Bibliographic Essay

Environmental Toxicology, Its History & Related Disciplines

By Brian R. Shmaefsky

Many new fields of scientific inquiry have emerged in the past forty years as the various disciplines of science merged their knowledge and technologies to address a growing inventory of societal issues. The 1970s ushered in the new interdisciplinary field of environmental toxicology, also known as ecotoxicology. This bibliographic essay will discuss the development of the field from its inception up to present issues and practices. It will focus on key resources in environmental toxicology as well as resources on general toxicology and its origins and other disciplines related to environmental toxicology. Most works contain ample references for further investigation and are accessible to undergraduates; they will primarily be of interest to students of environmental science, ecology, pharmacology, chemistry, biology, toxicology, public health, food science, and veterinary science. The first half of this essay begins with a brief overview of the field of environmental toxicology and is followed by sections titled Nomenclature, General Toxicology, The Origins of General Toxicology, and Disciplines Related to Environmental Toxicology. The latter includes subsections titled Pharmacology, Forensic Toxicology, Food Toxicology, and Veterinary Toxicology. The second half of the essay provides a more in-depth discussion of environmental toxicology (ecotoxicology), with sections titled General Principles of Environmental Toxicology, Environmental Pharmacology, The Nature of Environmental Toxins, The Fate of Environmental Toxins, and Testing for Environmental Toxins. The accompanying "Works Cited" list is divided into three sections: Print Resources, Serials, and Online Resources.

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A Brief Overview

Rachel Carson's classic environmentalism book *Silent Spring*, published in 1962, is attributed with building an environmental consciousness movement in the United States. By the late 1960s, this work pushed environmental issues to the forefront of problems created by the growth of societies in developed nations. The first Earth Day, held on April 22, 1970, reflected the general public's sentiment about environmental concerns. This event was considered the birth of the American environmental movement, and was described in *Natural Protest: Essays on the History of American Environmentalism*, edited by Michael Egan and Jeff Crane.

Environmental toxicology developed as a specialized branch of toxicology with the goal of gaining a better understanding of the impact of pollution on humans and the environment. The United States Environmental Protection Agency (EPA) was established on December 2, 1970, to deal with an increasing awareness of the environmental decay brought about by unchecked urbanization and the resultant pollution, and to "consolidate in one agency a variety of federal research, monitoring, standard-setting and enforcement activities to ensure environmental protection." According to the Web site of the US Environmental Protection Agency, the overall mission is "to protect human health and to safeguard the natural environment—air, water, and land—upon which life depends."

Like many newly emerging disciplines, such as biotechnology and medical robotics, environmental toxicology had to go through a trial period before many research findings developed by the discipline were fully accepted by

governmental organizations, the legal system, medical professionals, and the public. Even the scientific community heavily scrutinized environmental toxicology methodology and research until the findings and conclusions proved accurate and consistent over time. In the 1970s, environmental toxicology focused primarily on regional air and water pollution problems. Agricultural chemical runoff and industrial air pollutants were the major issues that helped define many policies based on early environmental toxicology research. Certain types of chemicals caused particular concern as pollutants because they were linked to birth defects in animals and possibly humans.

Today, environmental toxicology investigates the impacts of localized pollution problems unique to a city or a neighborhood, e.g., lead exposure in children in older houses in certain urban areas such as Houston, New Orleans, and New York City. In addition, this discipline deals with widespread environmental problems, such as global climate change. The science has also grown in sophistication; it started out using anecdotal and simple data collection, and evolved to a complex field of monitoring models using highly specialized analytical equipment. Intricate mathematical representations of the environment are a newer means of studying the impacts of particular toxins on the environment.

A new defining global issue in environmental toxicology deals with a spectrum of commonly used chemicals shown to affect the endocrine system. It is now known that certain chemicals can interfere with human growth and sexual development. This finding was brought to the forefront of governmental and public concern by the publication of *Our Stolen Future,* by Theo Colborn, Dianne Dumanoski, and John Peterson Myers. As a result, there is now tight scrutiny of any consumer item that may promote exposure to endocrine-disrupting chemicals. Society is reassessing the use of plastics and other materials that likely contain and leak out chemicals that disturb endocrine function, particularly in pregnant women. Almost every nation has endocrine-disrupting pollutants contaminating the air, food, soil, and water.

Nomenclature

The literature in all areas of toxicology is replete with the terms "poison" and "toxin." Surprisingly, there is some inconsistency in how the words poison and toxin are applied. The etymology of the terms shows that they have distinct origins. "Poison" comes from the Old French word *puison*, developed around 1230 in reference to a deadly potion or drink. "Toxin" was derived from the Ancient Greek word *toxikon* to describe organic poison. The term was coined by German physician Ludwig Brieger in 1888. He initially used it to describe poisonous chemicals produced by microbes implicated in human illness.[1]

Many modern environmental toxicology references use the terms poison and toxin synonymously, while others strictly distinguish between the words. According to *Merriam-Webster's Online Medical Dictionary*, the modern definition of "poison" is "a ... substance that through its chemical action usually kills, injures, or impairs an organism." In contrast, it defines "toxin" as "a poisonous substance that is a specific product of the metabolic activities of a living organism and is usually very unstable, notably toxic when introduced into the tissues, and typically capable of inducing antibody formation."[2] Initially, the literature used the term "toxin" to refer to a naturally occurring poison. Most modern references to harmful chemicals use "toxin" to describe a general class of hazardous chemicals.

