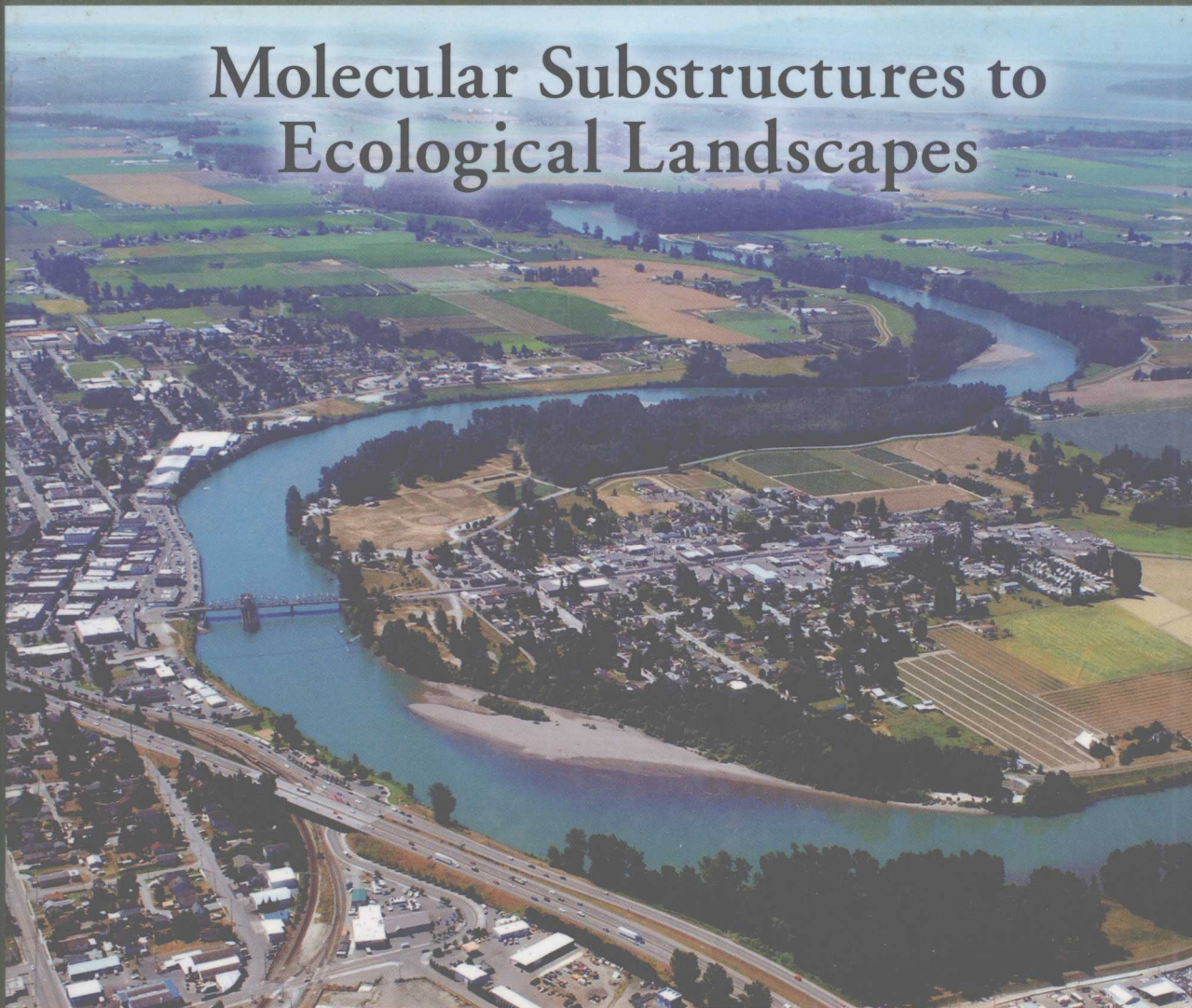


Fourth Edition

Introduction to

ENVIRONMENTAL TOXICOLOGY

**Molecular Substructures to
Ecological Landscapes**



Wayne G. Landis | Ruth M. Sofield | Ming-Ho Yu



CRC Press
Taylor & Francis Group

Introduction to ENVIRONMENTAL TOXICOLOGY

Molecular Substructures to
Ecological Landscapes

Fourth Edition

Wayne G. Landis | Ruth M. Sofield Ming-Ho Mu



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

© 2011 by Taylor and Francis Group, LLC
CRC Press is an imprint of Taylor & Francis Group, an Informa business

