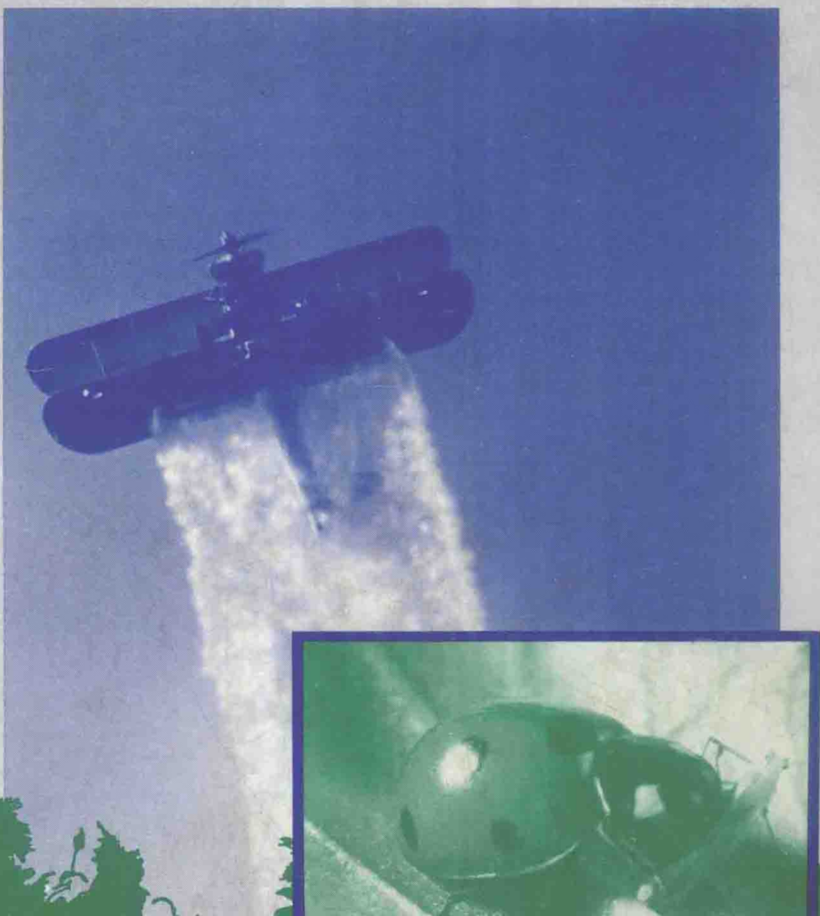
ARTHROPOD BIOLOGICAL CONTROL AGENTS AND PESTICIDES



Brian A. Croft

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Edited by Robert L. Metcalf and Werner Stumm

ARTHROPOD BIOLOGICAL CONTROL AGENTS AND PESTICIDES

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ARTHROPOD BIOLOGICAL CONTROL AGENTS AND PESTICIDES

This volume honors B. R. Bartlett of the University of California, Riverside, who pioneered the study of natural enemy–pesticide interactions and who influenced me by his ability to combine biological control research with the evaluations of "dirty pesticides."

SERIES PREFACE

Environmental Science and Technology

The Environmental Science and Technology Series of Monographs, Textbooks, and Advances is devoted to the study of the quality of the environment and to the technology of its conservation. Environmental science therefore relates to the chemical, physical, and biological changes in the environment through contamination or modification, to the physical nature and biological behavior of air, water, soil, food, and waste as they are affected by man's agricultural, industrial, and social activities, and to the application of science and technology to the control and improvement of environmental quality.

The deterioration of environmental quality, which began when all first collected into villages and utilized fire, has existed as a serious problem under the ever-increasing impacts of exponentially increasing population and of industrializing society. Environmental contamination of air, water, soil, and food has become a threat to the continued existence of many plant and animal communities of the ecosystem and may ultimately threaten the very survival of the human race.

