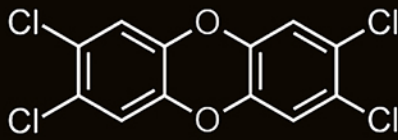

Basics of Ecotoxicology

Donald W. Sparling

CRC Press
Taylor & Francis Group

Basics of Ecotoxicology

Basics of Ecotoxicology

Donald W. Sparling

CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

Printed on acid-free paper

International Standard Book Number-13: 978-1-138-03171-5 (Hardback)

Library of Congress Cataloging-in-Publication Data

Names: Sparling, D. W. (Donald W.), author.
Title: Basics of ecotoxicology / Donald W. Sparling.
Description: Boca Raton : Taylor & Francis, CRC Press, 2017. | Includes bibliographical references and index.
Identifiers: LCCN 2017005194| ISBN 9781138031715 (hardback) |
ISBN 9781315158068 (ebook)
Subjects: LCSH: Environmental toxicology. | Pollutants.
Classification: LCC RA1226 .S67 2017 | DDC 615.9/02--dc23
LC record available at https://lccn.loc.gov/2017005194

Visit the Taylor & Francis Web site at
http://www.taylorandfrancis.com

and the CRC Press Web site at
http://www.crcpress.com

Contents

Preface

To a large extent, this book started 20 years ago. I was a wildlife research biologist working for the U.S. Fish and Wildlife Service studying endangered forest birds in Hawaii when I received a transfer back to the home research center in Maryland. At that time, I was placed in the Environmental Contaminants Branch at Patuxent Wildlife Research Center because contaminant studies were of great interest to the U.S. Fish and Wildlife Service. To make a long story short, ultimately research within the U.S. Department of the Interior was moved around from one agency to another, finally landing within the U.S. Geological Survey where experimental research was not as appreciated as it was in the U.S. Fish and Wildlife Service. Over the years, I worked with a variety of animals, including mallards, northern bobwhite, and several species of frogs, salamanders, mourning doves, and turtles. These animals were variously exposed to multiple pesticides, white phosphorus, polycyclic aromatic hydrocarbons, contaminated sediments, lead, aluminum, and mercury.

The field of ecotoxicology is broad and includes ecologists, wildlife physiologists, environmental chemists, statisticians, modelers, and others. The whole time I worked in ecotoxicology my specialty area was wildlife toxicology or the effects contaminants had on wildlife individuals, populations, and communities. While I was also interested in how the chemicals moved through the environment, from water to sediments to organisms, I was never a research chemist and left those analyses up to cooperators. My general approach has been that contaminants are another source of stress to individuals and to wildlife populations, much like predation, disease, inter- and intraspecific competition, and resource allocation and that their effects could be studied in similar ways but using different methods.

After many years working within the U.S. Department of the Interior, I took a faculty position at my old alma mater in the Zoology Department and continued research in wildlife toxicology and added teaching to my resume. I also wrote and published a significantly sized tome in ecotoxicology.

It was during my efforts to educate college students and in preparing that book that I came to realize that there was a gaping hole in the offerings of ecotoxicology-related books on the market. Many of the available books were lengthy, somewhat to very ponderous volumes that were deficient in simplicity and clarity. It was then that I resolved to attempt to publish a book that was written in clear, easily understandable English so that undergraduates and perhaps even advanced placement high-school seniors could understand the science of ecotoxicology.

This, then, is the goal of this current text. I hope that students without an extensive (dare I say "no"?) background in chemistry can read and understand what has been written here. I do assume that students have had at least a college-level course in biology and hopefully an ecology or conservation course, but I hope I have written a primer on chemistry that, with the instructor's lectures, will provide sufficient understanding of that discipline's core elements even with no formal training in chemistry. I will leave it to the student to determine if I have been successful.

In this book key words are indicated in bold type. There are too many key words to include in a glossary and some of these words are easily recognized to not all are included in the glossary. Phrases of particular interest are often surrounded by single quotations whereas actual quotes are defined by double quotation marks.