No claim to original U.S. Government works

Printed in the United States of America on acid-free paper
10 9 8 7 6 5 4 3 2 1

International Standard Book Number: 978-1-4398-0410-0 (Hardback)

This book contains information obtained from authentic and highly regarded sources. Reasonable efforts have been made to publish reliable data and information, but the author and publisher cannot assume responsibility for the validity of all materials or the consequences of their use. The authors and publishers have attempted to trace the copyright holders of all material reproduced in this publication and apologize to copyright holders if permission to publish in this form has not been obtained. If any copyright material has not been acknowledged please write and let us know so we may rectify in any future reprint.

Except as permitted under U.S. Copyright Law, no part of this book may be reprinted, reproduced, transmitted, or utilized in any form by any electronic, mechanical, or other means, now known or hereafter invented, including photocopying, microfilming, and recording, or in any information storage or retrieval system, without written permission from the publishers.

For permission to photocopy or use material electronically from this work, please access www.copyright.com (<http://www.copyright.com/>) or contact the Copyright Clearance Center, Inc. (CCC), 222 Rosewood Drive, Danvers, MA 01923, 978-750-8400. CCC is a not-for-profit organization that provides licenses and registration for a variety of users. For organizations that have been granted a photocopy license by the CCC, a separate system of payment has been arranged.

Trademark Notice: Product or corporate names may be trademarks or registered trademarks, and are used only for identification and explanation without intent to infringe.

Library of Congress Cataloging-in-Publication Data

Landis, Wayne G.

Introduction to environmental toxicology : molecular substructures to ecological landscapes. -- 4th ed. / Wayne G. Landis, Ruth M. Sofield, Ming-Ho Yu.
p. cm.

Includes bibliographical references and index.

ISBN 978-1-4398-0410-0 (hardcover : alk. paper)

1. Pollution--Environmental aspects. 2. Environmental toxicology. I. Sofield, Ruth M. II. Yu, Ming-Ho, 1928- III. Title.

QH545.A1L35 2011
571.9'5--dc22

2010026488

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

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

¥ 844 -

Preface to the Fourth Edition

Fifteen years ago we submitted the original text because we had no suitable book for teaching courses introducing environmental toxicology and biochemistry. The current edition still reflects those origins. A good textbook presents not just lists of information but also has a design to teach students how the science is connected and how to delineate the frontiers. These connections and frontiers are the items that will stay with the student long after the “facts” are displaced by better information.

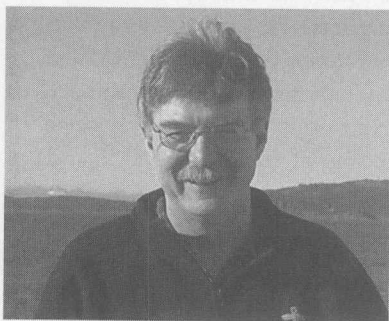
The mid-1990s were long ago and our understanding of environmental toxicology was very basic. Computation was still hard, genes stayed put, and it was only then becoming recognized that xenobiotics could have hormonal effects. Ecological risk assessment was in its very early stages and the consideration of the effects of toxicants on landscapes was nascent. These developments are now taken for granted.

The third edition was noteworthy as the work of D. Moore, P. Caux, and M. Newman demonstrated that curve fitting is superior to hypothesis testing for the modeling of concentration-effects data. Endocrine disruption was a major part of the text and risk assessment became a stand-alone chapter. The unifying construct of the hierarchical patch dynamics paradigm was introduced early and used in following chapters to integrate the spatial and temporal scales in environmental toxicology. The third edition explicitly recognized that ecological structures were complex systems being dynamic, not in equilibrium, and historical.

This fourth edition sees the inclusion of a new author, Dr. Ruth M. Sofield, who prepared the chapter on the fate and transport of contaminants. This chapter is a major addition to the text and emphasizes the relationships between chemical structure and the resultant properties with regard to the fate and transport of the material. The relationship between structure and toxicological properties has been a major theme of this book since its inception. In this edition, this fundamental concept is expanded to fate and transport as well. Our current students have the background to utilize the mathematical approaches necessary to predict fate and transport in many systems. Indeed, modeling has become a major theme of this edition.