General Toxicology

A proficient understanding of environmental toxicology requires a background in the parent field of toxicology. Toxicology primarily emphasizes the medical and veterinary aspects of biology and chemistry. It encompasses a variety of specialized discipline areas that all rely on basic toxicological principles and methodology. Each discipline follows a particular problem-solving strategy for resolving societal issues. These issues impact people in everyday life in circumstances ranging from drug safety to environmental quality. General toxicology readings vary from technical references to simple-to-read books that highlight societal issues.

Toxicology is a difficult field to describe without using many technical concepts and terms. One good book that well represents the overall field of toxicology and summarizes the facts about environmental toxicology is Irving Rossoff's *Encyclopedia of Clinical Toxicology*. It is considered the epic work on toxicology terminology and expounds on each concept critical to all areas of the field. It will be a critical complement to any environmental toxicology library, useful as a quick reference and as a resource for people who are unfamiliar with the breadth of toxicology principles.

Toxicology for Non-Toxicologists by Mark Stelljes explains the field in general terms, focusing on the fundamental principle that certain chemicals called poisons or toxins are hazardous to living systems. The crucial premise is that hazardous chemicals interfere with specific functions of an organism. Each different type of poison or toxin has a characteristic effect on an organism's cells. Stelljes highlights how hazardous chemicals either alter the structure of a cell or impede a cell's chemical processes. He investigates the ways that this knowledge is applied to the various disciplines of toxicology, and includes a discussion of the principles of risk assessment that are used to determine if a chemical truly poses a hazard.

John Timbrell's *Introduction to Toxicology* is another useful, understandable resource, which effectively highlights the major principles of the field. The author takes a systematic approach to presenting details about concepts and methodology. The sequencing of information in the book is logical, starting with historical information and a discussion of the background biology, chemistry, and medicine that form the basis of toxicology. The succeeding chapters focus on different toxicological substances.

Concepts in Toxicology by John Duffus, Douglas Templeton, and Monica Nordberg also provides many useful facts about modern toxicology principles and practices. *A Textbook of Modern Toxicology,* edited by Ernest Hodgson, with similar content, includes contemporary writings from toxicology researchers and covers assessments of current toxicology methodology. In addition, it introduces most terminology needed to understand advanced concepts. The work's coverage reflects the breadth of toxicology applied to all toxicology disciplines.

The field of toxicology is replete with diverse technical facts needed to understand the ways hazardous chemicals harm organisms. The most accurate depiction is best represented in technical books such as the classic *Handbook of Toxicology*, edited by Michael Derelanko and Mannfred Hollinger. This is not a book for general reading, but it can serve as a useful desk reference. It partitions toxicology into facts about the major categories of toxic chemicals found in automobile products, construction materials, drugs, foods, household products, industrial chemicals, and pollutants, and epitomizes the type of information needed by toxicology practitioners. Diagrams, flowcharts, lists, and tables used by laboratories, manufacturing facilities, and public health agencies augment the text.

One cannot fully appreciate the effects of toxicology on people without investigating the molecular mechanisms of chemical hazards. *Principles of Biochemical Toxicology* by John Timbrell conveys the biochemistry of toxicology. This clearly written book completely discusses the latest research on the effects of poisons and toxins on cell and body functions. It investigates all concerns that toxicologists must address when investigating the effects of hazardous chemicals on humans. Timbrell explains how hazardous chemicals enter the body, and how they selectively do their damage. The author also describes the different categories of toxins and their inherent risks to the environment and to humans. The book's textbook format makes it useful for readers with no background in the field.

Toxicological research is performed primarily with the goal of assessing the risks of hazardous chemicals. Certain risks are minor and have negligible effects on humans and the environment. Helmut Greim and Robert Snyder's *Toxicology and Risk Assessment* describes this aspect of the field. This readable book has purely utilitarian goals and shows how the scientific aspects of toxicology are used to determine risk. Risk assessment takes into account complex statistical modeling that evaluates the short- and long-term impacts of hazards. As explained in the book, certain risks are acceptable, meaning that they cause little harm or they do not significantly affect overall health or environmental quality. Subsequently, the authors show how risk is used to determine public policy. The National Research Council's *Science and Decisions: Advancing Risk Assessment* is a recent general work that also discusses how risk assessment helps to establish public policies related to environmental contamination.

The federal government establishes policies for particular types of hazardous chemicals. This partly depends on the nature of the chemical and the probability that humans will come into contact with it. A comprehensive resource that illustrates the modern process used to investigate public health issues is *Patty's Toxicology, Tox Issues Related to Metals/ Neurotoxicology and Radiation/Metals and Metal Compounds*, edited by Eula Bingham, Barbara Cohrssen, and Charles Powell. This work is representative of technical policy books that back risk assessment decisions with scientific experimentation. The first part discusses how toxicological research is performed and interpreted. It then investigates how risk assessments are determined using several models. Decision-making schemes are described from the perspective of risk assessment analyses.