This book consists of three sections. Section I consists of some basic information, including the definition and inclusiveness of ecotoxicology, the chemistry primer, and another primer on the various ways contaminants can affect wildlife. Section II covers the primary classes of contaminants, including inorganic and organic molecules. Each chapter discusses something about the history of the class, what it was or is used for, how the chemicals behave in the environment, and the expected effects caused by contaminants in this class. Section III covers higher-level discussions on how contaminants affect populations, communities, and ecosystems; methods used to determine the real and predictable harm chemicals can inflict on organisms and their habitats; and how contaminants are regulated at the local, national, and international levels. I hope that you find this book enjoyable to read as well as informative.

Acknowledgments

Behind every book there are many people who are involved in its writing, even if they do not know it. Such is the case with this one. I first thank Dr. Elwood Hill, who was my early mentor when I began the study of ecotoxicology in the 1980s. Woody had a lot of patience for a younger PhD student who did not know much about environmental contaminants at all. He taught me the basics of the science and was often there when I needed support. I also thank a group of biologists at Patuxent Wildlife Research Center, including Drs. Russell Hall, David Hoffman, Barnett Rattner, and Hank Pattee for their guidance. Many more scientists, technicians, and students helped form my professionalism and challenged me to be my best. Drs. Greg Linder and Christine Bishop along with Sherri Krest were coeditors with me on four other books that finally led to this one. Special thanks to my wife, Paulette, and family for their support and patience.

Author

Dr. Donald Sparling's career has been a mixture of college-level teaching and government service. After receiving his PhD in biology, he taught wildlife management courses at Southern Illinois University and biology at Ball State University. In 1982, he started a career in the U.S. Department of the Interior, first as a statistician and then as a research wildlife biologist. There he conducted research on the effects of contaminants on wildlife, with publications on acid deposition, munitions, pesticides, metals, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, and polybrominated diphenyl ethers. The animal models he and his students have used include amphibians, turtles, mallards, quail, doves, invertebrates, and others. He left the government in 2004 to resume teaching various courses including ecotoxicology and to continue research at Southern Illinois University, Carbondale. Although he retired from that position in 2015, he continues to teach online courses at Holy Apostles College and Seminary and write books in the ecological sciences. Dr. Sparling has more than 100 scientific publications and 6 books to his credit.

Section I

An Introduction to Ecotoxicology

1 What Is Ecotoxicology?

1.1 INTRODUCTION—WHAT DO WE MEAN BY 'ECOTOXICOLOGY'?

Since we are going to spend some time studying the subject, we probably should discuss what the word '**ecotoxicology**' means and what its study includes. If we take the word apart we find 'eco' and 'toxicology.' You are probably familiar with the prefix 'eco' as in eco-friendly, eco-systems, and eco-logy. These uses of 'eco' all pertain to the science of understanding the environment, otherwise known as ecology. 'Toxicology' is the study of poisons. The two terms were first brought together in a lecture provided by René Truhaut in 1969 to denote a natural extension of ecology and toxicology that included the effects of chemical pollutants or **contaminants** on any aspect of the environment (Truhaut, 1977). A concern about contaminants existed in earnest in the Western developed countries in the mid-1960s, but there wasn't a comprehensive term for the newly developing science until then.

In its early years, ecotoxicology typically included two things: (1) where chemical contaminants were located as well as how much was present and (2) a basic understanding of how toxic individual chemicals can be to single species of wildlife and plants, with an emphasis on short-term or **acute** studies. The greatest emphasis has always been on human-caused or **anthropogenic** sources of environmental chemicals, although many instances of natural pollution have also been studied.

Over the years the chemical aspect of ecotoxicology has expanded to include the life cycle of contaminants—how they get into the environment, what changes occur when they are there, and how natural processes or human activities can reduce or eliminate these contaminants. From the toxicological side there has been growing interest on longer-term or **chronic** studies that may occur over weeks, months, or a particular stage in an organism's life, such as the larval stage. More recently, ecotoxicologists are learning how interactions of chemicals may affect organisms and are finding some very interesting results. There is also a developing interest in modeling the potential effects of one or more chemicals on selected species without the need for controlled experimentation.

Some fundamental discoveries in ecotoxicology over the past 50 years include the following—we will spend more time with each of these and many more concepts in future chapters:

1. The half-life of chemicals in the environment ranges widely. A **half-life** is the amount of time it takes to degrade 50% of an original concentration of a contaminant. Following the dynamics of degradation, this means that if we had an initial concentration of a chemical in soil, for example, of 10 parts per million (ppm) and the chemical had a half-life of 20 years, in 20 years 50% of the chemical would be gone, leaving a concentration of 5 ppm, in 40 years there would be 2.5 ppm, in 60 years 1.25 ppm, and so on.