One of the major enhancements to the fourth edition has been a new emphasis on the use of all types of models in understanding nature. In the early chapters, the use of models in science is discussed and this theme carries throughout the remainder of the book. Inevitably this emphasis on using models to describe toxicological relationships continues to lead to the fundamental flaws in using hypothesis testing to describe toxicity. It is time to move toward the use of models that describe concentration-response relationships and all the diversity of form that may exist. Because the use of biotic indices is incompatible with our current model of how ecological systems operate, the treatment of them recommends a number of methods that take advantage of the increase in

Authors



Wayne G. Landis, Ph.D., has been the Director of the Institute of Environmental Toxicology and Chemistry, part of Huxley College of the Environment at Western Washington University, Washington State, since 1989. A graduate of Wake Forest University with a BA in biology in 1974, he subsequently received an MA and a Ph.D. in zoology from Indiana University in 1978 and 1979, respectively. Prior to Dr. Landis's university experience he was a toxicologist for the Chemical Research Defense and Engineering Center at Aberdeen Proving Ground, Maryland.

Dr. Landis has authored more than 120 publications and 300 scientific presentations. He has served on a number of USEPA (U.S. Environmental Protection Agency) and other committees, and consulted for industry; nongovernmental organizations (NGOs); print and electronic media; and federal (U.S. and Canada), state, provincial, and local governments. In 2007, he was selected as a Fellow of the Society for Risk Analysis. Currently, Dr. Landis serves on the board of editors for *Human and Ecological Risk Assessment*; he is one of the founding editors for the new Society of Environmental Toxicology and Chemistry (SETAC) journal *Integrated Environmental Assessment and Management*; and is the environmental risk assessment editor for *Risk Analysis*.

Dr. Landis has had a varied research program. During the 1980s and early 1990s, he discovered and characterized enzymes that degrade organophosphates and bacteria that metabolize riot control materials. He also conducted an extensive research program using microcosms to investigate the effects of jet fuels and other materials on the dynamics of ecological structures. Using patch dynamics models, he also formulated the theory of how to incorporate landscape scale effects as part of environmental toxicology. He is the codeveloper of the Community Conditioning Hypothesis and the Action at a Distance Hypothesis. Dr. Landis's most recent efforts have been to apply ecological risk assessment at regional and landscape scales using the relative risk model. The use of the relative risk model has now been applied to contaminated sites, invasive species, and forestry and species conservation. The approach has been used to estimate risk to sites across the world.



Ruth M. Sofield, Ph.D., is an Associate Professor at the Huxley College of the Environment at Western Washington University. She has been at the university since 2003, and is one of the faculty specializing in environmental toxicology and chemistry. She routinely teaches environmental toxicology, and fate and transport courses at the university, as well as workshops in aquatic toxicology throughout the United States.

Dr. Sofield has a BA in biology from West Virginia University (1993), an MS in environmental science from McNeese State University (Louisiana) (1995), and an MS and Ph.D. in environmental science and engineering from the Colorado School of Mines (1999, 2002). She completed her Ph.D. work in collaboration with the Center for Coastal Environmental Health and Biomolecular Research, Marine Ecotoxicology Branch, National Ocean Service, National Oceanic and Atmospheric Administration (NOAA), Charleston, South Carolina. This work focused on the genetically based tolerance to chemical exposures in *Palaemonetes pugio*. In 2003, Dr. Sofield completed her postdoctoral work on the binding of environmental ligands to uranium and plutonium.

Her current research program is focused on the effects of altered water chemistry and other environmental parameters on metal fate, transport, and aquatic toxicity. These studies range from laboratory bench scale to field scale investigations and include organism exposures combined with chemical modeling.



Ming-Ho Yu, Ph.D., is Professor Emeritus at the Department of Environmental Sciences, Western Washington University. He received his BS degree from National Taiwan University, and MS and Ph.D. from Utah State University. He did his postdoctoral research at Utah State University and the University of Alberta, Canada. Dr. Yu was a visiting professor and conducted research for a year at the Department of Public Health and Hygiene, Iwate Medical University, Morioka, Japan; and also at the Institute of Whole Body Metabolism in Chiba, Japan, for three months. He serves as an associate editor of *Fluoride*, the official journal of the International Society for Fluoride

Research. Dr. Yu is coeditor of *Environment Fluoride 1985* (Elsevier, 1986); and the author of *Environmental Toxicology—Impacts of Environmental Toxicants on Living Systems*, Second Edition (CRC Press, 2005), and coauthor of *Introduction to Environmental Toxicology*, Third Edition (CRC Press, 2005).