A valuable online resource for in-depth toxicology information is *TOXNET* from the National Library of Medicine. This Web site provides access to a variety of toxicology resources organized in a comprehensive list of databases. Many databases are most useful for environmental and medical researchers. However, links are available for the public as well as policy makers. Nontechnical readers who have gleaned basic toxicology information from some of the print resources previously described will have sufficient background to take advantage of the wealth of information in *TOXNET*. The database is continually updated to provide the most recent information on toxicology research and policy.

The Origins of General Toxicology

As Vivian Nutton notes in *Ancient Medicine,* the principles of toxicology go back further in history than most other scientific disciplines. Ancient cultures were familiar with toxic plants and medicinal compounds found in their natural surroundings. In fact, people as early as 8000 BCE recorded the use of plant chemicals with toxic abilities. Some compounds were used in hunting to poison fast-moving prey, but many chemicals were recognized as having some medical value if used properly. Studies on mummified human remains showed that early physicians applied local anesthetics extracted from toxic plants.

Toxicology became a methodical science with the development of organic chemistry in the 1800s. Chemists during that period were learning how to predict the characteristics of toxic chemicals by using analytical chemistry studies. Spanish physician Matthieu Joseph Bonaventure Orfila (1787-1853) made toxicology a formal discipline with the publication of his 1812 book *A General System of Toxicology; or, A Treatise on Poisons Found in the Mineral, Vegetable, and Animal Kingdoms*. Orfila used toxicology data in an effort to improve public health by developing techniques for analyzing toxins in blood. So toxicology started out more as a medical practice and by the late 1900s blossomed into the specialty areas of pharmacology, forensic toxicology, food toxicology, and lastly, environmental toxicology, with each discipline serving different scientific purposes.

Antonio Escohotado and Ken Symington discuss the ancient origins of toxicology in *A Brief History of Drugs: From the Stone Age to the Stoned Age*, which primarily focuses on the ancient uses of drugs and toxins in a variety of ancestral

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cultures. Toxicology was founded on the principles of how people used their local resources for medical cures. Other cultures used these materials for religious rituals. The authors approach the use of early medicinals as a culture's way of understanding the effect of chemical compounds on the human body and mind. They also explore the social implications of ancient drug use and how they influenced the practice of toxicology.

Readers looking for a good general introduction to the origins of toxicology will want to consult *Principles and Practice of Toxicology in Public Health* by Ira Richards. This work, designed as an introductory resource for students in public health programs, is highly instructive and presents complex topics in simple terms, while maintaining the integrity of the science behind the field. It begins with an accurate synopsis of the origins of toxicology, and mentions historical aspects of toxicological practices throughout the text. It also presents the types of careers associated with toxicology, including environmental toxicology.

Post-mortem: Solving History's Great Medical Mysteries by Philip Mackowiak takes another approach to the history of the field. This very readable, interesting work, which focuses on forensic and medical analysis applications, uses a case study approach to show how toxicological studies determined the illnesses and deaths of famous people such as Germanicus, Christopher Columbus, Wolfgang Amadeus Mozart, Florence Nightingale, and Booker T. Washington. The book starts with early developments dating 3,500 years ago and progresses to modern toxicology, emphasizing European and Middle Eastern origins of toxicology and related pathology studies. Mackowiak critiques the development of toxicological methodology and thoroughly describes the technologies in an understandable manner.

Readers can find a highly specialized account of toxicology's history in *A Short History of the Drug Receptor Concept,* edited by Cay-Rüediger Prüll, Andreas-Holger Maehle, and Robert F. Halliwell. This work describes the history of research on how drugs and toxins affect the functions of cells. Since every principle of toxicology relies on the knowledge of drug and toxin actions on cell receptors, the discovery and mode of action of these receptors heralded the birth of modern toxicology. Receptors are proteins on the surface of a cell that respond to specific signals in the body. These signals can be hormones produced by the body or chemicals that enter the body through the diet or the environment. Chapter contributors clearly explain the biology of receptor proteins, and then describe the specific functions of drug and toxin receptors. This book also evaluates the role of toxicology in the growth of contemporary medical ideology.

Disciplines Related to Environmental Toxicology

"Toxicology" can be defined in various ways, based on its pertinence to the particular discipline that uses toxicological methods. An inclusive definition provided by the National Institute of General Medical Sciences in *Medicines by Design* describes toxicology as "the study of how poisonous substances interact with living organisms."[3] Some definitions limit toxicology to the study of drug effects on humans. Others expand the definition to include the effects of any type of chemical on the overall health of humans and the environment. It is a broad field of study with many subspecialties. These subspecialties are categorized by historical criteria that integrate toxicology into existing disciplines such as medicine or environmental science. Examples of toxicology subspecialties related to environmental toxicology include pharmacology, forensic toxicology, food toxicology, and environmental toxicology.

Principles of Toxicology by Karen Stine and Thomas Brown, designed for an introductory college course, offers an easy-to-understand overview of the different disciplines of toxicology research and practice. The authors provide significant technical detail to describe how toxicology is carried out in the disciplines of pharmacology, forensic toxicology, food toxicology, and environmental toxicology. They discuss modern methods used in each area, including the influences of contemporary discoveries in biochemistry, chemistry, cell biology, and genetics on toxicology.

