21st Century Biology and Agriculture:

Textbook Series (VOL. 1-4)

Series Editor : Anantanarayanan Raman

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Insect Physiology

About the Author

Dr. K.P. Sanjayan is an Associate Professor and Head, in the Department of Advanced Zoology and Biotechnology, Guru Nanak College, Chennai, India. Since 1981 he has been researching in the field of insect plant interactions with primary focus on digestive and reproductive physiology of bugs and grasshoppers. His research has been funded by grants from the Government of India funding agencies like the DST, DBT, ICAR, CSIR, MoEF and UGC. He has more than 150 research publications in national and international peer reviewed journals. During the span of more than three decades of teaching and research, twenty students have obtained their doctorate degrees and twelve student received their M.Phil degree from the University of Madras. He is a member of two prestigious scientific organization such as the Madras Science Foundation and the Indian Academy of Entomology besides being a member for various National Scientific Bodies. He is a life member of the Association for Advancement of Entomology, Trivandrum, the National Institute of Ecology, New Delhi and the Indian Academy of Environmental Sciences, Haridwar.

Insect Physiology

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SCIENTIFIC
PUBLISHERS

Published by
SCIENTIFIC PUBLISHERS (INDIA)
Jodhpur –
5 A, New Pali Road
P.O. Box 91
Jodhpur - 342 001 INDIA
INDIA

ISBN: 978-93-86652-27-0
eISBN: 978-93-87991-95-8

Visit the Scientific Publishers (India) website at
http://www.scientificpub.com
Printed in India

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.

Dr. K.P. Sanjayan
email: kpsanjayan@yahoo.co.in

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

Editor-in-Chief, Textbook Series
21st Century Biology and Agriculture
School of Agricultural & Wine Sciences
Charles Sturt University
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21st Century Biology and Agriculture

Wildlife Ecology and Conservation

21st Century Biology and Agriculture

Wildlife Ecology and Conservation

– Mundanthra Balakrishnan
Professor, Department of Zoological Sciences, College of Natural Sciences, Addis Ababa University, Addis Ababa, Ethiopia

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Published by:

SCIENTIFIC PUBLISHERS (INDIA)

Jodhpur
–
5 A, New Pali Road
P.O. Box 91
Jodhpur - 342 001
INDIA

Delhi
–
4806/24, Ansari Road
Daryaganj
New Delhi - 110 002
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E-mail: info@scientificpub.com
Website: www.scientificpub.com

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: Otididae). The great Indian bustard has been a part of Indian culture and tradition, known as *gonãdh* (*Sanskrit*), because the male call closely resembles the mooing of cows. Artist: Urvashi Sharma.

ISBN: 978-81-7233-974-6
eISBN: 978-93-87307-70-4

Printed in India

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
School of Agricultural & Wine Sciences
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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

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21st Century Biology and Agriculture

Growth and Development in Plants

– K.V. Krishnamurthy
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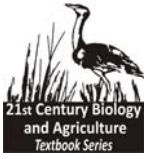
SCIENTIFIC PUBLISHERS

Published by:
Scientific Publishers (India)
5 A, New Pali Road, P.O. Box 91
JODHPUR – 342 001 (India)

Scientific Publishers (India)
4806/24, Ansari Road, Daryaganj
NEW DELHI – 110 002 (India)

E-mail: info@scientificpub.com
Website: www.scientificpub.com



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 *gonãdh* (*Sanksrit*), because the male GIB's call closely resembles the mooing of cows. Artist: Urvashi Sharma.

ISBN: 978-81-7233-945-6
eISBN: 978-93-86237-20-0

Printed in India

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 Bharathisasan 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.

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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
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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

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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We are 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.

Titles in this series:

- Growth and Development in Plants
- Medical and Veterinary Virology
- Ocean and Coastal Ecology
- Wildlife Ecology

21st Century Biology and Agriculture

Ocean and Coastal Ecology

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JODHPUR – 342 001 (India)

Scientific Publishers (India)
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NEW DELHI – 110 002 (India)

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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 (GIB) *Ardeotis nigriceps* (Gruiformes: Otididae). GIB has been a part of Indian culture and tradition, known as *gonãdh* (*Sanksrit*), because the male GIB's call closely resembles the mooing of cows. Artist: Urmila Sharma.

ISBN: 978-81-7233-891-6
eISBN: 978-93-8623-725-5

Typeset by Rajesh Parihar
Printed in India

Series Preface

With great pleasure, the Scientific Publishers (Jodhpur) and I launch the first 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 *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.

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 Kathiresan; 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
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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.

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