Contents

Preface to the Fourth Edition.....	xv
Acknowledgments	xvii
Authors.....	xix
1 Introduction to Environmental Toxicology	1
1.1 Environmental Toxicology as an Interdisciplinary Science	1
1.2 A Brief History and Organizations in Environmental Toxicology	3
1.3 Interactions and Connections of Environmental Toxicology to the Management of Ecological Systems.....	3
1.3.1 Research Programs	3
1.3.2 The Scientific Community.....	5
1.3.3 Risk Assessment.....	5
1.3.4 Governmental and Regulatory Agencies.....	6
1.3.5 Industry.....	6
1.3.6 The General Public	7
1.4 Legislation	7
1.5 Introduction to This Textbook	9
Study Questions.....	11
2 Frameworks and Paradigms for Environmental Toxicology.....	13
2.1 The Fundamentals	13
2.2 Models.....	14
2.3 Fundamental Models for Environmental Toxicology.....	19
2.4 The Classical Viewpoint for Classifying Toxicological Effects	20
2.5 Chemical Physical–Chemical Characteristics	21
2.6 Bioaccumulation/Biotransformation/Biodegradation	22
2.7 Receptors and the Mode of Action	22
2.8 Biochemical and Molecular Effects.....	22
2.9 Physiological and Behavioral Effects.....	23
2.10 Population Parameters.....	23
2.11 Community Effects	24
2.12 Ecosystem Effects	25
2.13 An Alternative Framework Incorporating Complexity Theory.....	25
2.14 Spatial and Temporal Scales	26

2.15	Combining Scale and Ecological Dynamics: The Hierarchical Patch Dynamic Paradigm	28
2.16	Strategy and Tactics in the Use of Models in Environmental Toxicology	31
	Study Questions.....	32
	References and Suggested Readings	32
3	An Introduction to Toxicity Testing.....	35
3.1	Introduction	35
3.2	The Dose-Responsive Curve	36
3.3	Thresholds and Hormesis.....	41
3.4	Terminology Based upon Hypothesis Testing.....	42
3.5	Classification of Toxicity Tests.....	43
3.6	Design Parameters for Single-Species Toxicity Tests	44
3.6.1	Exposure Scenarios	45
3.6.2	Test Organisms.....	47
3.6.3	Comparison of Test Species	48
3.6.4	Overview of the Tools for the Analysis of Concentration (Dose)-Effect Relationships	48
3.7	Limitations and Alternatives to Hypothesis Testing	49
3.8	Commonly Used Methods for the Calculation of Endpoints.....	51
3.9	Comparison of Calculations of Several Programs for Calculating Probit Analysis	52
3.10	Hypothesis Testing.....	54
3.11	Curve Fitting and Regression Modeling versus Hypothesis Testing.....	55
3.12	The Design of Multispecies Toxicity Tests	59
3.12.1	The Nature of Multispecies Toxicity Tests	60
3.12.2	Data Analysis and Interpretation of Multispecies Toxicity Tests.....	61
3.12.2.1	Sample Design.....	61
3.13	Univariate Methods.....	61
3.14	Multivariate Methods.....	62
3.15	Visualization.....	64
3.16	Summary of Design Guidelines for Multispecies Toxicity Tests	64
3.17	Standard Methods	65
3.17.1	Advantages of Standard Methods	65
3.17.2	Disadvantages of Standard Methods.....	66
	Study Questions.....	66
	References and Suggested Readings	67
4	Survey and Review of Typical Toxicity Test Methods	71
4.1	Introduction	71
4.2	Animal Care and Use Considerations.....	73
4.2.1	Institutional Animal Care and Use Committee.....	73
4.2.2	Replace, Reduce, Refine	75
4.3	Single-Species Toxicity Tests.....	75
4.3.1	<i>Daphnia</i> 48-Hour Acute Toxicity Test.....	75
4.3.2	Algal 96-Hour Growth Toxicity Test	76