2. Environmental chemists have developed an understanding that some chemicals are extremely persistent and can last in the environment for decades. The poster child, so to speak, for these persistent chemicals is dichlorodiphenyltrichloroethane (DDT), which can have a half-life in soil of 20–30 years or more, depending on conditions (ATSDR, 2002). Extending a few half-lives, a single instance of DDT contamination of a few hundred parts per million could still be measured more than a hundred years later. In contrast, other contaminants can disappear in a few hours when exposed to sunlight. Half-lives depend on many factors, but where the contaminant is located is paramount—those in the atmosphere tend to disappear most rapidly, those in deep water sediments the most slowly.
3. Early on, biologists determined that the toxicity of a given chemical was dependent, in part, on the length of time organisms are exposed to the chemical. As mentioned, early studies focused on the concentration or amount of a contaminant that resulted in death, a **lethal dose**. In general, the shorter the duration, the higher the concentration a chemical must have to be lethal. At longer durations, it usually takes lower concentrations of a chemical to cause death in a substantial proportion of a population. In addition, other **sublethal effects** may occur in chronic exposures, such as reduced growth, developmental defects, or cancers; acute exposures may be too short to make these effects apparent.
4. Toxicity also varies across species. It is a generalization that aquatic organisms such as fish or aquatic invertebrates are more sensitive to chemicals than terrestrial species such as birds or mammals. A major factor affecting this is that aquatic organisms are surrounded by contaminated water and everything they encounter has burdens, while birds and mammals are usually exposed only through food or by drinking and hence do not experience the degree of exposure that fish do. Even within a related group of organisms, such as birds, toxic concentrations may vary by 10 or 20 times across species. For example, Story et al. (2011) found that fenitrothion, an organophosphorus pesticide (see Chapter 5 for more information on this type of pesticide), differed by 26% in two species of Australian rodents, and both were 10–14 times more sensitive than house mice (*Mus musculus*) and other rodents.
5. Now that toxic concentrations have been identified for many contaminants and species, attention is increasingly being turned toward the effects of contaminants on entire populations, communities, and even ecosystems. New research is also focused on the interactive effects of contaminants.

1.2 HOW DID THE SCIENCE OF ECOTOXICOLOGY COME ABOUT?

Both ecology and toxicology have long histories, although not always in the form of sciences that we might recognize today. Environmental concerns go back to antiquity, with the first writings credited to Aristotle (384–322 BC) and his student Theophrastus (371–287 BC), both of whom described interrelationships between animals and their environment as early as the fourth century BC. However, the interest remained only a part of the broader science of biology until 2300 years later when ecotoxicology was recognized as a separate discipline.

People have been poisoning each other for an even longer time, but toxicology as a formal study probably began with Paracelsus, a German-Swiss philosopher, physician, botanist, astrologer, alchemist, and general occultist whose real name was Philippus Aureolus Theophrastus Bombastus von Hohenheim (1493–1541). Among other things, he is credited with the saying that "the poison is in the dose." Bombastus showed that all things, even water, can be poisonous in sufficient quantities. Some substances require a large dose before being toxic, whereas others only require a small dose, perhaps only a few milliliters for a human. In very small amounts, even substances that are considered highly toxic do not produce any symptoms. Bombastus is known as the 'Father of Toxicology.'

The marriage of ecology and toxicology occurred in the early 1960s and gained a strong boost in popular interest through the publication of *Silent Spring* by Rachel Carson (Figure 1.1) in 1962. Carson wrote about the possible dangers of DDT and other pesticides and how we were poisoning our environment in many ways. There was an acute rise in interest for protecting our environment in the late 1960s, resulting in the first Earth Day in Washington, DC, on April 22, 1970 (Figure 1.2), that rocked

FIGURE 1.1 Rachel Carson, the author of *Silent Spring*, 1962. (Courtesy of U.S. Fish and Wildlife Service, Washington, DC.)

FIGURE 1.2 Huge crowds gathered to hear speeches on the Mall in Washington, DC, during the first Earth Day in 1970. (Courtesy of National Park Service, Washington, DC.)

the country and the Congress. If we look at a timeline of scientific publications going back several decades, we see a very sharp increase in publications, indicating a growing research interest in ecotoxicology, starting in the late 1960s and rising exponentially since then (Figure 1.3). This figure shows only those publications dealing with pesticides, but similar curves exist for other contaminants.