It seems clear that if we are to preserve for future generations some semblance of the biological order of the world of the past and hope to improve on the deteriorating standards of urban public health, environmental science and technology must quickly come to play a dominant role in designing our social and industrial structure for tomorrow. Scientifically rigorous criteria of environmental quality must be developed. Based in part on these criteria, realistic standards must be established and our technological progress must be tailored to meet them. It is obvious that civilization will continue to require increasing amounts of fuel, transportation, industrial chemicals, fertilizers, pesticides, and countless other products; and that it will continue to produce waste products of all descriptions. What is urgently needed is a total systems approach to modern civilization through which the pooled talents of scientists and engineers, in cooperation with social scientists and the medical profession, can be focused on the development of order and equilibrium in the presently disparate segments of the human environment. Most of the skills and tools that are needed are already in existence. We surely have a right to hope a technology that has created such manifold environment problems is also capable of solving them. It is our hope that this Series in Environmental Sciences and Technology will not only serve to make this challenge more explicit to the established professionals, but that it also will help to stimulate the student toward the career opportunities in this vital area.

ROBERT L. METCALF

WERNER STUMM

PREFACE

The science and the practice of biological control have expanded considerably since the classic introduction of the vedalia beetle for control of the cottony cushion scale in the late 1800s to early 1900s. Recent emphasis on integrated pest management has not only taught chemical pest control specialists to appreciate and take advantage of the natural pest-regulating power of predaceous and parasitic arthropods, but it has also convinced biological control purists of the necessity of chemical pest control in many crops and managing natural enemies within the constraints of pesticide-structured agroecosystems. Major international organizations with interest in biological control are focusing attention on the efficacy of predators and parasites of pests and on the influence of pesticides on these natural control agents. Use of pesticides selectively, mostly through ecological manipulations and through physiological mechanisms, is improving. The genetic improvement, colonization, and management of pesticide-tolerant and resistant predators and parasites has come to merit a comparable footing with classical biological control and conservation/augmentation as fundamental goals of the discipline.

This book integrates research findings from numerous fields that focus on the interaction of pesticides with entomophagous arthropods. Emphasis is on those characteristics that make natural enemies unique in their responses to chemical toxins. This volume treats the history of research; susceptibility assessment; lethal, sublethal, and ecological effects of pesticides; selectivity; resistance; and resistance management. The goal is to discuss conservation of natural enemies through the use of pesticides in selective ways and the use of physiologically selective pesticides. This must be done while achieving necessary control of pests with pesticides and other pest control measures.

Appreciation is expressed to the graduate students who constructively criticized the book, including A. Knight, D. Sewell, R. Miller, K. Theiling, L. Flexner, R. Messing, S. Booth, S. Harwood, D. Carmean, and M. Arshad. I thank them for their input and blame none of them for the faults of the book. The editing of especially Karen Theiling and Russ Messing was most helpful. Kevin Currans helped me with the computer database and graphics programs. Karen Theiling developed many of the figures and Karen and my daughter Marnie worked extensively on the bibliography. Financial support came from USDA Western Regional Project W-161 on IPM, and an EPA project on Risk Assessment of Microbial Pesticides to Nontarget Organisms. Finally, I thank Candy Croft for encouragement to see this volume through to completion.

BRIAN A. CROFT

Corvallis, Oregon
July 1989

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PART ONE

INTRODUCTION AND SCOPE

1

NATURAL ENEMIES AND PESTICIDES: AN OVERVIEW

1.1. INTRODUCTION

Modern agriculture has come to rely extensively on synthetic chemical pesticides for pest control. Thousands of compounds from dozens of chemical classes have been developed by industry to control a wide range of pests, including insects, mites, nematodes, rodents, weeds, and bacterial, viral, and fungal pathogens. Although these toxins are targeted at plant pests, many of them are broad-spectrum biocides that have profound effects on nontarget species in agricultural ecosystems. Even the recently developed biorational pesticides, which are based on natural products and are more host- or pest-specific, can have far-reaching side effects. Biorational pesticides include agents such as microbial insecticides, insect growth regulators, chitin inhibitors, and probably many future genetically engineered pesticides.