4.3.3	Acute Toxicity Tests with Aquatic Vertebrates and Macroinvertebrates	81
4.3.4	Terrestrial Vertebrate Toxicity Tests.....	86
4.3.5	Frog Embryo Teratogenesis Assay: FETAX.....	89
4.4	Multispecies Toxicity Tests	94
4.4.1	Standardized Aquatic Microcosm	98
4.4.2	Mixed-Flask Culture Microcosms	101
4.4.3	FIFRA Microcosm	101
4.4.4	Soil Core Microcosm.....	105
4.5	Summary.....	105
	Study Questions.....	107
	Appendix 4.1: The Natural History and Utilization of Selected Test Species	108
	References and Suggested Readings	115
5	The Fate and Transport of Contaminants	117
5.1	Introduction	117
5.2	Transport Mechanisms.....	118
5.2.1	Advection, Diffusion, and Dispersion.....	118
5.2.2	Long-Range Atmospheric Transport (LRAT).....	134
5.3	Persistence	135
5.4	Biotransport	137
5.5	Abiotic Degradation/Transformation	140
5.6	Multimedia Box Models.....	142
5.7	Equilibrium.....	146
5.8	The Fugacity Approach.....	151
5.9	Bioconcentration versus Biomagnification	152
5.10	Bioavailability.....	153
5.10.1	Measures of Bioavailability	154
5.10.2	Metal Speciation and the Biotic Ligand Model.....	155
5.10.3	Acid Volatile Sulfide (AVS)/Simultaneously Extracted Metals (SEM) in Anoxic Sediment	155
5.11	Summary.....	157
	Study Questions.....	157
	References and Suggested Readings	158
6	Uptake and Modes of Action.....	163
6.1	The Damage Process.....	163
6.2	Atmospheric Pollutants and Plants	163
6.2.1	Plant Injury	164
6.2.2	Vertebrates.....	165
6.2.2.1	Exposure.....	166
6.2.2.2	Uptake.....	166
6.2.2.3	Transport.....	166
6.2.2.4	Storage.....	166
6.2.2.5	Metabolism.....	166
6.2.2.6	Excretion	167
6.3	Mechanisms of Action.....	167
6.3.1	Disruption or Destruction of Cellular Structure.....	167

6.3.2	Direct Chemical Combination with a Cellular Constituent	168
6.3.3	Effect on Enzymes	168
6.3.4	Secondary Action as a Result of the Presence of a Pollutant.....	170
6.3.5	Metal Shift	172
6.4	Specific Modes of Action in Detail	173
6.4.1	Narcosis.....	173
6.4.2	Organophosphates	173
6.4.3	Modes of Action of Chemical Warfare Agents.....	179
6.4.4	Monohaloacetic Acids.....	181
6.5	Receptor-Mediated Toxicity, Endocrine Disruption.....	183
6.5.1	Specificity of the Hormone-Receptor Interaction.....	184
6.5.2	The Receptor Pathway for TCDD	189
6.5.3	The Structure-Activity Relationships of PCB and Related Compounds.....	191
6.5.4	Polybrominated Diphenyl Ethers (PBDEs)	198
6.5.5	The Multiple Modes of Action of Atrazine.....	198
6.6	Introduction to QSAR.....	201
6.6.1	Construction of QSAR Models	202
6.6.2	Typical QSAR Model Development	204
6.6.3	Estimation of Toxicity Using QSAR.....	207
	Study Questions.....	208
	References and Suggested Readings	209
7	Factors Modifying the Activity of Toxicants.....	213
7.1	Introduction	213
7.2	Physicochemical Properties of Pollutants	213
7.3	Time and Mode of Exposure	214
7.4	Environmental Factors.....	214
7.4.1	Temperature	214
7.4.2	Humidity	214
7.4.3	Light Intensity	215
7.5	Interaction of Pollutants	215
7.5.1	Synergism and Potentiation	215
7.5.2	Antagonism	216
7.6	Toxicity of Mixtures	216
7.6.1	Simple Models of Mixture Toxicity	216
7.6.2	Mixture Estimation System	219
7.6.3	Estimating the Toxicity of Mixtures of Polynuclear Aromatic Hydrocarbons.....	220
7.6.4	Mixtures and Carbamate and Organophosphate Synergistic Toxicity	222
7.7	Biological Factors Affecting Toxicity	225
7.7.1	Plants.....	225
7.7.2	Animals.....	225
7.7.3	Genetic Factors.....	225
7.7.4	Developmental Factors	225
7.7.5	Diseases	226