In *Toxicology: A Case-Oriented Approach,* John Fenton uses case studies to facilitate an understanding of the various disciplines. Each of the book's sixty-five cases tells a story about different aspects of pharmacology, forensic toxicology, food toxicology, and environmental toxicology, and also highlights applications from other fields that contribute to toxicology practices. The book is comprehensive in scope without overwhelming readers with too much detail and terminology. Study aids reinforce the work's content.

Another good source of information about toxicology disciplines is *Molecular, Clinical and Environmental Toxicology,* edited by Andreas Luch. This two-volume technical reference provides up-to-date research synopses about the fastest-growing areas in the field. Chapter contributors highlight the major principles and instrumentation used in analytical, environmental, and medical toxicology; they also cover historical perspectives and future directions in toxicology.

There are many excellent journals, available electronically or both in print and online, that provide the most current information about the specific disciplines related to environmental toxicology. Key peer-reviewed journals include *Toxicology, International Journal of Toxicology, Toxicological Sciences, Journal of Applied Toxicology, Chemical Research in Toxicology, Journal of Toxicology,* and *Journal of Medical Toxicology.* Each illustrates the research shaping the general principles of environmental toxicology. They are essential sources of information about new scientific findings that may affect future research studies and changes in environmental policies and regulations.

Pharmacology

"Pharmacology" is typically defined as the science of drug action on the human body. It represents the oldest field of toxicology, and has branched out to medical pharmacology and veterinary pharmacology. Medical pharmacology investigates the effects of drugs on humans, whereas veterinary pharmacology investigates animals. Pharmacological research contributes to three important toxicological principles: pharmacogenetics,

pharmacodynamics, and pharmacokinetics. These concepts describe how drugs or toxins interact in an organism and will be discussed later in this essay. Pharmacology focuses on the fate of a drug or toxin in an individual organism, and requires a full understanding of the organism's physiology and the chemistry of the drug or toxin.

The principles of pharmacology are essential for understanding environmental toxicology or ecotoxicology. Drugs are similar to pollutants in the ways they act on cells and whole organisms, interacting with the same metabolic pathways to produce an effect. Pharmacology is an ancient practice that predates science. It is known that prehistoric cultures used various animal, plant, and soil extracts to treat disease. However, the first systematic approach to pharmacology was undertaken from 400 BCE to 250 CE by Greek and Roman physicians. They evaluated the effectiveness of many ancient remedies and developed new ones based on trial-and-error testing on people. Modern, science-based pharmacology evolved in the nineteenth century. This new approach to pharmacology included the development of new medicines by screening for desired drug activity and effects, determining mode of action or mechanism of the drug, and measuring drug activity, chemical methods, and cell studies. Readers should consult Ryan Huxtable's article "A Brief History of Pharmacology, Therapeutics and Scientific Thought," in the *Proceedings of the Western Pharmacology Society* and Chauncey Leake's *An Historical Account of Pharmacology to the Twentieth Century* for additional information on the development of pharmacology.

Richard Finkel, Michele Clark, and Luigi Cubeddu provide a good overview of pharmacology principles and practices in *Pharmacology,* part of the "Lippincott's Illustrated Reviews" series. This book, geared to students in introductory pharmacology courses, begins by describing the concept of pharmacokinetics, i.e., how drugs and toxins enter and are distributed throughout the body. This is followed by an introduction to pharmacodynamics, the study of the physiological effects of drugs on the body or on an infectious organism. Just like drugs, toxins possess pharmacokinetic and pharmacodynamic properties. The remaining chapters describe the properties of the different categories of drugs used in modern medicine, emphasizing the action of drugs on different body parts.

For a historical account of the techniques and instruments used in toxicological investigations, readers should consult *Basic and Clinical Pharmacology,* edited by Bertram Katzung. This book presents the basic principles of toxicology testing backed by early developments that led to the different technologies. The clearly written work makes complex concepts easy to comprehend. It should be noted that environmental toxicology investigations use many of the analytical techniques performed in other fields of toxicology. The same instrumentation is applied to investigate the presence of toxic substances and to determine their effects on living systems.

Forensic Toxicology

Forensic toxicology is probably the most well known of the toxicological fields because of the popularity of television crime shows such as *CSI*, *Law and Order*, and

reality TV police programs. It was initially part of the ancient technique of criminology, which began with fingerprint identification of individuals in Babylon about 1000 BCE. Early Greek and Roman physicians were able to decipher intentional poisoning with certain known toxins based on the appearance of the eyes and skin on an ailing or a dead person. Modern forensic toxicology was established by French physician Edmond Locard in his 1920 book *L'Enquête criminelle et les méthodes scientifique*. Locard is credited with making the hallmark statement of forensic toxicology, "Every contact leaves a trace." His book encouraged criminologists to adapt and create chemical analysis techniques for identifying chemicals in body fluids associated with illness and cause of death.

Principles of Forensic Toxicology by Barry Levine covers the basic principles of toxicology as well as its applications in forensic analysis. The book is divided into three sections. It begins by explaining the basic principles of forensic toxicology, including the methods by which toxins enter the body and cause harm. The second section describes the analytical techniques used to determine the presence of toxins in the body, including methods for determining the toxin by measuring by-products or by analyzing specific types of cell and body damage. The last section explains different types of toxins, including environmental pollutants.