Arthropod predators and parasitoids are the most important naturally occurring biological control agents of insect and mite pests in most crop ecosystems. Many of these entomophagous species have biologically adapted to their hosts or prey and have become efficient exploiters of herbivore populations. Even in intensively structured, highly simplified agroecosystems, they often provide complete or partial biological control of plant pests. Pesticides are often disruptive to trophic relationships involving these beneficial species. Consequently plant pest populations may increase to more damaging levels than occurred before treatment. Because of basic physiological similarities between arthropod pests and their natural enemies, pesticides often inflict severe mortality on both groups of organisms. This is especially true for those general toxins that act as nerve poisons. Nerve poisons comprise the vast majority of insecticides and acaricides in use today.

In addition to their direct impact, pesticides often disrupt trophic relationships by their toxic effects on associated species in the community, including competitors, hyperparasites, and alternate hosts or prey of natural enemies. As noted, some of the practical consequences of these disruptions are outbreaks of primary and secondary pests, increased pest control problems, and difficulties in establishing biological controls (Newsom et al. 1976, Flint and van den Bosch 1981, Velasco 1985).

Pesticides influence the biology of natural enemies in even more subtle ways. These species may experience sublethal effects on development or behavior. Fecundity, fertility, rate of development, and survivorship may be altered. Behaviors such as host or prey finding and general mobility may also change (Croft 1977; Chapter 7).

The impact of pesticides on arthropod communities may extend over long time periods and large areas. Pesticide induced perturbations in a given habitat can last for several months or years, until the delicate numerical balance needed for biological control or pest regulation is reestablished (Chapter 8). If pesticides eliminate natural enemies within a crop, pest populations may increase and subsequently emigrate to surrounding habitats. Pests may then damage crops at a considerable distance from the site where the actual chemical application took place (Vickerman and Sunderland 1977, Lopez and Morrison 1985; Chapter 8). In complex ecosystems, pesticides may cause disruptive responses in peripheral species that were not treated at all, but were sensitive to the overall ecological balance.

Because of the negative consequences associated with pesticide use, these toxins and biological control organisms have long been considered incompatible. This became particularly evident following the development of DDT and other broad-spectrum pesticides. As a result, entomologists often were split into opposing camps—those favoring chemical control methods and those favoring biological controls as the primary means to achieve pest suppression. In time it was realized that problems were associated with either of these classes of pest control methods. Often biological controls were not effective enough and yet pesticides were overly disruptive to nontarget species.

The integrated pest management (IPM) concept was developed essentially as a response to the incompatibility of pesticide and biological controls. From the beginning, its primary emphasis was to integrate these two pest control measures (Ripper et al. 1949, Ripper 1956, Bartlett 1956, 1964). Modern IPM is based on an understanding of the necessary interrelatedness of pesticides and natural enemies. Pest management seeks to exploit the more subtle interaction between biological and chemical pest control agents in the development of selective pesticides. One of the goals of this book is to highlight research on pesticide/natural enemy relationships and to show how this type of study may improve IPM.

1.2. KNOWLEDGE OF PEST/NATURAL ENEMY RESPONSES TO PESTICIDES

Much less is known about the effects of chemical pesticides on predators and parasites than on herbivorous pests (Croft and Brown 1975). This is understandable in light of the fact that pests are the primary objects of pest control activities, whereas the contributions of natural enemies to pest control and crop loss prevention are only sometimes recognized.