7.7.6	Behavioral Factors	226
7.7.7	Sex Variation	226
7.7.8	Nutritional Factors	226
7.7.9	Fasting/Starvation	227
7.7.10	Proteins	227
7.7.11	Carbohydrates	228
7.7.12	Lipids.....	229
7.7.13	Vitamin A.....	230
7.7.14	Vitamin D	230
7.7.15	Vitamin E.....	230
7.7.16	Vitamin C	231
7.7.17	Minerals	232
	Study Questions.....	233
	References and Suggested Readings	233
8	Inorganic Gaseous Pollutants.....	237
8.1	Sulfur Oxides	237
8.1.1	Sources of SO ₂	237
8.1.2	Characteristics of SO ₂	238
8.1.3	Effect on Plants	240
8.1.4	Effect on Animals.....	240
8.1.5	Effect on Humans	241
8.2	Nitrogen Oxides	241
8.2.1	Forms and Formation of Nitrogen Oxides.....	241
8.2.2	Major Reactive N Species in the Troposphere.....	242
8.2.3	Effect on Plants	242
8.2.4	Effects on Humans and Animals	243
8.2.5	Physiological Effects	243
8.2.6	Biochemical Effects	244
8.3	Ozone.....	244
8.3.1	Sources	244
8.3.2	Photochemical Smog.....	245
8.3.3	Effect on Plants	246
8.3.4	Effects on Humans and Animals	246
8.3.5	Biochemical Effects	247
8.4	Carbon Monoxide	249
8.4.1	Formation of CO.....	249
8.4.2	Human Exposure to CO	250
8.4.3	Toxicological Effects	250
8.4.4	Mechanism of Action	251
	Study Questions.....	252
	References and Suggested Readings	252
9	Fluoride as a Contaminant of Developing Economies	255
9.1	Environmental Sources and Forms of Fluoride.....	255
9.1.1	Minerals and Soils	255
9.1.2	Natural Waters	255

9.1.3	Foods.....	255
9.1.4	Air	256
9.2	Industrial Sources of Fluoride Pollution.....	256
9.3	Effect on Plants	258
9.3.1	Injuries to Leaf Tissues	258
9.3.2	Effect on Germination.....	260
9.3.3	Biochemical Effect.....	260
9.4	Effect on Animals.....	261
9.4.1	Acute Effects.....	261
9.4.2	Chronic Effects.....	261
9.5	Effect on Human Health.....	263
9.5.1	Daily Intake	263
9.5.2	Absorption.....	263
9.5.3	Acute Toxicity	264
9.5.4	Chronic Toxicity.....	264
9.6	Biochemical Effect.....	264
	Study Questions.....	266
	References and Suggested Readings	267
10	Heavy Metals.....	269
10.1	Introduction	269
10.2	Lead	269
10.2.1	Properties and Uses	270
10.2.2	Exposure.....	270
10.2.2.1	Atmospheric Lead.....	270
10.2.2.2	Waterborne Lead	270
10.2.2.3	Lead in Food	270
10.2.2.4	Lead in Soils.....	271
10.2.3	Lead Toxicity.....	271
10.2.3.1	Effect on Plants	271
10.2.3.2	Effect on Animals.....	271
10.2.3.3	Effect on Humans	272
10.2.3.4	Biochemical Effect.....	272
10.3	Cadmium	273
10.3.1	Properties and Uses	273
10.3.2	Exposure.....	274
10.3.3	Cadmium Toxicity	274
10.3.3.1	Effect on Plants	274
10.3.3.2	Effects on Animals/Humans.....	275
10.3.4	Biochemical Effect.....	275
10.4	Mercury.....	276
10.4.1	Properties and Uses	276
10.4.2	Sources of Mercury Pollution	276
10.4.3	Toxicity	276
10.4.3.1	Effect on Plants	276
10.4.3.2	Effect on Animals.....	277

