

3rd Edition

33090197
UNIVERSITY BOOKSTORE
\$55.05



THE SCIENCE OF



ENTOMOLOGY



William S. Romoser / John C. Vala Jr.



3rd Edition

THE SCIENCE OF ENTOMOLOGY

William S. Romoser

John G. Stottelano, Jr.
University of Massachusetts



Wm. C. Brown Publishers

Dubuque, Iowa • Melbourne, Australia • Oxford, England

Book Team

Editor *Kevin Kane*
Developmental Editor *Jim Dagget*
Production Editor *Michelle M. Campbell*
Designer *Kristyn A. Kalnes*
Art Editor *Kathleen Huinker*
Photo Editor *Shirley Lanners*
Permissions Editor *Vicki Krug*



Wm. C. Brown Publishers

A Division of Wm. C. Brown Communications, Inc.

Vice President and General Manager *Beverly Kolz*
Director of Sales and Marketing *John W. Calhoun*
Marketing Manager *Carol J. Mills*
Advertising Manager *Amy Schmitz*
Director of Production *Colleen A. Yonda*
Manager of Visuals and Design *Faye M. Schilling*
Design Manager *Jac Tilton*
Art Manager *Janice Roerig*
Publishing Services Manager *Karen J. Slaght*
Permissions/Records Manager *Connie Allendorf*



Wm. C. Brown Communications, Inc.

President and Chief Executive Officer *G. Franklin Lewis*
Corporate Vice President, President of WCB Manufacturing *Roger Meyer*
Vice President and Chief Financial Officer *Robert Chesterman*

Cover photographs: top front and center back © John Gerlach/Tom Stack & Associates; bottom front © Milton Rand/Tom Stack & Associates; background © Dee Wilder/Tom Stack & Associates.

Copyedited by Brown Editorial Service

The credits section for this book begins on page 509 and is considered an extension of the copyright page.

Copyright © William S. Romoser 1973, 1981

Copyright © 1994 by Wm. C. Brown Communications, Inc. All rights reserved

A Times Mirror Company

Library of Congress Catalog Card Number: 92-81634

ISBN 0-697-03349-X

No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior written permission of the publisher.

Printed in the United States of America by Wm. C. Brown Communications, Inc.,
2460 Kerper Boulevard, Dubuque, IA 52001

10 9 8 7 6 5 4 3 2 1

Preface

The magnitude of the role played by insects in the scheme of life is undisputed. In adaptive diversity and number of species, they are among the most successful of all organisms. The relatively few that cause problems have taxed our ingenuity to its fullest throughout history, and the battle will probably never be over. Thus the science of entomology is a vital applied science as well as one of the major areas of basic biology. In keeping with this fact, we have treated entomology from both basic and applied points of view.

Our objective in the third edition of this text has been to continue to provide a broad, balanced introduction to the topic of entomology for use in a one-quarter or one-semester general course. At the same time, we hope professional entomologists will find it useful as an up-to-date review and source of literature references.

The discussion of the literature of entomology has been retained in the introductory chapter from earlier editions with the hope that the student will be encouraged to make full use of the vast amount of information available. The remainder of the text is developed around four topics: structure and function spanning the cellular to organismal levels of biological organization (Part One); insects in an environmental context (Part Two); unity and diversity as reflected in insect systematics and as the result of organic evolution (Part Three); and finally, applied entomology (Part Four).

Substantial changes have been made throughout the book. All chapters have been updated and/or expanded; a new chapter on insects and plants has been added; a new chapter on integrated pest management in agroecosystems has been added; the coverage of the orders of Insecta has been increased; the glossary has been expanded to include new terms; new illustrations have been added, and a few old ones omitted; and the number of literature citations has been increased.

Part One, "Structure and Function," begins with a discussion of the diverse roles played by the integumentary system and subsequently elaborates on the structure and function of the insect skeleton. This is followed by discussions of the nervous, glandular, and muscular systems, and then the alimentary and remaining systems. The placement of the control and effector systems first facilitates discussions of regulation of the alimentary and remaining systems. Because the chapter on reproduction and morphogenesis stresses anatomy and physiology, it follows the chapters on anatomy and physiology. The chapters dealing with sensory mechanisms, locomotion, behavior, follow in a continuous and logical sequence.

Part Two, "Insects and Their Environment," begins with a discussion of insect populations and how these populations are influenced by, and react to, the physical, chemical, and biological factors in their environment. A separate chapter is devoted to the relationships between insects and plants.

Part Three, "Unity and Diversity," begins with a discussion of basic systematics, a topic that is all too often neglected in this day and age of molecular biology, and yet a topic that provides a foundation for the rest of biological science. The remainder of the first chapter in this section of the book centers around the origin and evolution of insects. The following two chapters provide an overview of the orders and selected major families in the class Insecta. We have tried to show how the various groups relate to one another, as well as provide information regarding their biology and medical, economic, and ecological significance.