Food Toxicology

The general public is very familiar with food toxicology, due to media coverage of poisonings resulting from intentionally tainted children's formula and pet food, as well as unintentional cases of food poisoning from diverse food products. Greg Möller provides a good definition of the field, "the study of the nature, properties, effects, and detection of toxic substances in food, and their disease manifestation in humans," on the Web site of *Food Toxicology*, his University of Idaho Webcast lecture course. This discipline includes three aspects of food safety: food allergies, chemical food poisoning, and microbial food poisoning. Food allergy studies focus on harmful effects on the immune system caused by naturally occurring chemicals and additives in foods. Studies on chemical food poisoning alert public health agencies to toxic proteins such as melamine found in tainted foods, and glutamine, a naturally occurring protein potentially harmful to people with certain genetic conditions. Lastly, toxins produced by microbes contaminate many types of foods, and tests are regularly conducted to ensure the safety of the food supply. Readers are well aware of recent cases of *Salmonella* poisoning related to various foods including eggs and peanut butter.

Three excellent books present representative overviews of food toxicology. *Introduction to Food Toxicology* by Takayuki Shibamoto and Leonard Bjeldanes provides technical details of food toxicology in a readable manner. *Principles of Food Toxicology* by Tõnu Püssa is a more technical work that explains current application-based principles. For an even more detailed account covering current research, readers should consult *Food Toxicology*, edited by William Helferich and Carl Winter. These well-referenced books cover the basic principles of toxicology, show how food toxicology fits into the overall discipline, and discuss food policy and safety issues. The works also include aspects of ecotoxicology, describing how environmental factors can introduce toxins into food production and processing.

Another detailed book about food toxicology is *Process-Induced Food Toxicants*, edited by Richard Stadler and David Lineback. This book investigates the roles of food processing, handling, storage, and preparation on toxins that contaminate foods. Each chapter gives details about the toxins that can make their way into different types of human and pet foods. It also provides insights into how federal agencies develop food safety policies and regulations.

The Web sites of the U.S. Food and Drug Administration (FDA) and the U.S. Department of Agriculture Food Safety and Inspection Service (FSIS) are excellent sources of information on food toxicology. The FDA site highlights a section related to food on its main page, and includes an extensive Food Safety subsection. The main page also lists any current food-safety-related issues in its News and Events section. The FSIS site offers a wide range of information on food toxicology, including fact sheets, food safety guidelines, and food recall information of interest to consumers, farmers, food handlers, and restaurateurs.

Veterinary Toxicology

Veterinary toxicology, a branch of pharmacology, uses many principles of environmental toxicology. One classic book in "The National Veterinary Medical Series for Independent Study" that provides a good summary of the field is Gary Osweiler's *Toxicology*. It begins with a section on the general principles of toxicology related to animals. The second section focuses on toxic effects in specific body systems/organs such as gastrointestinal, respiratory, and reproductive. The final section discusses different types of toxins found in the environment, in foods, and in medications. This readable, textbook-style work is a good learning tool that reinforces content by using a problem-based approach. Note: the growing field of wildlife toxicology is beyond the scope of this essay.

General Principles of Environmental Toxicology

As mentioned earlier, environmental toxicology is one specialized branch of toxicology, arising from the environmental awareness movement, which deals with the effects of an array of harmful chemicals on individual organisms and ecosystems. Environmental toxicology began as a blend of forensic toxicology and pharmacology, and evolved into a separate discipline that developed techniques unique to its needs. The same techniques used in forensic toxicology and pharmacology are applied to investigate the effects of environmental toxins on individual organisms, including humans. Toxicology studies on the ecosystem level blend traditional ecological research with chemical analysis techniques. Traditional ecology provides ways of measuring and monitoring the quality of the environment. The field of environmental chemistry investigates the fate of hazardous chemicals that are introduced into ecosystems. It applies analytical chemistry to the characterization of hazardous chemicals and the detection of toxins in an organism and in the environment.

Environmental toxins are any artificial or natural harmful chemical released into the air, soil, or water. Artificial toxins include a

wide range of simple or complex chemicals created for commercial use. They can be compounds found in everyday items such as plastic containers or household bug sprays. Many environmental toxins have specific uses—for example, in heat-resistant machine coatings or specialized industrial lubricants. Natural toxins are chemicals produced by organisms, many of which are extracted from microorganisms and plants for use as medications, pesticides, or preservatives. Antibiotics are examples of natural toxins used in medical and veterinary applications.

Several useful books provide a comprehensive general overview of the field. *Principles of Environmental Toxicology* by Ian Shaw and John Chadwick concisely but thoroughly describes its breadth, ranging from scientific aspects to environmental policy. Coverage includes the transport of chemicals in the environment and their effects on organisms, environmental toxicity testing using instrumentation and biological assessments, environmental monitoring, and the future impact of industrial development on the environment. The authors use technical information to explain environmental health risk assessment and legislation related to risk studies.