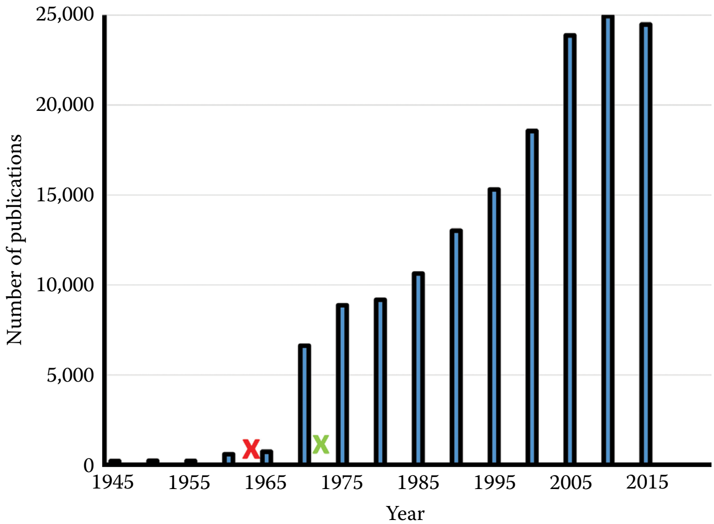

FIGURE 1.3 Annual number at 5-year intervals of pesticide-related publications in ecotoxicology. Publications on other contaminants are not included. The red X marks the beginning of an interest in the effects of contaminants in the environment and the green X is when *Silent Spring* was published. (Data from Web of Science, Washington, DC.)

1.3 WHAT DOES IT TAKE TO BE AN ECOTOXICOLOGIST?

Ecotoxicology is a rigorous discipline that has chemistry, physiology, and ecology as its main components. Chemistry is important in knowing the makeup and characteristics of the contaminants of interest, including their probable behavior in the environment. Physiology is useful in understanding how these chemicals may affect organisms at the subcellular, cellular, organ, or overall homeostasis levels. Ecology puts these two elements into real-life environmental contexts and asks how they might affect individual survival and reproduction as well as asking bigger questions of populations, communities, and ecosystems.

Statistics and modeling are also often used in ecotoxicological studies. Statistics are essential in designing studies and research experiments and in analyzing the data that are obtained. Modeling and statistics are very useful in evaluating the potential threats of contaminated areas to living organisms in a discipline called **risk assessment**.

In the ever-evolving world of ecotoxicology very few, if any, scientists can be experts in all of these specialties. Subspecialty fields exist in that some chemists may focus on a particular group of chemicals such as pesticides, polyhalogenated compounds (see Chapters 6 and 7), or metals. ‘Effects people’ may specialize in certain organisms such as plants, fish, aquatic invertebrates, amphibians, birds, or mammals.

Because of the complexity of the science, most practitioners have advanced or graduate degrees in their areas of specialty. With a bachelor’s degree one might look for jobs as technicians or field assistants. A master’s degree and work experience may be required for being a leader in investigations. Overseeing scientific investigations and research experiments often requires a PhD in one of the specialty areas listed above. A few universities offer programs specifically in ecotoxicology and a far larger number of support-related courses.

1.4 OBJECTIVES OF THIS BOOK

In writing this book, I hope to offer an introduction or overview of ecotoxicology for the science major who may not necessarily be headed toward a career in ecotoxicology or even graduate school. I hope that I have written a book that avoids much of the jargon and specific language of a specialty in ecotoxicology so that this book can be easily read and enjoyed by undergraduates. In this way, I hope that more students can obtain an understanding of ecotoxicology and through this develop a better appreciation for our environment and the complex interactions between it and contamination, more familiarly called pollution.

We will cover a variety of topics, including a brief introduction or refresher of chemistry and an examination of some of the ways that contaminants can affect organisms. These are found in Section I of this text. Section II deals with the major groups of contaminants including metals, a whole variety of organic contaminants, plastics, and even radioactive compounds. The final section includes several areas of current and developing concern, including contaminant-caused effects in higher levels of ecological organization. It also includes a section on how contaminated