10.4.3.3	Terrestrial Animals.....	277
10.4.3.4	Effect on Human Health.....	277
10.4.4	Biochemical Effect.....	278
	Study Questions.....	279
	References and Suggested Readings.....	279
11	Biotransformation, Detoxification, and Biodegradation	281
11.1	Introduction	281
11.2	Metabolism of Environmental Chemicals: Biotransformation	281
11.3	Types of Biotransformation	282
11.4	Mechanisms of Biotransformation.....	282
11.5	Consequences of Biotransformation	286
11.6	Microbial Degradation	287
11.7	Bioremediation	291
11.7.1	Isolation and Engineering of Degradative Organisms.....	299
11.7.2	The Genetics of Degradative Elements	299
11.8	An Example of a Detoxification Enzyme: The Organophosphate Acid Anhydrolases	301
11.8.1	Characteristics of the <i>opd</i> Gene Product and Other Bacterial OPA Anhydrolases	302
11.8.2	Eukaryotic OPA Anhydrolases	305
11.8.3	Characteristics of Other Invertebrate Metazoan Activities.....	306
11.8.4	Characteristics of the Fish Activities	307
11.8.5	Comparison of the OPA Anhydrolases	308
11.8.6	Natural Role of the OPA Anhydrolases	309
	Study Questions.....	311
	References and Suggested Readings.....	311
12	Ecological Effects from Biomarkers to Populations	315
12.1	Introduction	315
12.2	Terminology and Context.....	315
12.3	The Key to Context: The Hierarchical Patch Dynamics Paradigm	316
12.4	Measurement of Ecological Effects at Various Scales or Levels of Biological Organization	321
12.5	Bioaccumulation/Biotransformation/Biodegradation	323
12.6	Molecular and Physiological Indicators of Chemical Stress Biomarkers.....	324
12.6.1	Enzymatic and Biochemical Processes	324
12.6.2	Physiological and Histological Indicators	326
12.6.3	Toxicity Tests and Population Level Measures.....	327
12.6.4	Sentinel Organisms and <i>In Situ</i> Biomonitoring	328
12.6.5	Population Parameters.....	330
12.7	Assemblage and Community Parameters.....	330
12.7.1	Species Abundance Curves	331
12.7.2	Species Richness, Diversity, and Equability	331
12.7.3	Biotic Indices.....	331
12.8	Effects at the Population Scale.....	332
12.8.1	Populations.....	332

12.8.2	Modeling of Populations Using Age Structure and Survivorship Models.....	334
12.8.2.1	Population Biology, Nonlinear Systems, and Chaos.....	335
12.8.3	Age-Structured Populations.....	341
12.8.4	Measurement of Effects on Populations.....	344
12.8.5	Point Estimates, TRVs, NOECs, LD ₅₀ s.....	344
12.8.6	Intrinsic Rate of Growth r or λ	345
12.8.7	Biomass, Percent Cover, Productivity.....	347
12.8.8	Change in the Pattern of the Age Structure.....	348
12.8.8.1	Normalized Effects Vector.....	348
12.8.8.2	So What Measure to Use?.....	351
12.8.9	Observed Changes in Age Structure Experimental and Field Populations.....	352
12.8.10	Contaminants in Spatially Structured Populations.....	353
12.8.10.1	The Spatial Structure of Populations.....	353
12.8.11	The Use of Metapopulation Models to Investigate Toxicant Effects.....	356
12.8.12	Patch Dynamic Models Based on Spromberg et al. (1998).....	357
12.9	Interacting Populations in a Patchy Environment.....	360
12.10	The Importance of Patch Dynamics.....	365
12.11	Implications.....	366
Appendix 12.1:	Age-Structured Population Modeling in Detail.....	367
	Study Questions.....	369
	References and Suggested Readings.....	370

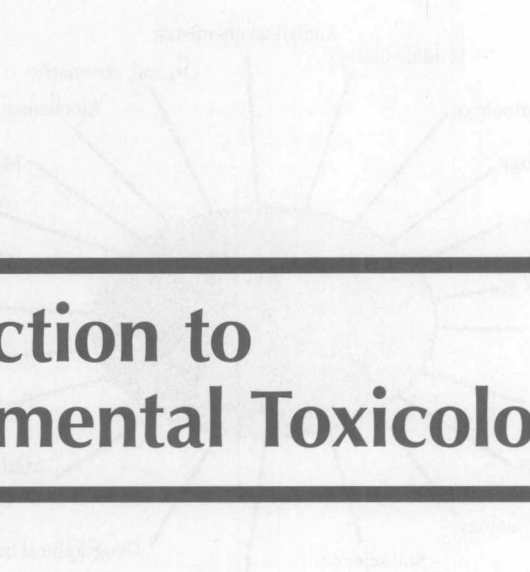
13 Ecological Effects: Community to Landscape Scales of Toxicological