Another helpful work is David Wright and Pamela Welbourn's *Environmental Toxicology*, which reinforces the fundamentals by presenting several representative case studies. The authors explain molecular environmental toxicology, then address organismic levels, and end with the methods used to study toxicological effects on ecosystems.

Sigmund Zakrzewski's *Environmental Toxicology* describes fundamental principles, using understandable terminology. Zakrzewski begins by discussing the basic pharmacology of environmental toxins. He also addresses the properties of contemporary high-risk toxins that cause cancers or disrupt the endocrine system, the transport and distribution of environmental toxins, and toxins that are major pollutants. This book includes coverage of environmental health and risk-assessment principles that lead to environmental policy.

Still another valuable work is *Principles of Ecotoxicology* by C. H. Walker et al. This comprehensive, simple-to-read overview clearly explains the contemporary issues faced by environmental toxicologists, including a historical perspective that highlights environmental toxicology investigations. Walker and colleagues, who come from diverse backgrounds, demonstrate how their disciplines contribute to the field. Like other environmental toxicology books, this one covers the science from molecular to ecosystem levels.

Two books, *Environmental Toxicology: Biological and Health Effects of Pollutants* by Ming-Ho Yu and *Environmental Pollution: Health and Toxicology* by S. V. S. Rana, take similar approaches to environmental toxicology by focusing on human health effects. These works cover the fundamental principles of pollutants, and then explain how pollutants are transmitted through the environment. The books also describe how the effects of pollution are measured and how these measurements determine public policy.

A classic technical reference is William Hughes's *Essentials of Environmental Toxicology: Environmentally Hazardous Substances and Human Health.* This work is reinforced with archetypal case studies on the role of environmental toxicology in public health. It provides detailed explanations of fundamental ecotoxicology concepts that are likely to endure the test of time. Hughes starts by covering the general principles of toxicology, and follows with explanations about the effects of pollutants on humans and other organisms. The book also includes information about the overall environmental decay caused by common widespread pollutants.

Environmental toxicology requires knowledge of the encompassing field of environmental sciences. *Principles of Environmental Sciences*, edited by Jan Boersema and Lucas Reijnders, provides a comprehensive overview of the environmental science principles needed to understand environmental toxicology. Chapter contributors address how the environmental sciences are used to resolve a variety of environmental issues, including those related to ecotoxicology.

A primary focus of environmental toxicology is the creation of policies and regulations that protect human health. Three books that investigate the science of environmental chemicals and their impact on human health are *Environmental Toxicology II*, edited by A. G. Kungolos, C. A. Brebbia, and M. Zamorano; *Ecosystems and Human Health* by Richard Philp; and *Persistence and Spatial Range of Environmental Chemicals: New Ethical and Scientific Concepts for Risk Assessment* by Martin Scheringer. *Environmental Toxicology II* and *Ecosystems and Human Health* demonstrate how the broad spectrum of ecology research is applied to the environmental toxicology principles related to human health. The chemical nature of toxins and how they impact the ecology of an area is described in *Persistence and Spatial Range of Environmental Chemicals*. It blends chemistry with ecology and provides a knowledge base for investigating the impacts of ecosystem pollution on human health.

Lastly, the Web site of the U.S. Environmental Protection Agency is a rich source of information about the field. The Popular Topics section highlights topics such as air pollution, radon, climate change, and pesticides, with each section offering numerous links to further facts. The Science and Technology and Laws and Regulations sections provide additional content for consumers, students, and professionals. Most interesting is the My Environment section, which allows site visitors to search for environmental data by ZIP code or geographic location.

Environmental Pharmacology

Environmental pharmacology is a newly evolved subdiscipline of environmental toxicology or ecotoxicology recognized by the EPA, which looks at the fate of pharmaceutical compounds on the environment. These compounds enter the environment when drugs are improperly discarded in landfills and sewerage systems. Environmental pharmacology also investigates the biochemical mechanisms of toxins, considering how a toxin causes deleterious changes to an organism. Readers should consult Nena Baker's *The Body Toxic: How the Hazardous Chemistry of Everyday Things Threatens Our Health and Well-Being* for a more extensive discussion of this topic.

Environmental Toxicology and Pharmacology of Human Development, edited by

Sam Kacew and George Lambert, is a classic compendium of essays on environmental toxins that specifically affect human development. The book demonstrates the earliest findings of the health effects of pharmaceuticals including endocrine disruptors, which are a contemporary concern. A related work is Kathryn Hilgenkamp's *Environmental Health: Ecological Perspectives*. Hilgenkamp covers the full breadth of toxicology, focusing on many of the pollutants that have pharmacological effects on humans. Another work that stresses the behavioral effects of environmental pharmaceuticals is *Behavioural Ecotoxicology*, edited by Giacomo Dell'Omo. It explains how animal and human behavior is related to the environmental impairment caused by many pollutants.

