Natural Enemies

An Introduction to Biological Control

This second edition of *Natural Enemies* will give students, professionals, and anyone wishing to learn the basics of biological control a fully updated and thorough introduction. The book discusses the huge diversity of organisms used in the control of pests, weeds, and plant pathogens and compares the many different strategies referred to as "biological control": the introduction of exotic natural enemies; application of predators, parasitoids, and microorganisms for shorter term control; and manipulation of the environment to enhance natural enemy populations.

The authors present the ecological concepts which form the bases of biological control and discuss recent changes to make biological control safe for the environment. Case studies are included throughout, providing in-depth examples of the use of different organisms and strategies in a variety of ecosystems. A new chapter covers the current challenges, the impact of climate change, the problem of invasive species, and how biological control can aid sustainability.

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An Introduction to Biological Control

Second edition

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Preface

This book provides a new and updated view on what was presented in the 2004 edition by the same name. The first edition was single-authored by Ann Hajek while in this version Jørgen Eilenberg has joined Ann as a coauthor. As in 2004, our goal has been to write an introductory book with broad coverage of the diverse uses of natural enemies for control of invertebrate and vertebrate pests, weeds, and plant pathogens. There are numerous excellent books on biological control that provide more advanced coverage, but our book is intended for people that do not already have extensive knowledge in these subject areas.

The field of biological control has grown and changed in many ways since 2004 and an updated and revised version is needed. Natural enemies are important for pest control in agriculture, in both greenhouses and fields, in forestry, and in managing and protecting natural areas as well as in controlling medical and veterinary pests. One reason for the growth in biological control, especially in agriculture and forestry, is that not as many new chemical pesticides are coming on the market and many older ones can no longer be used. In addition, the public is often more knowledgeable and less tolerant of the uses of pest controls that are potentially harmful to people and the environment. What has changed since 2004 that requires a new book? In particular, in 2004 classical (importation) biological control was considered by many people concerned about the environment and especially biodiversity as being a practice that had great potential for being dangerous to our environment. Since then, the amount that this strategy has been used has decreased significantly, but, with the need to control ever-increasing introductions of invasive species and the development of safer methods for classical biological control, use of this strategy with environmentally safe measures is now beginning to rebound. Another big change is the growth in the diversity and use of natural enemies not released for permanent establishment, a strategy that is generally called augmentation; in addition to arthropod predators and parasitoids applied augmentatively, products based on invertebrate pathogens, insect-pathogenic nematodes, antagonists of plant pathogens, and plant pathogens killing weeds are produced by commercial companies. A prime example of augmentative use of biological control agents today is the greenhouse industry, where natural enemies are often used extensively and very successfully for a variety of reasons including enhanced worker safety. Conservation biological control has also been growing, with practical and theoretical emphases on understanding how we can change environments in order to manipulate the preexisting biodiversity toward controlling pests.

Our book is arranged in the same way as in 2004, beginning with two introductory chapters about why to use biological control and defining biological control. Then we present sections describing the major strategies (classical biological control, augmentation, and conservation), followed by sections on biological control of invertebrates and vertebrates, biological control of weeds, and biological control of plant pathogens, and plant parasitic nematodes. We next discuss safe use of biological control and its integration with other control methods. Finally, we examine the future for this growing and changing field, including discussions on biological control in the context of invasive species, climate change, and the potential for increased use against medically important arthropods, and we discuss how biological control fits into the context of sustainability.

Throughout the book, we have included stories from around the world about how diverse natural enemies have been used successfully in the context of different strategies. As in the 2004 book, we do not provide references throughout the text, with the goal of making this introductory book more easily readable. However, the references that have been used in writing the book are listed at the end of the book in the general references section. We have emphasized examples of biological control that are in practical use, while describing some pest/natural enemy systems that are close to utilization, and only occasionally discussing systems that are simply tantalizing. Those readers interested in biological control agents that hold promise but are not yet being used or who want more in-depth information are referred to the further readings suggested at the end of each chapter, as well as to the large number of reviews and enormous number of primary papers in the scientific literature.

This book is intended as a basic presentation and readers should not need an extensive background in entomology, weed science, or plant pathology. We have attempted to use scientific jargon as little as possible and have provided a glossary at the end to help with specific terms used in the text. We have used English common names for pests and natural enemies when possible, but not all of these organisms have common names (e.g., among insects, actually relatively few have common names). Therefore, we have always provided Latin genus and species names regardless of whether the English common name is given. We assume this will also be helpful for readers who are not familiar with English common names.

Both authors of this book have taught biological control over decades to undergraduate and graduate students at their respective universities and this book grew from their interests in providing more accessible background readings for students taking their classes. The 2004 book has been used for classes around the world and we hope that this version, with many examples from different continents of use of natural enemies in a variety of contexts, finds similar use. In particular, we hope that in reading this book, you will find the interactions between natural enemies and their hosts as fascinating and interesting as we do and will feel that it makes sense to use these relationships to control pests toward increased safety for humans and the environment whenever possible.

Generalization pertaining to biology must always be followed by exceptions. In fact, making generalizations virtually means leaving out at least some of the fascinating variability found in biological systems. There are many tales of amazing interactions and relationships among natural enemies and their hosts or prey and only a small fraction

of these could be included in this book. The diversity of manipulations of biological systems for pest control also made it difficult to decide which examples to include in a book such as this. There are really many good stories to be told. Our emphasis has been on providing a glimpse of the diversity of natural enemies used and the diversity of biological control approaches that have been applied. In summary, with this book we hope that we have shared our personal excitement about the field of biological control and that you will become as fascinated as we are with the practice and potential of using natural enemies to control pests.

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This book has not changed entirely from the 2004 version, although the text has definitely changed quite a lot, and more than we had expected. We are not going to list again the many people who helped in many ways and were acknowledged in the 2004 version, but we thank them again as parts of the 2004 book remain. In particular, many of the figures used in the 2004 book have been used again. We especially want to

acknowledge again Alison Burke, who helped extensively with organizing the excellent figures for the 2004 version and even drew some of the illustrations herself.

We also want to thank our editors, Dominic Lewis and Lindsey Tate, for their steadfast faith and patience that this revised edition could and would be completed. Finally, we thank our spouses, James Liebherr and Betty Østergaard Jacobsen, for their encouragement, patience, and assistance throughout the long process of revising, writing, and putting this book together.