Three chapters are included in Part Four, "Applied Entomology." In chapter 14, the many ways insects are beneficial and are harmful are discussed. In chapter 15, the various methods available to control insects are considered. In chapter 16, we use the topic of integrated pest management in agroecosystems to illustrate approaches

to insect control that are designed to be compatible with the need to minimize environmental damage.

We have arranged the topics in the sequence we think most appropriate for dealing with the various aspects of entomology. However, each chapter can be read and understood with minimal reference to other chapters. Thus, this text should be amenable to any organizational framework a given instructor may choose to follow. A reference list for each chapter, consisting mainly of major review papers, monographs, and specialized textbooks is given at the end of the book.

In addition to those persons who contributed to the first and second editions, we wish to express our sincere appreciation to the following individuals who have played important roles in the development of this edition. "Guest authors" Lance A. Durden (Institute of Arthropodology and Parasitology; Georgia Southern University), Bruce A. McPherson (Pennsylvania State University), Dave Ferro (University of Massachusetts), Patrice Morrow (University of Minnesota), and Margaret Lowman (Williams College), have greatly enriched the text by providing insightful revisions of chapters from the last edition or by writing new chapters. Although, unfortunately, in most cases their identities to us remain pleasant voices over the phone, the senior editorial staff at Wm. C. Brown—Kevin Kane, Carol Mills, and Michelle Campbell—have been delightful to work with and extraordinary in their patience and guidance in developing this text from the untidy first draft to the finished product. We also wish to thank the following Wm. C. Brown editorial staff members for their contributions to our project: Shirley Lanners, Connie Gibbs, Kathy Huinker, Kristyn Kalnes, and Vicki Krug. Copy editor Lynn Brown and her staff at Brown Editorial Service have done a diligent job of policing our grammatical blunders, run-on sentences, and various other unintentional assaults on the English language.

We also wish to thank our professional colleagues whose constructive comments have proven very helpful in producing an accurate, up-to-date text. These colleagues are as follows:

Chih-Ming Yin

University of Massachusetts, Amherst

Donald G. Cochran

Virginia Polytechnic Institute and State University

Robin Leech

Northern Alberta Institute of Technology/University of Alberta

Hal C. Reed

Oral Roberts University

A. G. Scarbrough

Towson State University

We offer a special thank you to Roger Meola, Texas A & M University, who has provided encouragement and advice throughout the life of this text.

As with past editions, the development of this third edition has been a challenging, demanding, at times frustrating, but ultimately very rewarding, experience. We are enthusiastic about our field; we are pleased to have an opportunity to share it with you; and we wish you well in your entomological quest.

W. S. R.

J. G. S.

Preface xiii

CHAPTER ONE	Introduction	1
PART ONE	<i>Structure and Function</i>	7
CHAPTER TWO	The Integumentary System	9
CHAPTER THREE	The Nervous, Glandular, and Muscular Systems	53
CHAPTER FOUR	Alimentary, Circulatory, Ventilatory, and Excretory Systems	83
CHAPTER FIVE	Reproduction and Morphogenesis	125
CHAPTER SIX	Sensory Mechanisms; Light and Sound Production	167
CHAPTER SEVEN	Locomotion	191
CHAPTER EIGHT	Behavior	205
PART TWO	<i>Insects and Their Environment</i>	243
CHAPTER NINE	Insect Populations and the Physical-Chemical and Biotic Environment	245
CHAPTER TEN	Insects and Their Environment: Plants (Lowman/Morrow)	267
PART THREE	<i>Unity and Diversity</i>	291
CHAPTER ELEVEN	Insect Classification and Evolution (McPheron/Romoser)	293
CHAPTER TWELVE	Survey of Class Insecta: I. Apterygota and Exopterygota (Durden/Romoser)	313
CHAPTER THIRTEEN	Survey of Class Insecta: II. Endopterygota (Holometabola) (Durden/Romoser)	355

PART	FOUR	<i>Applied Entomology</i>	387
CHAPTER	FOURTEEN	Beneficial and Harmful Insects	389
CHAPTER	FIFTEEN	The Insect Control Arsenal (Ferro/Romoser)	401
CHAPTER	SIXTEEN	Integrated Pest Management in Agroecosystems (Ferro)	429
GLOSSARY			443
REFERENCES			461
CREDITS			509
INDEX			515