The Nature of Environmental Toxins

THERE IS NO ONE WAY OF CATEGORIZING the thousands of chemicals that have toxic effects in the environment. Since toxicology is a fusion of scientific disciplines, there are different methods of classifying toxins. The common ways to categorize toxins are by chemical structure, physical properties, biochemical mechanism, toxicological effect, and usage. All these categories are present in almost all documentation describing a particular toxic chemical. A form called a materials safety data sheet (MSDS) contains this type of information. The MSDS is used to communicate information about chemicals and is required by federal laws to be available on-site in commercial and industrial operations using toxic chemicals. An excellent technical introduction to this topic is *Occupational, Industrial, and Environmental Toxicology*, edited by Michael Greenberg, Richard Hamilton, and Scott Phillips. It explains in detail the regulatory aspects of environmental toxicology and public health issues related to toxins. This authoritative book is a valuable reference on various hazardous substances and the rationale for their regulation.

Chemical structure is a complex concept that is generally simplified to mean the arrangement and types of elements that make up a particular molecule. Chemical structure also considers the shape of the molecule and any electrical charges distributed on the molecule. Toxicologists use a structural analysis of a toxin to better understand how an environmental toxin harms an organism, and how it is transported through the environment and the body of an organism. Toxicologists analyze a component of a molecule called a functional group to interpret a molecule's toxic effects. A functional group is a specific arrangement of elements characteristic of a category of molecules, which determines many of a particular molecule's properties and reactions. For example, researchers can predict if a toxin interferes with the human endocrine system by analyzing the functional group properties of a toxin. Functional groups also give information about how toxins interact with other molecules in the environment, possibly leading to reactions that disable or worsen the toxic effects.

The physical properties of a molecule include physical state, boiling and melting points, solubility, density, electrical conductivity, and three-dimensional shape. A molecule's physical state relates to whether it is a gas, liquid, or solid under normal atmospheric conditions. The physical state of a toxin determines how it enters and is transported in the environment and in the body of an organism. Gaseous toxins tend to spread in the atmosphere, and consequently settle on land and water—sometimes great distances from the entry point. Liquid toxins can enter the environment by seeping in the ground or leaking into water. Some liquid toxins can evaporate and get transported as a gas. Solid toxins can enter the atmosphere as a blowing powder or can be transported to soil and water as a solid or as a liquid dissolved in water from the environment.

Toxins are considered either point source or nonpoint source pollutants.

Three useful reference books about the physical nature of environmental toxins are Donald Crosby's *Environmental Toxicology and Chemistry*, Wayne Landis and Ming-Ho Yu's *Introduction to Environmental Toxicology: Impacts of Chemicals upon Ecological Systems*, and Anu Ramaswami, Jana Milford, and Mitchell Small's *Integrated Environmental Modeling: Pollutant Transport, Fate, and Risk in the Environment*. These detailed volumes describe how certain chemical properties of a molecule have toxic effects on organisms. All works cite numerous original research studies, making them valuable for researchers as well as those interested in environmental policy related to toxins.

Two other helpful resources that describe the physical chemistry principles needed to understand the chemical structure of toxins are *The Elements of Physical Chemistry: With Applications in Biology* by Peter Atkins and *Principles and Problems in Physical Chemistry for Biochemists* by Nicholas Price et al. Both clearly explain the physical principles that determine the transport and toxic effects of hazardous chemicals. The books also explain the analytic methods used by physical chemists for studying the properties of toxic substances.

The Fate of Environmental Toxins

ARTIFICIAL AND NATURAL TOXINS ENTER the environment in a variety of ways, depending on their usage or disposal. Herbicides and pesticides are intentionally introduced into the environment with the anticipation that they will not spread too far beyond the area of application. Harmful gasoline additives accidentally leak out of vehicles, and enter the environment from gas stations, repair shops, and roadways. A certain amount of accidental seepage of artificial hazardous chemicals into the environment is expected and is one consequence of a high-tech lifestyle.

Toxins are considered either point source or nonpoint source pollutants. Point source pollution refers to pollutants released into the environment via an identifiable source and location, such as a pipe or a vent from a particular building. Point source pollutants are monitored and regulated by local, state, and federal environmental

policies. Nonpoint source pollution refers to contamination from numerous locations that are difficult to recognize as point source. Examples of nonpoint sources are agricultural, household, and urban runoff. It is surprising to learn that most toxins enter the environment as nonpoint pollutants from household sources in suburban and urban areas.

The term "waste stream" refers to the disposal materials used by society. Much of the time, the waste stream involves the disposal of a hazardous substance once it is used. It is hoped that the particular method of disposing of the hazardous substance reduces its release into the environment or converts the substance to a harmless byproduct before entering the environment. Almost all household hazardous wastes are disposed of as sewage and solid waste along with nonhazardous wastes. Small amounts of commercially used toxic artificial substances can also end up in the same waste stream as household materials if they are mildly toxic. It is assumed that after disposal, these wastes are diluted to a level that causes negligible, if any, harm in the environment.

One major problem with determining the fate of environmental toxins is recognizing the difference between natural substances that act like toxins and anthropogenic or human-made toxic pollutants. *Ecological Variability: Separating Natural from Anthropogenic Causes of Ecosystem Impairment*, edited by Donald Baird and G. Allen Burton Jr., is a scholarly work that evaluates the assessment of ecosystem damage by toxic chemicals. It first investigates the differences between natural and anthropogenic toxins and their relative impacts on the environment. The book then uses case studies to analyze different toxic pollutant events and policies that resulted from the incidents.

