Tissue.....	126
4.4.4. Sclerenchyma Tissue.....	134
4.4.5. Vascular Tissues.....	135
4.4.6. Secretory Tissues.....	153
4.5. Morphogenesis at Organ Level.....	154
4.5.1. Development of Leaf Form.....	154
4.5.2. Heteroblastic Development.....	156
4.5.3. Heterophylly.....	157
4.6. Whole Plant Morphogenesis.....	158
4.7. Programmed Cell Death and Morphogenesis.....	161

5. Vegetative Growth and Development.....	165
5.1. Introduction.....	165
5.2. Apical Meristems	167
5.2.1. Shoot Apical Meristem	168
5.2.2. Root Apical Meristem.....	183
5.3. Intercalary Meristem	199
5.4. Development of the Primary Plant Body.....	200
5.4.1. Metamers and Modules.....	201
5.4.2. Origin and Development of Nodes and Internodes	203
5.4.3. Procambialization and Primary Vascularization in Stem	213
5.4.4. Development of Root Tissues.....	217
5.5. Origin of Axillary Buds and Branches	222
5.5.1. Structure and Development.....	222
5.5.2. Apical Dominance	224
5.5.3. Genetic Control of Branching.....	225
5.6. Origin and Development of Lateral Roots.....	225
5.7. Root–Stem Transition	227
5.8. Latitudinal Growth in Plants	230
5.8.1. Primary and Secondary Thickening Meristems	230
5.8.2. Vascular Cambium	235
5.8.3. Phellogen	263
5.9. Origin and Development of Leaves.....	265
5.9.1. Phyllotaxy.....	265
5.9.2. Leaf Initiation and Development	268
6. Pre–Fertilization Reproductive Growth and Development	284
6.1. Introduction.....	284
6.2. Flowering.....	285
6.2.1. Acquisition of Floral Competence	285
6.2.2. Physiology of Floral Evocation.....	286
6.2.3. Structural Changes and Molecular Control in Floral Evocation.....	289
6.2.4. Formation of Floral Organs	291
6.3. Ovule and Female Gametophyte	302
6.3.1. Configuration.....	303
6.3.2. Structure of Ovule.....	305
6.3.3. Archegonium, Megasporogenesis and Embryo Sac Development.....	312
6.3.4. Gene Expression during Embryo Sac Development	318
6.4. Anther and Male Gametophyte	319
6.4.1. Introduction	319
6.4.2. Structure and Development of Anther	319
6.4.3. Microsporogenesis and Microgametogenesis	328
6.4.4. Anther Dehiscence.....	338
6.5. Double Fertilization	339
6.5.1. Stigmatic Environment	340
6.5.2. Pollen Germination and Pollen Tube Growth	343

6.5.3. Stylar Environment.....	345
6.5.4. Growth of Pollen Tube into the Ovule.....	347
6.5.5. Male Gametes and Double Fertilization.....	351
6.6. Self-Incompatibility.....	356
7. Post-Fertilization Reproductive Growth and Development.....	358
7.1. Introduction.....	358
7.2. Fruit Development.....	359
7.2.1. Fruit Types.....	359
7.2.2. Basics of Fruit Development.....	366
7.2.3. Biochemical factors in fruit development.....	366
7.2.4. Physical Factors in Fruit Development.....	368
7.2.5. Fruit Ripening.....	370
7.2.6. Histology of Fruits.....	374
7.2.7. Dehiscence of Fruit and Release of Seeds.....	374
7.3. Seed Development.....	376
7.3.1. Introduction.....	376
7.3.2. Role of Chalaza in Seed Development.....	377
7.3.3. Seed Coat and Accessory Structure.....	380
7.3.4. Perisperm.....	385
7.3.5. Micropyle.....	386
7.3.6. Endosperm.....	386
7.4. Embryo.....	405
7.4.1. Introduction.....	405
7.4.2. Zygote.....	406
7.4.3. Embryogenesis.....	408
7.4.4. Histological Differentiation.....	411
7.4.5. Genetic Control of Embryogenesis.....	418
7.4.6. Embryo Maturation.....	425
7.4.7. Nutrition of Embryo.....	426
7.4.8. Synthesis of Storage Substances.....	427
7.4.9. Embryo Suspensor.....	427
7.5. Seedling Development.....	429
7.5.1. Viability of Embryos.....	429
7.5.2. Germination.....	430
8. Growth Movements.....	433
8.1. Introduction.....	433
8.2. Some Basic Concepts.....	433
8.3. Nastic Movements.....	435
8.3.1. Nyctinasty.....	435
8.3.2. Hydronasty.....	437
8.3.3. Thigmonasty.....	437
8.3.4. Thigmo-Morphogenesis and Seismo-Morphogenesis.....	438
8.4. Tropisms.....	439
8.4.1. Introduction.....	439