Preface xiii

CHAPTER 1

Introduction 1

Significance of Insects 1

The Science of Entomology 2

Entomological Information 2

*Publications That Contain the Actual Information
about Entomology 3*

*Publications That Attempt to Coordinate the
Literature 4*

The Language of Entomology 6

The History of Entomology 6

PART ONE

Structure and Function 7

CHAPTER 2

The Integumentary System 9

Histology of the Integument 9

Basic Components 9

Chemical Composition of the Cuticle 12

Sclerotization 12

Physical Properties of Cuticle 12

Coloration 13

Permeability Characteristics 14

Molting 14

External Integumentary Processes 17

The Insect Skeleton 18

Segmentation 18

The General Insect Plan 20

Tagmata 20

Head 20

Thorax 24

Legs 28

Wings 28

Abdomen 29

Variations of the General Insect Plan 30

Patterns of External Integumentary Processes 30

Modifications of the Head 30

Modifications of the Thorax 40

Modifications of the Legs 41

Modifications of the Wings 44

Modifications of the Abdomen 46

Modifications of the General Body Form 51

CHAPTER 3

The Nervous, Glandular, and Muscular Systems 53

The Nervous System 53

Structure and Function of the Nervous System 53

Nervous Integration 63

Exocrine and Endocrine Glands 66

Exocrine Glands 66

Functions of the Exocrine Glands 67

Endocrine Glands 68

Functions of the Endocrine Glands 71

The Muscular System 73

Skeletal Muscles 73

Visceral Muscle 81

Muscle Development and Maintenance 81

CHAPTER 4

Alimentary, Circulatory, Ventilatory, and Excretory Systems 83

The Alimentary System 83

- Foregut 84
- Midgut 85
- Hindgut 87
- Digestion 87
- Absorption 90
- Regulation of the Alimentary System 90
- Microbiota and Digestion 92
- Insect Nutrition 93
- Nutritional Ecology 94
- Insect Nutrition and Mass Rearing Programs 94
- Microbiota and Nutrition 94
- Controversy and Hope 94

The Circulatory System 95

- The Dorsal Vessel and Accessory Pumping Structures 95
- Sinuses and Diaphragms 95
- Cardiac Regulation 96
- Circulation 98
- General Characteristics of the Hemolymph 98
- Chemical Composition of the Hemolymph 99
- Functions of Hemolymph 101

General Characteristics of the Hemocytes 102

- Origin of Hemocytes 102
- Number of Hemocytes 102
- Functions of Hemocytes 103
- Other Tissues Associated with the Circulatory System 105

The Ventilatory System 108

- Structure of the Ventilatory System 108
- The Ventilatory Process 113

The Excretory System 118

- Malpighian Tubules 118
- Dietary Problems 119
- Salt and Water Balance 120
- Control of Diuresis and Gut Motility 122
- Nitrogenous Excretion 122
- Insect Urine 123

CHAPTER 5

Reproduction and Morphogenesis 125

Reproductive System and Gametogenesis 125

- Male Reproductive System, Spermatogenesis, and Spermatozoa 125
- Female Reproductive System, Oogenesis, and Ova 129

Seminal Transfer, Fertilization, and Sex

- Determination 134
 - Seminal Transfer 134
 - Multiple Matings and Sperm Precedence 136
 - How and Why Questions 136
 - Male Contributions 136
 - Fertilization 137
 - Sex Determination and Parthenogenesis 137
- Overall Integration of the Reproductive System 139
- Embryogenesis 139
 - Formation of the Blastoderm and Germ Cells 140
 - Formation of the Germ Band and Extraembryonic Membranes 140
 - Differentiation of the Germ Layers 140
 - Segmentation, Appendage Formation, and Blastokinesis 141
 - Organogenesis 143
 - Polyembryony 145
 - Control of Embryogenesis 145
 - Symbionts in Eggs and Embryos 147
 - Oviparity and Viviparity 147
 - Oviposition 148
 - Eclosion 149
- Postembryonic Morphogenesis 149
 - Growth 149
 - Metamorphosis 150
 - Imaginal Discs 156
 - Pupa 156
 - The Instar Definition Controversy 158
 - Control of Growth and Metamorphosis 158
 - Diapause 161
 - Polymorphism 161
 - Regeneration 162
 - Aging 163

CHAPTER 6

Sensory Mechanisms; Light and Sound Production 167

Sensory Mechanisms 167

- Morphology of Sense Organs 167
- Methods Used to Study Insect Sense Organs 169
- Sensory Fields 170

Mechanoreception 170

- The Tactile Sense 170
- The Proprioceptive Sense 170
- Sound Perception 173

Chemoreception 175

- Sensory Coding: Phagostimulants and Phagodeterrents 178

Thermoreception 178

Hygroreception 179

Photoreception 179
 Compound Eyes 179
 Stemmata 185
 Dorsal Ocelli 186
Magnetic Field Reception 187
Visual Ecology 187
Light Production 187
Sound Production 188

CHAPTER 7

Locomotion 191

Terrestrial Locomotion 191
 Walking and Running 191
 Functional Morphology of the Insect Leg 191
 Patterns of Leg Movement during Walking and Running 192
 Muscle Contraction and Coordination of Legs during Walking and Running 193
 Aids to Walking and Running 193
 Jumping 194
 Crawling 195
Aquatic Locomotion 196
 Surface Locomotion 197
 Subsurface Locomotion 197
Aerial Locomotion 198
 Functional Morphology of the Flight Mechanism 199
 Flight and Its Control 201