Environmental Analysis of Contaminated Sites, edited by Geoffrey Sunahara et al., describes the techniques used to study the fate of environmental toxins. The authors clearly explain quantitative techniques, and then describe strategies for remediating impaired sites and restoring sites to their original condition. The book provides extensive technical details in a highly readable style. It is written for a broad audience that is interested in all aspects of environmental toxicology, including advocacy and policy. Another book, *Fundamentals of Aquatic Toxicology: Effects, Environmental Fate and Risk Assessment*, edited by Gary Rand, focuses on the fate and impacts of toxins on aquatic systems. It similarly looks at the quantitative assessment and repair of toxin damage.

Chemical Consequences: Environmental Mutagens, Scientist Activism, and the Rise of Genetic Toxicology by Scott Frickel also discusses the fate of environmental toxins, focusing on the transport and impact of toxins that cause cancer and birth defects. Frickel discusses how new advances in genetics help scientists to explain the specific effects of toxins on genetic material, and how genetic differences determine the ultimate fate of a toxin molecule. The book cites current research and then investigates how the research drives advocacy and policy.

Testing for Environmental Toxins

Environmental toxicologists need accurate and sensitive analytical tools to detect and confirm environmental toxins in the environment and in the body's organs. Testing for environmental toxins is more difficult than other types of chemical analysis. Samples are a complex mixture of chemicals, and many analytical techniques require pure samples of the chemical in order to carry out an accurate assessment. As a result, environmental toxicologists have to either come up with methods to isolate the toxin from a sample or develop techniques that detect the toxin in the mixture. In *Handbook of Water Analysis*, Leo Nollet explains the precise technical protocols that must be followed to test toxins and nonhazardous materials in environmental samples such as water.

Several books cover, in great detail, the techniques for purifying samples. *Environmental Toxicology,* edited by T. P. Mommsen and T. W. Moon, discusses collecting and purifying samples from living organisms. *Environmental Field Testing and Analysis Ready Reference Handbook* by Donald Drum, Shari Bauman, and Gershon Shugar is an authoritative book on testing a variety of complex environmental samples; it includes techniques approved by governmental agencies such as the EPA. The book explains how toxins are extracted from air, biological specimens, soil, and water.

The analysis of environmental toxins is conducted using in vivo and in vitro testing methods. "In vivo" means in "in life" and refers to experimentation or testing carried out in the environment on the body of an organism. 'In vitro" means "in glass" and is used to describe experiments or testing conducted in a laboratory or outside the body of an organism. Some types of in vivo toxicological tests are called "in situ," meaning that testing is done in the location where the toxin is having its effect. Most environmental toxin testing is conducted to identify a toxin or determine the levels of a toxin in the environment or in an organism's body. Frank Barile, in *Principles of Toxicology Testing*, explains standard testing techniques, and further explains newer methods, such as bioassays. Bioassays use cells or whole organisms as indicators of toxins and their hazardous effects.

New molecular biology techniques are being developed to determine the presence of environmental toxins and their effects on organisms. These strategies look at subtle changes in cell function and structure to assay environmental toxins. One method called in-situ spectroscopy makes it possible to analyze molecules and molecular changes in preserved and living specimens placed on special microscopes. Early developments in this field are covered in *Ecological Toxicity Testing: Scale, Complexity, and Relevance*, edited by John Cairns and B. R. Niederlehner. These early techniques led to the development of other molecular methods that ultimately replaced the need for whole organisms. In *Toxicologic Biomarkers*, Anthony DeCaprio provides a detailed analysis of this type of biological testing and describes new techniques that investigate changes in DNA that result from toxin exposure. *Alternatives to Animal Testing,* edited by Ronald Hester and Roy Harrison, also discusses new testing methods that eliminate the need for animal testing in toxicological studies.

Conclusion

Environmental toxicology is a dynamic, evolving science that relies on the integration of biology, chemistry, information technology, and statistical analysis. As discussed earlier in this essay, the field branched off from forensic toxicology to specifically address the concerns of the growing environmental awareness movement of the 1970s. Environmental toxins vary greatly in their chemical properties and on the types of organisms they harm. To detect these toxins, scientists must use many specialized methods, some of which were borrowed from traditional chemical analysis technologies. New techniques that target environmental toxins help toxicologists determine the effects of toxins on the environment and on specific organisms. Many of these strategies use novel ways of monitoring toxins as they enter the environment.

Environmental toxicology will continue to grow in importance as the world deals with a host of issues such as tainted food, air pollution, chemical leaching from plastics, climate change, and most recently, oil spills, which can cause serious damage to entire ecosystems. A sound knowledge of the science behind this field will be important for understanding what is happening in the world today, and learning how we can help to improve our environment.

Notes

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2. *Merriam-Webster's Online Medical Dictionary*, accessed August 31, 2010, http://medical.merriamwebster.com/medical/.
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University of Idaho
http://www.agls.uidaho.edu/foodtox/

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U.S. National Institutes of Health, National Library of Medicine
http://toxnet.nlm.nih.gov/

U.S. Environmental Protection Agency (CH, Nov'10, 48-1434)
U.S. Environmental Protection Agency
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U.S. Food and Drug Administration (CH, Jan'07, 44-2744)
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