8.4.2. Phototropism.....	440
8.4.3. Solar Tracking	444
8.4.4. Skototropism.....	445
8.4.5. Gravitropism.....	445
8.5. Other Tropisms	460
8.6. Circumnutation	460
8.7. Reaction Wood.....	463
9. Rhythmic Phenomena and Growth Periodicity.....	467
9.1. Introduction.....	467
9.2. Some Basic Concepts.....	469
9.3. Rhythmic Responses to Environment	471
9.3.1. Light	471
9.3.2. Temperature.....	472
9.3.3. Chemicals	472
9.4. Clock Mechanism	473
9.5. Use of Clocks.....	474
9.6. Photoperiodism	475
9.6.1. Discovery.....	475
9.6.2. Some General Principles.....	476
9.6.3. Aspects of a Plant's Life Cycle Controlled by Photoperiod.....	476
9.6.4. Types of Response to Photoperiod.....	477
9.6.5. Ripeness to Respond or Competence.....	480
9.6.6. Role of Dark Period	480
9.6.7. Time Measurement in Photoperiodism	481
9.6.8. Chemical Basis of Photoperiodism	482
9.7. Thermoperiodic and Other Temperature-Related Events	483
9.7.1. Temperature Effects on Plant Growth.....	483
9.7.2. Thermoperiodism.....	484
9.7.3. Vernalization	484
9.8. Dormancy.....	487
9.8.1. Concept and Definitions	487
9.8.2. Classification of Dormancy	488
9.8.3. Induction and Overcoming of Seed Dormancy.....	489
9.8.4. Bud Dormancy.....	494
9.8.5. Dormancy of Underground Storage Organs.....	497
9.8.6. Root Dormancy.....	499
9.8.7. Periodicity in Latitudinal Growth	500
9.8.8. Growth Rings.....	505
10. Alternate Strategies in Growth and Development.....	510
10.1. Introduction.....	510
10.2. Apomixis.....	512
10.2.1. Agamospermy.....	513
10.2.2. Molecular Basis of Apomixis	517
10.3. Polyembryony	518

10.4. Hemigamy, Androgenesis, Single Fertilization and Polyspermy	521
10.4.1. Hemigamy	521
10.4.2. Androgenesis	522
10.4.3. Single Fertilization	522
10.4.4. Heterofertilization	523
10.4.5. Polyspermy	523
10.5. Incompatibility Barriers and Promotion of Fertilization.....	523
10.6. Parthenocarpy	525
10.7. In Vitro Organogenesis and Embryoidogenesis	527
10.7.1. In Vitro Callus Production	528
10.7.2. In Vitro Embryoid Production	532
10.8. Pollen Callus and Embryoid Production	533
10.9. About Embryos and Embryoids	536
10.9.1. Introduction	536
10.9.2. Zygote vs. Embryoid—initial	536
10.9.3. Division of Zygote and Embryoid—Initial Cell.....	537
10.9.4. Suspensor.....	537
10.9.5. Polarity	538
10.9.6. Cell Division, Pattern Formation and Symmetry Changes.....	538
10.9.7. Tissue and Organ Differentiation.....	539
10.9.8. Dormancy	541
10.9.9. Gene Expression	541
10.9.10. Morphology of the Embryoid	541
11. Abnormal Growth and Development	544
11.1. Introduction.....	544
11.2. Callus	546
11.3. Tumors and Galls	546
11.3.1. Crown Gall Tumors	547
11.3.2. Hairy Roots.....	549
11.3.3. Galls.....	550
11.4. Abnormal Growths Associated with Symbiotic and Mutualistic Interactions.....	561
11.4.1. Root Nodules	562
11.4.2. Cyanobacterial Roots.....	567
11.4.3. Mycorrhizal Associations	568
11.5. Hypersensitive Reactions in Plants	574
11.5.1. PCD Associated with HR.....	574
11.5.2. Cytological Changes Associated with HR	575
References	577
Subject Index.....	629
Species Index.....	633