CHAPTER 8

Behavior 205

Kinds of Behavior 206
 Innate Behavior 206
 Learned Behavior 209
Periodicity in Behavior 211
The Control of Behavior 213
 Nervous Control 213
 Endocrine Control 215
 Genetic Control of Behavior 216
Communication 218
The Biological Functions of Behavior 219
 Feeding Behavior 219
 Escape and Defense Behavior 226
 Behavior and the Fluctuating Environment 228
 Reproductive Behavior 231
 Insects in Groups 238

PART TWO

Insects and Their Environment 243

CHAPTER 9

Insect Populations and the Physical-Chemical and Biotic Environment 245

The Life-System Concept 245
Populations 247
 Relationship between Environmental Components and Populations 247
Insects and the Abiotic Environment 250
 Temperature 250
 Moisture 253
 Light 256
 Other Factors 257
Insects and the Biotic Environment 258
 Intraspecific Interactions 258
 Interspecific Interactions 258
 Adaptations Associated with Interspecific Interactions 263

CHAPTER 10

Insects and Their Environment: Plants 267

Structural Complexity and Age of Host Plants 269
 Insects on Structurally Simple Plants 269
 Insects on Structurally-Complex Plants 269
 Insects on Plants of Different Ages 272
Plant Nutrition and Herbivory 273
 Ways of Eating Plants 273
 Plants as Food 277
 Plant Defenses 280
 Catching Food: Temporal and Spatial Availability 283
Mutualism and Coevolution 285
 Ants and Plants 285
 Plants and Pollinators 286
Insects in Forests as an Example of Community Aspects of Insects and Plants 288

PART THREE

Unity and Diversity 291

CHAPTER 11

Insect Classification and Evolution 293

Systematics 293

Identification 294

Description 295

Classification 296

Nomenclature 299

Insect Evolution 300

Arthropods and Relatives 300

Origin of Arthropoda 304

Origin of Insects 306

Insect Phylogeny 309

CHAPTER 12

Survey of Class Insecta: I. Apterygota and Exopterygota 313

Apterygota (Ametabola) 313

Entognathous Apterygotes 315

Ectognathous Apterygotes 318

Fossil Apterygotes 319

Pterygota (Hemimetabola and Holometabola) 319

Paleopterous Exopterygota 320

Fossil Paleopterous Exopterygote Orders 325

Neopterous Exopterygota 325

Fossil Neopterous Exopterygote Orders 354

CHAPTER 13

Survey of Class Insecta: II. Endopterygota (Holometabola) 355

Endopterygota 355

Neopterous Endopterygotes 355

Fossil Neopterous Endopterygotes 386

PART FOUR

Applied Entomology 387

CHAPTER 14

Beneficial and Harmful Insects 389

Beneficial Insects 389

Insect Products 389

Use of Insects in Medicine 391

Insects in Biological Research 392

Pollination by Insects 392

Insects Consumed and as Consumers 392

Forensic Entomology 394

Insects, Esthetics, Philosophy, and Blatant

Anthropomorphism 394

Harmful Insects 396

Growing Plants 397

Stored Products, Household Goods, and Structural

Materials 398

People and Their Animals 398

CHAPTER 15

The Insect Control Arsenal 401

Biological Control 401

Parasitoids and Predators 401

Microbial Agents and Nematodes 404

Genetic Control 408

Breeding Insect-Resistant Hosts 409

Ecological Control 410

Cultural Control 411

Ecological Control of Nonagricultural Insect

Pests 413

Chemical Control 413

Insecticides 413

Nomenclature 416

Toxicity 416

Mode of Action 416

Synergists 416

Formulations 417

Repellents 419

Attractants 419

Other Chemical Controls 421

The Positives and Negatives of Chemical Control 421

Physical Control 426

Regulatory Control 427

CHAPTER 16

Integrated Pest Management in Agroecosystems 429

Chemical Control and IPM 429

IPM Program Development 430

IPM and Weather Factors 430

Temperature 432

Humidity 433

Wind 433

Sampling and Monitoring 433

Sampling Design 434

Sequential Sampling 435

Relative Sampling 435

Economics of IPM 435

Cost/Benefit 435

Reality of Pest Control 437

Insect Vectors of Plant Pathogens and IPM 437

Aphids 437

Leafhoppers 438

Whiteflies 438

Beetles 438

Case Studies 439

Cotton 439

Biointensive Potato IPM Program 440

Comments on Case Studies 441

Glossary 443

References 461

Credits 509

Index 515

Introduction

Insects are arthropods, the largest group in the Animal Kingdom. Arthropods are characterized by a segmented body that bears a varied number of paired and segmented appendages; bilateral symmetry; an exoskeleton that contains the nitrogenous polysaccharide, chitin; and various internal features, such as an open circulatory system, Malpighian tubules (generally), and in most a system of ventilatory tubules (the tracheae and tracheoles).