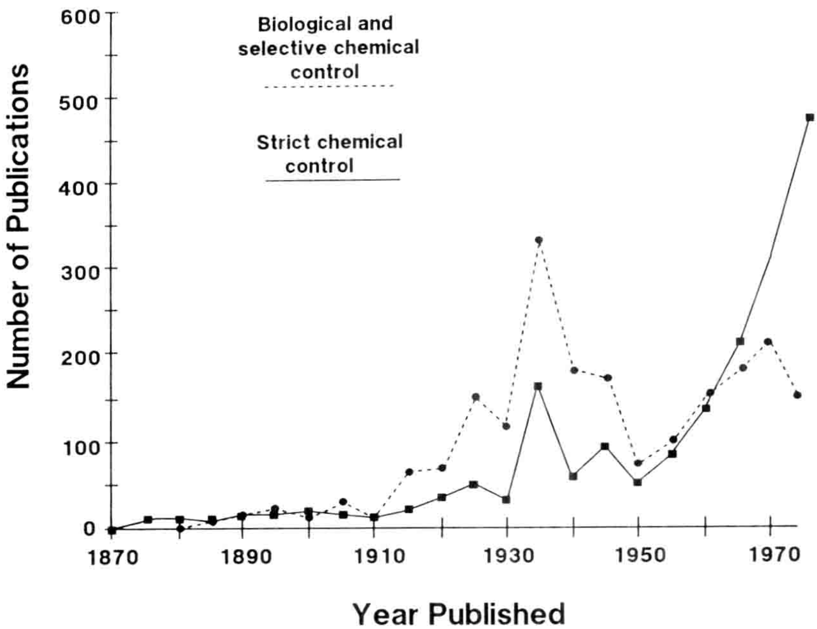

Figure 1.1. Worldwide literature citations dealing with biological and chemical control of codling moth (*Cydia pomonella*) since 1870 (taken from the bibliography of Butt 1975).

Susceptibility, resistance, sublethal effects, and other pesticide impacts on pests are commonly documented in the applied pest control literature (Brown 1978b, Metcalf 1980). In fact, during some eras this type of research almost exclusively dominated the literature, although this was not always the case. During the early years of agricultural research, a more balanced perspective between biology and chemical control of pest arthropods was maintained. However, from 1940 to 1960, pesticide impact evaluations on pests were the single most common type of literature published in applied entomology. This research was often conducted in preference to more basic study of the biology and biological control of these species.

An example of the changing emphasis in pest control is illustrated in a plot of data from the global bibliography of Butt (1975). This document contains literature on the biology (it also includes selective chemical control) and strict chemical control of the common apple pest, the codling moth *Cydia pomonella* (Fig. 1.1). From 1870 to 1910, a reasonable balance between biological and chemical control research was maintained on this species. Both areas of investigation were deemed equally necessary. Research into chemical control may have been limited by the efficacy of pesticides available during this period (e.g., heavy metal poisons, botanicals, and other inorganic products). From 1920 to 1950 almost 70% of all published research featured chemical control of the codling moth (Fig. 1.1). Since 1955, proportions have become more equal, and since the late 1960s, research with a biological or biological control emphasis has predominated.

These literature trends for *C. pomonella* are much like those cited by Metcalf (1980), who surveyed the U.S. *Journal of Economic Entomology* to obtain a similar index for a wide spectrum of economic pests. He noted that "those [publications] dealing with chemical