21st Century Biology and Agriculture

Ocean and Coastal Ecology

The Text book Series *21st Century Biology and Agriculture*

This series aims at fulfilling the knowledge needs of postgraduate learners in agriculture and biology, focussing on self-directed learning. Keeping this point in full view, the volumes published under this series would dilate on contemporary information in chosen themes in a pertinent, but brief backdrop of historical knowledge, with appropriate textual information laced with relevant illustrations. Most importantly, these books aim to cater to the self-learning needs in passionate and committed learners. By self-learning, the teacher's role turns into mentoring rather than tutoring. Vital details have been 'box'ed so that learners can internalize them easily, swiftly, and forever. Care has been exercised to integrate examples from the Indian subcontinent, so that the learners can relate to concepts and integrate principles quickly.

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– K. Kathiresan

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This book entitled *Ocean and Coastal Ecology*, executed by K. Kathiresan, a distinguished marine biologist of India, and a full professor at the Advanced Centre of Marine Biology, Annamalai University, Porto Novo, Tamil Nadu, commences this series. Many more similar titles have been enlisted and will be appearing in the near and far future. Scientific Publishers (Jodhpur) and I thank Kathiresan for readily and willingly accepting to our request by executing this task, and importantly doing it speedily.

India is a land of varied landscapes. One of the remarkable natural icons of India is the Great Indian Bustard, the populations of which are restricted to Western India. Because this series is being published from Jodhpur, I thought it will be appropriate to remind ourselves of the uniqueness of this splendid bird and make every effort of conserve its diminishing population.

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Anantanarayanan Raman
Editor-in-Chief, Textbook Series
21st Century Biology and Agriculture
School of Agricultural & Wine Sciences
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Orange, NSW 2800, Australia

Preface

Life on the Earth without ocean is impossible. Life originated on the Earth planet only in the oceans, some 500 million years ago. Oceans are unique in vastness, amazing in processes, astonishing in resources and remarkable in controlling global climate. Marine environment is the largest aquatic system on the earth and the biggest storehouse of mineral, food and energy resources. This supports 50% of the primary production of the earth, 85% of the global fish catch and more than 50% of the world's populations to live in the coastal areas. The oceans are of great ecological significance to have direct effect on global environment and human life.

Marine ecology is to understand on how organisms interact with each other and with their surrounding environment. There has been a growing interest in marine ecological studies in view of the global issues: losses of coastal habitats, serious declines in marine living resources, ever increasing human population, elevated levels of pollution, poor seawater qualities, overall deterioration of marine environment, natural calamities and climate change including sea temperature rise, sea level rise, and ocean acidification. It is a matter of necessity to understand scientific principles of the marine ecology in order to manage the marine environment and its resources.

Bearing this in mind, the present text book *entitled "Ocean and Coastal Ecology"* has been written in 10 chapters. Chapter-1 deals with basic principles and unique features of marine ecology. Chapter-2 is explaining various physical and chemical factors that influence the marine organisms. Chapter-3 is dealing with ecology of the ocean beyond 200 metres depth with a special note on hydrothermal vents and cold seeps. Chapter-4 is describing on various coastal ecosystems within 200 metres depth with additional information about seagrasses and kelp forests. Chapter-5 is dealing with ecological wonders of coral reef ecosystem. Chapter-6 is discussing about the ecobiology of estuaries with a special note on salt marsh community. Chapter-7 is explaining about ecological characteristics and importance of the mangrove ecosystem. Chapter-8 is on 'Functional marine ecology' discussing various oceanic processes: primary production, carbon sequestration, detritivory, herbivory, predation, parasitism, pathogenesis, fouling, boring, competition, succession, dispersal and settlement of larvae and marine food chains. Chapter-9 is dealing with different types of threats to various coastal and marine ecosystems.

Chapter-10 is discussing on the strategies for conservation and management of marine environment, in particular for promoting resilience of coral reefs and mangroves to climate change.

I am thankful to the authorities of Annamalai University, India for permitting me to write this book, to my team of research scholars particularly Dr. N. Rajendran, Mr. Sunil Kumar Sahu, Ms. Asmathunisha and Ms. V. Gomathi for helping me in preparatory work and to my wife Mrs. Sumathi Kathiresan for secretarial help.