Impacts.....	375
13.1	Introduction.....
13.2	Community Effects.....
13.2.1	Competition and Indirect Effects.....
13.2.2	Resource Competition as a Model of the Direct and Indirect Effects of Pollutants.....
13.3	Effects on Ecosystems or Ecological Structures.....
13.3.1	Similarity Measures.....
13.3.2	Classification.....
13.3.3	Clustering.....
13.4	Application of Multivariate Techniques.....
13.4.1	Normalized Ecosystem Strain (NES).....
13.4.2	State Space of Ecosystems.....
13.4.3	Nonmetric Clustering and Association Analysis.....
13.4.4	Projections for Visualizing Ecosystem Dynamics.....
13.4.5	Examples of the Use of Multivariate Methods in Multispecies Toxicity Tests and Field Studies.....
13.4.6	SiZer and the Detection of Thresholds.....
13.5	Pollution-Induced Community Tolerance.....
13.6	Interpretation of Ecosystem Level Impacts.....
13.7	An Alternative Model: The Community Conditioning Hypothesis.....

13.8	The Design of Field Studies	405
13.8.1	The Question	406
13.8.2	Context	406
13.8.3	Conceptual Model	407
13.8.4	Sampling Design	407
13.8.5	Sampling Techniques	408
13.8.6	Laboratory Studies	408
13.8.7	Data Analysis	408
13.8.8	Drawing Conclusions	409
13.9	Making Decisions	409
	Appendix: Multivariate Techniques—Nonmetric Clustering	409
	Study Questions	411
	References and Suggested Readings	412
14	Ecological Risk Assessment	415
14.1	Introduction	415
14.2	Basics of Risk Assessment	415
14.3	Ecological Risk Assessment	416
14.4	Ecological Risk Assessment Framework	417
14.4.1	Problem Formulation	418
14.4.2	Analysis	422
14.4.3	Exposure Analysis	423
14.4.4	Characterization of Ecological Effects	424
14.4.4.1	Ecological Response Analyses	424
14.4.4.2	Stressor-Response Profile	425
14.4.5	Data Acquisition, Verification, and Monitoring	426
14.5	Risk Characterization	426
14.5.1	Integration	426
14.5.2	Risk Description	428
14.5.3	Interpretation of Ecological Significance	429
14.5.4	Discussion between the Risk Assessor and Risk Manager	429
14.5.5	Data Acquisition, Verification, and Monitoring	429
14.6	Techniques in Ecological Risk Assessment	430
14.6.1	New Methods for Calculating Ecological Risk	430
14.6.2	The Curve Model	431
14.6.3	Spatially Distinct Risk Quotients	432
14.6.4	A Ranking Approach to Multiple Stressors, Wide-Area Ecological Risk Assessment	432
14.6.5	A Simple Example	436
14.6.6	Advantages and Dangers of the Ranking Approach	437
14.6.7	Establishing Causation and the Weight of Evidence Approach	438
14.6.7.1	Criteria for Causation	439
14.6.7.2	Weight of Evidence	439
14.6.8	A General Model for Regional Risk Assessment: The 10 Steps	441
14.6.9	Life Cycle Assessment	463
	Study Questions	465
	References and Suggested Readings	466

Appendix A: References for Toxicity Testing and Interpretation.....	469
---	-----

Index	495
-------------	-----



Chapter 1

Introduction to Environmental Toxicology

As all textbooks do, this volume reflects the points of view of each of the authors, developed from being active researchers, teachers, and participants in various professional societies and governmental panels. Since the early 1990s at Huxley College of the Environment there has been a two-course fundamental introduction to the science of environmental toxicology for which this text was originally developed. That series is supplemented by courses in aquatic toxicology, risk assessment, fate and transport, air pollution, and risk assessment. Since its first edition this book was designed to provide a keystone for the program in environmental toxicology.

The approach is to blend the classic aspects of the field with new developments as they prove fundamental to the understanding of environmental toxicology. Our approach is quantitative, recognizes the connection between molecular interactions and alterations of ecological functions, and understands that the findings of the field can have major implications for the making of environmental policy. We begin by defining the field of environmental toxicology.

1.1 Environmental Toxicology as an Interdisciplinary Science

Environmental toxicology is the study of the impacts of pollutants upon the structure and function of ecological systems. For the purposes of this text, the emphasis will be upon ecological structures, from the molecular to the individual organism to the community and to the ecosystem. The broad scope of environmental toxicology requires a multidisciplinary approach of a variety of specialists. These specialists interact with a variety of other persons, decision and policy makers, the public, educators, and other key individuals, in making decisions about the management