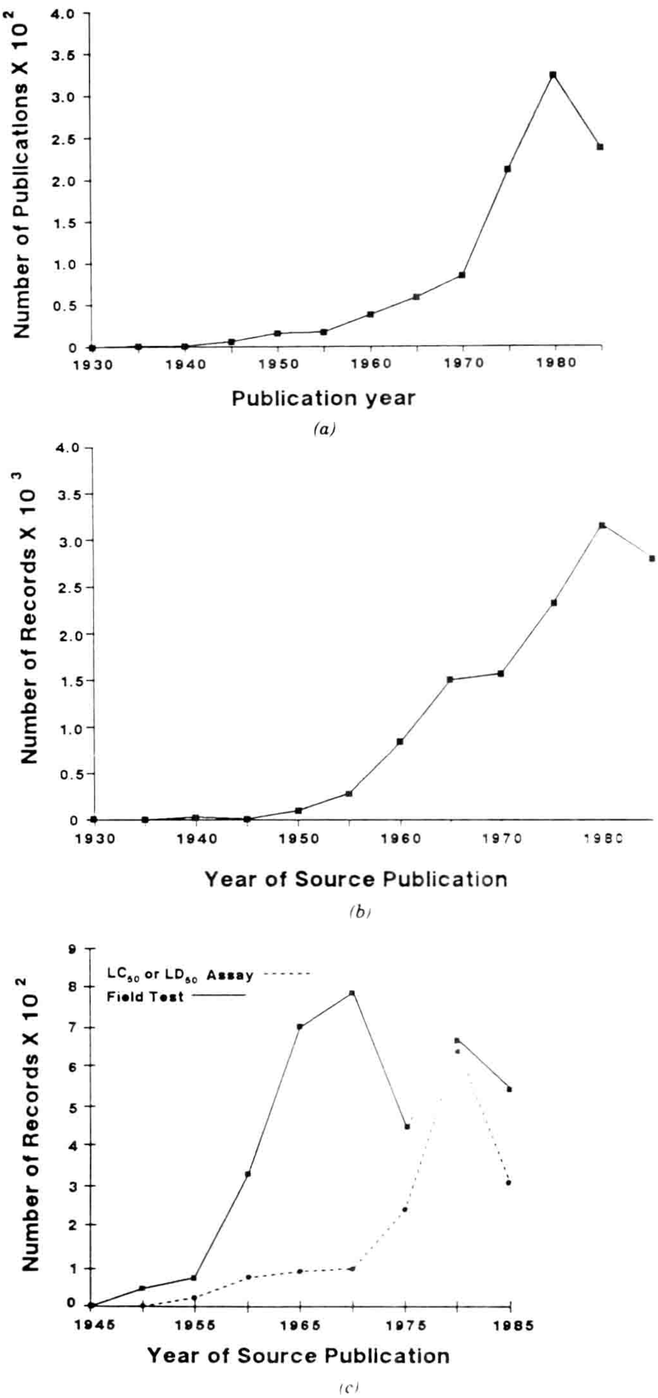

Figure 1.2. Distribution of (a) publications, (b) records, and (c) LC_{50} and LD_{50} versus field assessments of pesticide impact on arthropod natural enemies (1940–1985) (adapted from Theiling 1987).

evaluation and usage [of pesticides for pest control] comprised 76% of all the formal papers in 1950, 68% in 1960, 45% in 1970, and 43% in 1978." Presumably research in the 1980s has more heavily emphasized biological control.

In contrast to the trends for pests (Fig. 1.1), the number of publications (Fig. 1.2a) and records (Fig. 1.2b) on the impact of pesticides on natural enemies (i.e., those specific reports of pesticide side effects from a worldwide database; Chapter 2*) show an exponential increase beginning in the late 1950s. They show a particularly high rate of growth in the 1970s and 1980s (Figs. 1.2a and b). The decline in trends for the period 1980–1985 is due to incomplete sampling of the recent literature, rather than an actual decline in the numbers of records or publications (Theiling 1987; Chapter 2). The increase in pesticide impact research for natural enemies during the 1960s and 1970s occurred with a 20–30-year time lag following a similar increase for pest species (Fig. 1.1; Metcalf 1980).

Until the mid-1960s, observations of pesticide impact on natural enemies tended to be incidental. They usually were taken during pesticide evaluations on pests rather than resulting from direct studies on natural enemies (Croft and Brown 1975). However, a few in-depth field studies on the side effects of pesticides on natural enemies were conducted during this period (see reviews of Ripper 1956, Bartlett 1964). In the 1960s, a shift in perspective began that greatly expanded into the 1970s and 1980s. Studies of natural enemy responses to pesticides became more numerous and more specific. This shift is reflected in a plot of LD (lethal dosage) or LC (lethal concentration) pesticide response evaluations over time (Fig. 1.2c; Chapter 2). Median lethal tests involve more precise laboratory assessments with statistical analyses. This type of test has been increasingly employed in recent years, whereas field assessments which tend to reflect less direct and precise studies of natural enemies have leveled off (Fig. 1.2c).