I am extremely thankful to Anantanarayanan Raman, Editor-in-Chief, 21st Century Biology and Agriculture for having invited me to write this book and to Mr. Tanay Sharma, Managing Director, Scientific Publishers, Jodhpur, India for bringing out this book.

This book would be of immense help to students, scholars and all others who are interested in marine ecology.

K. Kathiresan, D.Sc.

Contents

1. Introduction to Marine Ecology	1
1.1. Ecology And Marine Ecology	1
1.2. Importance of Marine Ecology	4
1.3. Uniqueness of Marine Environment	6
1.4. Uniqueness of Marine Organisms	8
1.5. Marine Environment: Divisions	14
1.6. Marine Organisms: Major Groups	19
Questions for Review/Exercise*	23
2. Environmental Marine Ecology	24
2.1. Physical Environmental Factors	24
2.2. Chemical Environmental Factors	50
Questions for Review/Exercise*	59
3. Ocean Ecology	60
3.1. Pelagic Zone of Ocean	61
3.2. Benthic Zone of Ocean	72
3.3. Hydrothermal Vents and Cold Seep Communities	80
Questions for Review/Exercise*	85
4. Coastal Ecology	86
4.1. Pelagic Zone of Coast	87
4.2. Benthic Zone of Coast	90
4.3. Continental Shelf or Sub-Tidal Zone of Coast	116
Questions for Review/Exercise*	126
5. Ecology of Coral Reef Ecosystem	127
5.1. Importance of Coral	129
5.2. Coral Distribution	130
5.3. Types of Coral Reefs	131
5.4. Ecology of Coral Reefs	132
5.5. Biology of Coral Reefs	134
5.6. Organisms Associated with Reefs	137
5.7. Species Interactions and Ecology of Reefs	138
5.8. Ecology of Reef Fishes	141
Questions for Review/Exercise*	143
6. Ecology of Estuary	144
6.1. Definition of Estuary	145
6.2. Types of Estuaries	146
6.3. Classification of Estuaries	147
6.4. Environmental Features of Estuaries	149
6.5. Estuarine Organisms	157
6.6. Adaptation of Estuarine Organisms	159
6.7. Estuarine Productivity	161

6.8. Estuarine Food Webs	162
6.9. Salt Marshes	162
Questions for Review/Exercise*	167
7. Ecology of Mangroves.....	169
7.1. Distribution of Mangroves	171
7.2. Types of Coastal Settings	173
7.3. Types of Mangrove Forests	173
7.4. Mangrove Ecology	176
7.5. Mangrove Eco-Biology	181
7.6. Mangrove Ecological Functions	189
7.7. Uses of Mangroves	202
Questions for Review/Exercise*	207
8. Functional Marine Ecology	208
8.1. Marine Primary Production	209
8.2. Carbon Sequestration in Marine Environment	217
8.3. Marine Detrivory and Herbivory	220
8.4. Predation, Parasitism and Pathogenesis	223
8.5. Marine Fouling and Boring	228
8.7. Competition and Succession	234
8.8. Dispersal and Settlement	236
8.9. Marine Food Chains	241
Questions for Review/Exercise*	245
9. Threats to Marine Environment.....	246
9.1. Sudden Threats.....	248
9.2. Long Term and Continuous Threats	249
9.3. Threats to Coral Reefs	260
9.4. Threats to Mangroves.....	263
9.5. Threats to Estuaries	271
9.6. Threats to Seagrass Ecosystem.....	274
9.7. Threats to Salt Marsh Ecosystem	274
9.8. Threats to Coastal Sand Dunes.....	275
Questions for Review/Exercise*	276
10. Conservation and Management of Marine Environment	277
10.1. Regulatory Approach for Marine Management	280
10.2. Participatory Approach for Marine Management	294
10.3. Management of Coral Reefs.....	302
10.4. Conservation and Management of Mangrove Ecosystems	307
10.5. Management of Coral Reef Resilience and Resistance to Climate Change (Coral Bleaching).....	314
10.6. Management of Mangroves for Resilience to Climate Change (Sea Level Rise).....	318
Questions for Review/Exercise*	323
Bibliography.....	325
Subject Index.....	339