Insects can be differentiated from the vast majority of other arthropods by several rather distinct traits. Among these are three well-defined body regions: a head, a thorax, and an abdomen; three pairs of legs in the adult stage; commonly one or two pairs of wings; a single pair of segmented antennae on the head; and several less obvious but equally distinctive characteristics. The name *Hexapoda* (six legs) is commonly applied to insects. However, the name *Insecta* is preferable, because there is some question as to whether all arthropods with six legs in the adult stage actually belong in the same class (Sharov 1966). *Insecta* literally means "in-cut," which describes the segmented appearance of the members of this class. The arthropods will be discussed in more detail when we consider the evolution of insects.

Significance of Insects

Insects as a group are highly successful organisms. Their significance can be looked upon from two standpoints: their tremendous success relative to organisms other than human beings and their extreme importance from the human point of view.

One useful measure of the success of insects is the number of extant (as opposed to extinct) species. Insects probably outnumber all the other species of animals and all the species of plants combined. Estimates based on the current rates of description of new species of insects run

from one to several million, and several large groups have hardly been studied. Arnett (1985) estimates the number of described insect species in the world to be 751,012 and points out the sad fact that we may never know the actual number due to the rapid destruction of habitat worldwide. Studies of tropical insect fauna lead to widely divergent estimates of the total world insect fauna (described plus undescribed) ranging from somewhere between 5 and 10 million (Gaston 1991) to 30 million or more (Erwin 1982, 1988).

Other important criteria for success include the span of geologic time traversed by a group of organisms and their adaptability to various environmental situations. Insects are thought to have arisen in the Devonian era, approximately 400 million years ago. Mammals as a group are approximately 230 million years old; modern humans arose perhaps 1 million years ago. In this sense, insects have not invaded the human world; we have invaded theirs! The adaptability of the basic insectan plan has been phenomenal. Insects can be found in nearly every conceivable terrestrial habitat. As you proceed with your study of insects, you will come to realize the seemingly unlimited adaptability of insects and gain insight as to how they have reached their position of success.

From earliest times people have seen certain insect species as arch enemies. Although the pest species make up a very small proportion of the total number of insect species, members of this group are chronic troublemakers, destroying annually millions of dollars worth of agricultural crops, fruits, shade trees and ornamental plants, stored products of various sorts, household items, and other valuable material goods (Davidson and Lyon 1987). Pest species act as vectors of the causative agents of human and domestic animal and wildlife diseases, and their direct attacks cause irritation, blood loss, and sometimes death (Harwood and James 1979, Kettle 1984).

However, there are two sides to the picture. Insects provide many highly valued goods and services. Such insect products as honey and beeswax, silk, shellac, and cochineal are used for a variety of applications, ranging from sweetening biscuits to constituting one of the basic components of many cosmetics. In addition, there are many indirect benefits of insect activities, such as plant pollination and involvement in nutrient cycling.

Although there is much that can be said both for and against insects as they relate to humans, the vast majority of insects are neutral, neither bestowing benefit nor causing harm.

The Science of Entomology

Entomology is a specialized field within the biological sciences, because it is concerned with “living” systems. The biological sciences can be divided into basic divisions, such as morphology, physiology, genetics, and ecology, and into taxonomic divisions, such as ornithology, mycology, and bacteriology. Entomology, as the study of a very specific group of organisms, is a taxonomic division. Therefore, we can approach the science of entomology by considering the “basic” divisions as they apply to insects: insect morphology, physiology, ecology, and so on.

The study of insects has played and continues to play a major role in the development of biology. This is evident upon examination of a current general biology text. Among the entomological topics, one might find the following:

Redi's experiments with maggots and spontaneous generation; coevolution of plants and pollinating insects; the mechanisms of sex determination in insects; mutations in *Drosophila*; linkage groups, sex-linkage, chromosomal mapping, and induced mutations in *Drosophila*; chromosomal puffs in *Drosophila* and their induction by ecdysone; pheromones; behavioral genetics of cricket singing; spatial orientation of the digger wasp; migration of the monarch butterfly; circadian rhythms and adult emergence in *Drosophila pseudoobscura*; several other behavioral examples using insects (including behavior of the honey bee); termite–protozoan mutualism; temperature control in termite mounds and beehives; bees and orchids; ants and acacias; fig wasps and figs; industrial melanism; specialization in the *Drosophila willistoni* complex; pesticide problems. . . .

Further evidence for the major role played by entomology in the development of biology is that Nobel Prizes have been awarded to several scientists who studied insects, e.g., Karl von Frisch, Niko Tinbergen, and Konrad Lorenz.

For an excellent introduction to entomology as a science, see Wigglesworth (1976).