Research in the 1970s and 1980s has examined in more detail the behavioral responses of natural enemies to pesticides (Croft and Brown 1975, Croft 1977, Kirknel 1974, Kurdyukov 1980). This emphasis coincides with the acceptance of IPM as the philosophy of pest control in many countries throughout the world. IPM places a high premium on the conservation of natural enemies through the development and use of selective pesticides.

The study of pesticide impact on both pests and natural enemies has been influenced by factors other than the changing emphasis in pest control. Increased understanding of basic arthropod ecology, physiology, toxicology, biochemistry, and biological control has contributed much to expand the information base available for pesticide impact research.

1.3. BOOK OBJECTIVES

This volume presents progress made in the study of the arthropod natural enemy responses to pesticides at many different levels. The primary focus is confined to predators and parasitoids of pests of agricultural crops. Discussion of pest responses to toxins is secondary. It is included to aid in understanding the complex nature of pesticide interactions between pests and natural enemies. Also, selective pesticide development, one of the primary goals of all natural enemy/pesticide research (Chapters 9 and 10), requires the pest perspective. Numerous other ecological groups of species of secondary importance may be influenced by pesticides, including hyperparasites, omnivores, and

* *Editor's note*: Chapter citations refer to chapters in our present book (Croft, 1989).

other vagrant species. The impact of pesticides on these species is discussed in Chapters 8 and 21.

Some of the more specific pesticide/natural enemy relationships that are examined are: susceptibility, sublethal and ecological effects, physiological, ecological, and integrated selectivity, and resistance development and management. Different chapters span functional levels ranging from cellular toxicology and biochemistry to regional population dynamics and community ecology of natural enemies and associated species. The goal is to integrate knowledge into a more complete understanding of natural enemy/pesticide interactions. This information may ultimately contribute to more effective IPM systems.

1.4. PERIODS OF NATURAL ENEMY/PESTICIDE RESEARCH

The development of scientific inquiry on the responses of natural enemies to pesticides can be divided into several historical periods. As discussed by Kuhn (1975), new scientific paradigms emerge from time to time due to revolutions in thinking. Certainly pest control has undergone several eras of contrasting approaches. These eras are closely associated with trends in pesticide development from the late 1800s to the present. In several cases, a new era was stimulated by an impending crisis in the current pest control system. For example, the development of resistance to pesticides often influenced the shift from one era to another (e.g., from DDT to the organophosphate and carbamate insecticides; Chapter 21). The discovery of other negative side effects such as those on birds and other wildlife sometimes precipitated movement from one chemical pest control regime to another (e.g., from lead arsenate to DDT; Chapter 21). The historical perspective of natural enemy/pesticide research presented in this chapter is undoubtedly influenced by current attitudes on pesticide use and IPM. Furthermore, developments did not proceed in as continuous a manner as the following narrative may imply.

1.4.1. The Inorganic/Natural Products Era (1870–1944)

Prior to the development of DDT in the late 1930s and early 1940s, pesticides used for agricultural pest control were derived mainly from inorganic heavy metals (e.g., lead arsenate) or they were obtained from naturally occurring organic plant toxins (e.g., nicotine, ryania, rotenone). In general, these products provided moderately effective pest control, but they did not cause such excessive disturbances in pest populations as did later synthetic organic pesticides (Chapter 2).[1] In retrospect, we have discovered that these agents were less severely toxic to natural enemies than were later pesticides (Chapters 2 and 9). Certainly, our abilities to detect their effects on natural enemies were less well developed than they are today.

The taxonomic relationship between many beneficial predators and parasitoids and pest species is fairly close—in some cases within the same family. During this era, there was little reason to suspect (nor a great deal of experimental evidence to prove) that arthropods with different feeding ecologies might respond differently, either physiologically or ecologically, to these exogenous toxins.

Some observers during this period noted that pesticide applications destroyed more natural enemies than pests. These researchers were primarily concerned about the occasional pest resurgences associated with pesticide use (Ripper 1956, Bartlett 1956). As

[1] Our knowledge of the ecology of biological control agents was not as well developed at that time, so the impact of these pesticides may have been greater than was generally indicated in the literature.