Entomological Information

A serious study of entomology requires a knowledge of resources available that help entomologists to acquire information about insects. The oldest and still one of the most important means is by word of mouth. This is the method employed in the classroom, at scientific meetings, conferences, and so on. Perhaps its most valuable aspect is the opportunity for a two-way exchange of information. Ideally, in this situation the lines of communication are wide open and a minimal amount of ambiguity should be the result. Another, equally important—in fact, essential—means of acquiring scientific information is consultation of the literature. The advantage of this method is that one can go back in time as far as one wishes, but the two-way exchange of information is impossible if the author of a piece of recorded work is no longer living. Both these means of acquiring information should be considered to be prerequisites for a third means—personal investigation. This method is, of course, the source of new information. All three means are essential to the existence of science, and certainly no one method could take precedence over the other two. However, let us delve further into the use of entomological literature.

The literature of entomology consists of a wide variety of publications ranging from rather popularized accounts intended for the layperson to highly technical treatises on very specific aspects of the science. The information available on insects is vast and is growing so rapidly that no one person can stay abreast of and learn more than comparatively small portions of it. There is also a great deal of specialization, the concentration of effort on a single topic or a group of closely related topics. Thus, among entomologists there are, for example, insect physiologists, ecologists, morphologists, systematists, toxicologists, and economic entomologists. Generally, the specialization goes even further; someone in one of the preceding groups may concentrate on a particular insect species or group of insects, or on a specific topic, or both. For example, there are specialists in the systematics of a particular family of beetles or in mosquito physiology.

The tremendous number of entomological publications makes a comprehensive review inappropriate within the context of this book. However, a brief discussion of some of the different types of entomological literature may be helpful. More extensive treatments of the literature of entomology and zoology in general can be found in Smith, Reid, and Luchsinger (1980), Chamberlin (1952), and Blackwelder (1967). The recent compendium by Gilbert and Hamilton (1990) deserves special mention.

Publications pertinent to entomology (for that matter, the entire field of zoology) can be divided into two basic groups. The first group includes all those publications, irrespective of type, that contain the actual information about animals (insects). This group presents the products of zoological (entomological) research. The second group

includes all the publications that attempt to coordinate the vast information contained in the first group, making it more readily available to investigators. Examples of publications from each of these groups are presented. This method of classification, as with most, is certainly not without exception, as will be shown.

Publications That Contain the Actual Information about Entomology

Textbooks

A textbook is generally designed to give the reader an understanding of the basic principles involved in a given subject. A textbook may be quite general in scope, presenting a survey or overview of an entire field—for example, a general entomology textbook such as the one you are reading or any of several others, including Borror, Triplehorn, and Johnson (1989), C.S.I.R.O. (1991), Richards and Davies (1977, 1978) and Evans (1984). Other textbooks deal with a particular area within the field. For example, there are texts devoted to insect physiology—Chapman (1982), Blum (1985), and Wigglesworth (1972); insect ecology—Price (1984); insect behavior—Matthews and Matthews (1978), Atkins (1980); medical entomology—Harwood and James (1979), Kettle (1984); or economic entomology—Davidson and Lyon (1987). Books of this type treat a subject in more depth than the general text and are more likely to be used in advanced courses.

Monographs

A monograph is limited in scope, dealing with only a very small area within a science. However, monographs are usually comprehensive in their coverage of pertinent literature and handling of subject matter. Excellent examples are Dethier's superb *The Hungry Fly* (1976) and the 1990 Pulitzer Prize-winning book, *The Ants* by Hölldobler and Wilson.

Symposia

Symposia proceedings are published collections of the presentations of several specialists in a given area who have met to consider a specific aspect of science. A recent example, which deals in great depth with a particular group of mosquito-borne viruses, is *California Serogroup Viruses* (Calisher and Thompson 1983) which is the published proceedings of an international symposium.

Lectures

A lecture is an oral discourse presented to an audience or class, particularly for instructional purposes. Good examples of entomological lectures are the talks presented by outstanding scientists to the general sessions usually held several times during each annual meeting of the var-

ious entomological societies throughout the world. These talks are commonly published in bulletins issued periodically by these societies.

Essays

Essays are analytical or interpretative expositions that usually deal with a given topic from a rather personal or limited point of view. A well-known example is the book *Silent Spring* by Rachel Carson.

Reference Works

Reference books generally attempt to offer comprehensive coverage of a specific area and are designed to be consulted as needed rather than read and digested in their entirety. This category may seem rather arbitrary, since any piece of literature that is consulted can be classified as a reference, and rigorously documented and highly technical entomological texts, such as Richards and Davies (1977, 1978) and *The Insects of Australia* (C.S.I.R.O. 1991), can equally well be viewed as reference works. An especially valuable recent reference work is the thirteen-volume set entitled *Comprehensive Insect Physiology, Biochemistry, and Pharmacology* (Kerkut and Gilbert 1985).

Pamphlets

Pamphlets are usually rather brief writings on a specific topic, commonly geared to the persons who put many of the findings of entomological research into practice: farmers, exterminators, and so on. Examples of pamphlets are the *Farmer's Bulletins* published by the U.S. Department of Agriculture, which pertain to the biology and control of economically important species of insects.

Reports

From time to time, groups of experts are called together to investigate or to discuss an issue or problem of particular significance. For example, the World Health Organization (WHO) periodically sponsors meetings of expert committees on various problems pertaining to international health matters, including topics such as malaria and similar diseases with which insects are involved. These committees usually submit reports describing the problems discussed and the conclusions reached in the course of the meeting.

Series

Serial publications are issued periodically (sometimes at irregular intervals) and have a certain unity of subject matter; that is, a particular series deals, volume after volume, with more or less the same general subject matter. Series are published by most professional societies and many private and governmental concerns in the form of journals, bulletins, miscellaneous publications, yearbooks, and so on. Hammack (1970) and more recently

Gilbert and Hamilton (1990) provide useful and comprehensive descriptions of the serial literature pertinent to entomology. Some examples of entomological journals are *Annals of the Entomological Society of America*, *Journal of Economic Entomology*, *Environmental Entomology*, *Journal of Insect Physiology*, *Systematic Entomology*, *Ecological Entomology*, *Physiological Entomology*, *Psyche*, *Journal of Insect Behavior*, *Boletín de La Asociación Española de la Entomología*, *Canadian Entomologist*, *Deutsche Entomologische Zeitschrift* (*Berliner Entomologische Zeitschrift*), *Bulletin de La Société Entomologique de La France*.

Publications That Attempt to Coordinate the Literature

From the time scientists realized the fantastic rate of growth of the literature of science, many very useful attempts to coordinate and integrate the works in various areas have been made. In this section we want to discuss briefly some of the more common publications in this category. Most of these publications are quite expensive and are seldom purchased by an individual.

Bibliographies

A bibliography is to the literature of science as an index is to a book, the basic difference being that a bibliography lists only publications of various sorts on a single topic, instead of the subjects, authors, and so on, that are found in the index of a single book. Bibliographies appear in different forms. For example, one form is a list of pertinent references at the end of a chapter of a book or a scientific paper. Another type of bibliography is issued periodically and lists current publications in a particular field. Important examples of this type are *Zoological Record*, *Bioresearch Index*, *Bibliography of Agriculture*, *Cumulated Index Medicus*, and *Current Contents*. The *Zoological Record* has a very broad coverage, both foreign and domestic, and is arranged according to taxonomic groups and by subjects. The section on insects is quite extensive and contains references to papers of interest to most entomologists, not just taxonomists. *Bioresearch Index* is a monthly publication that furnishes bibliographies from various journals and contains citations of research papers. The *Bibliography of Agriculture*, a monthly publication, generally contains a large number of references to entomological papers. The last issue of each year is a cumulative subject index. *Cumulated Index Medicus* is issued four times yearly, covers much of the foreign and domestic medical literature, and may contain references of interest, particularly to medical entomologists. *Current Contents* reprints the tables of contents of many journals, several entomologically oriented ones included. It is issued weekly and is probably one of the best ways to keep abreast of the most current literature. This is especially important when one is

working in a very active area in which a number of researchers are publishing extensively and often. The recent availability of current contents on computer diskettes has greatly enhanced the process of using this publication.

Abstracting Journals

Abstracting journals contain brief descriptions or abstracts of the results reported in the journals that fall within their scope. Abstracts are extremely useful because they give an investigator a better idea of the content of a given reference than does a mere title listing, although they do serve also as bibliographies. This kind of information helps one decide whether or not to consult the actual references and compensates somewhat for the fact that some publications are extremely difficult to obtain or translate from a foreign language. Abstracting journals are usually extensively cross-indexed, which makes them efficient to use. One of the most significant examples of this type of publication is *Biological Abstracts*. This bimonthly publication is comprehensive in its coverage of the literature of both theoretical and applied biology. In addition to the volumes containing the abstracts, a semimonthly publication, *B.A.S.I.C.*, provides an elaborate computerized subject index to the issues of *Biological Abstracts*. A cumulative subject index based on all the issues of *B.A.S.I.C.* is published semiannually. Since January 1970 the abstracts and citations of research papers pertaining to insects and arachnids in *Biological Abstracts* and *Bioresearch Index* have been compiled into a separate publication, *Abstracts of Entomology*. One issue of this publication corresponds to two issues of *Biological Abstracts* and one issue of *Bioresearch Index*.

Other abstracting journals that specialize in covering entomological literature are *Entomology Abstracts* and *Review of Applied Entomology*. *Entomology Abstracts* is published monthly and covers a wide variety of entomological topics. *Review of Applied Entomology* is published in two series: Series A, Agricultural, and Series B, Medical and Veterinary. It is well indexed, both by subject and author, and contains abstracts covering a wide variety of entomological topics. Other periodical publications that are at least partly abstracting journals are *Biologisches Zentralblatt*, *Physiological Abstracts*, *Tropical Diseases Bulletin*, *Apicultural Abstracts*, and several others from various countries.

Another very useful monthly publication is *Dissertation Abstracts*. This contains abstracts of all dissertations (i.e., the printed results of doctoral student research) by contributing institutions in the United States and Canada. It is arranged by the type of subject matter. These abstracts are useful since there is commonly a significant period of time between the writing of a dissertation and the publication of a research paper or papers based on it. If one decides on the basis of a given abstract that more information is necessary, he or she may

readily obtain, for a fee, a microfilm or printed copy of an entire dissertation. In a similar vein, *Dissertation Abstracts* publishes abstracts from contributing worldwide institutions.

Review Journals

Review journals contain papers that discuss the literature on a rather specific topic in a given field. Review papers not only bring together information from the pertinent literature on a given topic but also commonly contain useful syntheses of information that may not occur in any other type of publication. In this sense they may be classed in either of the two rather arbitrary categories we have used to discuss entomological literature. Two very important review journals in the field of entomology are the *Annual Review of Entomology* and *Advances in Insect Physiology*. Other review journals that may contain reviews of entomological interest are the *Annual Review of Ecology and Systematics*, *Annual Review of Physiology*, *Annual Review of Phytopathology*, and the *Annual Review of Medicine*. In addition, review papers may appear in journals, bulletins, and so on, which contain other types of articles.

Taxonomic Indexes and Catalogs

Taxonomic indexes include literature references to such items as the original description of a given genus or species and revisions of genera. These publications are quite useful for tracing the taxonomic literature pertinent to a given group and for determining the systematic position of a given genus or species. Especially important indexes are *Nomenclator Zoologicus* edited by A. A. Neave, *Zoological Record*, and *Biological Abstracts*. *Nomenclator Zoologicus* lists the names of genera and subgenera of all zoological groups from 1758, the year of the publication of the 10th edition of Carl Linne's (Linnaeus) *Systema Naturae*, to 1950. *Zoological Record* contains the names of all new genera described each year and pertinent literature references from 1864. *Biological Abstracts*, in the section "Systematic Zoology," provides references to the original descriptions of genera and subgenera of animals since 1935. Smith (1958) points out that "Neave's *Nomenclator Zoologicus* and *Biological Abstracts* serve admirably as a complete generic index from 1758 to the present." He further suggests that "... for names published since the most recent issues of *Biological Abstracts*, journals in which new genera of the various groups might be expected to occur must be consulted."

For species indexes and catalogs similar to the generic ones just described, one must refer to one or more of several currently available. Sherborn's *Index Animalium* is the only general species index available and covers all the specific names proposed for animals from 1758 through 1800. Smith, Reid, and Luchsinger (1980),

Chamberlin (1952) and Blackwelder (1967) each contain lists of catalogs for various insectan and other groups.

Science Citation Index

The Science Citation Index is published by the organization that publishes *Current Contents* and is composed of two sets of indexes, a citation index and a source index, both of which are cumulative. Its objective is to list and index the current and past research papers that cite a given reference. It enables an investigator to begin with a given reference and find other references that have cited the "starting reference." Because both the "starting reference" and "citing reference" are likely to pertain to the same or very closely related topics, one is able to proceed forward or backward in time, using "citing references" as "starting references" in a cyclical manner and by doing so accumulate references on a given topic.

Union List of Serials and New Serial Titles

Most libraries do not have complete sets of all journals useful in entomology or any other science. However, they generally have agreements with other libraries, whereby volumes can be borrowed or copies of particular papers can be obtained, that is, interlibrary loans. *The Union List of Serials in Libraries of the U.S. and Canada* and *New Serial Titles* are listings of all journals and of the major libraries that house these journals. Thus, by consulting these lists, one may determine which libraries have the journal he or she is seeking. Both lists are indexed by journal name and by subject.

Books In and Out of Print

Books in Print is an annual listing of books currently available on the commercial market. This list is composed of four volumes: Volumes 1 and 2, titles; and Volumes 3 and 4, authors plus author and title indexes. Out-of-print books may be found by consulting the *A. B. Bookman's Weekly*, various companies that specialize in such books, and major libraries. Facsimiles of out-of-print books are available from University Microfilms International in Ann Arbor, Michigan.

Databases

In recent years the computer has come to play an important role in the management of scientific literature. Several major databases, such as computer-accessible indexes and bibliographies, are maintained and can be tapped for literature searches. Among the databases useful in entomology are AGRICOLA which includes, among others, citations from the *Bibliography of Agriculture*, Bioscience Information Service (BIOSIS), which includes citations from *Biological Abstracts* and *Bioresearch Index*, and Medical Literature Analysis and Retrieval System (MEDLARS), which includes citations from *Cumulated Index Medicus*. These databases are