Environmental toxicology

DAVID A. WRIGHT, PhD, DSc University of Maryland

PAMELA WELBOURN, PhD Queen's University



Foreword xvii Preface xix Abbreviations xxi Acknowledgements xxv

1 The emergence of environmental toxicology as science 1

- 1.1 The context
- 1.2 The historical background: Classical toxicology, ecotoxicology, and environmental toxicology 2
- 1.3 Social aspects: The environmental movement 5
- 1.4 Social aspects: Regulation
- 1.5 Education in environmental toxicology 16

1

- 1.6 The role of technology 16
- 1.7 Questions 18
- 1.8 References 19
- 1.9 Further reading 20

2 The science of environmental toxicology: Concepts and definitions 21

- 2.1 The development of environmental toxicology 21
 - 2.1.1 An historical perspective on the science of environmental toxicology 21
 - 2.1.2 An evolutionary perspective on environmental toxicology 21
- 2.2 Assessment of toxicity 24

2.2.1

- The dose-response 25
- 2.2.2 The acute toxicity bioassay 31
- 2.2.3 Subacute (chronic) toxicity assays 31
- 2.2.4 The relationship between acute and chronic toxicity 33
- 2.2.5 Statistical considerations 38
- 2.2.6 Comparative bioassays 43
- 2.2.7 Sediment toxicity assays 49
- 2.3 Toxicity at the molecular level 50
 - 2.3.1 Carcinogenesis 52
 - 2.3.2 Genotoxicity assays 58
 - 2.3.3 Chromosome studies 59

- 2.3.4 The concept of threshold toxicity 59
- 2.3.5 Hormesis 61
- 2.3.6 Receptors 61
- 2.4 Questions 65
- 2.5 References 66

3 Routes and kinetics of toxicant uptake 70

- 3.1 General considerations 70
- 3.2 Route of toxicant uptake 71
 - 3.2.1 Skin
 - 3.2.2 Lungs 73
 - 3.2.3 Gills 74
 - 3.2.4 Digestive system 76
 - 3.2.5 Toxicant uptake by plants 77

72

- 3.3 Uptake at the tissue and cellular level 78
 - 3.3.1 Toxicokinetics 80
 - 3.3.2 Single-compartment model 81
 - 3.3.3 Two-compartment model 83
 - 3.3.4 Volume of distribution 86
 - 3.3.5 Transporter-mediated transport 87
 - 3.3.6 Lethal body burden (critical body residue) 90
- 3.4 Questions 94
- 3.5 References 95
- 3.6 Further reading 96

4 Methodological approaches 97

- 4.1 Introduction 97
- 4.2 The general concepts and principles for biological indicators 100
- 4.3 Tolerance and resistance to potentially toxic substances 106
 - 4.3.1 Some conundrums related to tolerance in the context of environmental assessment 106
 - 4.3.2 Selection for tolerance, mechanisms of tolerance, and potential practical applications of the phenomenon 109

4.4 Biological scale 116

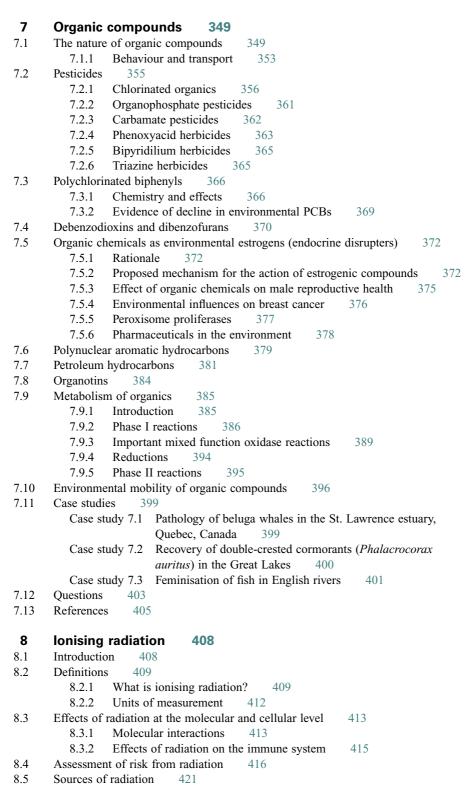
- 4.4.1 Principles and properties of biochemical markers/biochemical indicators 117
- 4.4.2 Some of the more commonly used groups of biochemical markers 119
- 4.4.3 Individual species as indicators or monitors 127
- 4.4.4 Surrogates for ecosystem indicators 142
- 4.5 Community and higher level indicators: The ecological approach to toxicology 143
 - 4.5.1 Interspecies effects of toxic substances 143
 - 4.5.2 Interaction between and among trophic levels as affected by toxic substances 146
 - 4.5.3 Population and community end-points 147
 - 4.5.4 Ecosystem equilibrium. Fact or fiction? 158
- 4.6 Modelling 160
 - 4.6.1 The concepts of modelling 160
 - 4.6.2 Mass balance models 164

	4.6.3 Some other models for use in environmental toxicology 1724.6.4 Advantages, limitations, and pitfalls in the modelling for
	environmental toxicology 173
4.7	Examples of methods and approaches for community or higher level
	responses 174
	4.7.1 Enclosures: Microcosms and mesocosms 175
	4.7.2 Whole system manipulations 178
4.8	The role of technical advances in methods for environmental toxicology 183
4.9	Choice of approaches 186
4.10	Case studies 190
	Case study 4.1 Benthic invertebrate communities in metal-contaminated sites exceeding criteria for acceptable sediment quality 190
	Case study 4.2 Biomarkers of organic chemical contamination in fish from Puget Sound 193
	Case study 4.3 The effect of coal-ash pollution on bullfrogs: An energy budget approach 196
	Case study 4.4 Phytotoxicology assessment for Nanticoke Generating Station: Biological indicators and monitors of air pollution 197
	Case study 4.5 Chesapeake Bay – A study of eutrophication and complex trophic interactions 201
	Case study 4.6 The use of lentic mesocosms in toxicity testing 202
	Case study 4.7 The cadmium spike experiment, Experimental Lakes Area 203
4.11	Questions 207
4.12	References 209
4.13	Further reading 217
5	Factors affecting toxicity 218
5.1	Introduction 218
5.2	Biotic factors affecting toxicity 219
	5.2.1 Taxonomic group 219
	5.2.2 Age/body size 221
5.3	Abiotic factors affecting toxicity 221
	5.3.1 Temperature 221
	5.3.2 pH and alkalinity 224
	5.3.3 Salinity 227
	5.3.4 Hardness 229
	5.3.5 Chemical mixtures 230
	5.3.6 Dissolved organic carbon 234
5.4	Role of particulates 236
	5.4.1 The importance of food 239
5.5	Quantitative structure-activity relationships 242
5.6	Implications for future environmental regulation 242
5.7	Questions 244
5.8	References 245
5.9	Further reading 248
6	Metals and other inorganic chemicals 249

- 6.1 Introduction 249
- 6.2 The properties and environmental behaviour of metals and metalloids 253

	6.2.1	General properties of metals and metalloids 253
	6.2.2	The mobilisation, binding, and chemical forms of metals
		in the environment 254
	6.2.3	The biological availability of metals in the environment 256
	6.2.4	Approaches for determining the chemical species and availability
		of metals 262
	6.2.5	The persistence of metals in the environment 267
	6.2.6	Bioconcentration, bioaccumulation, and biomagnification of metals
		in the environment 267
6.3		methods, temporal and spatial distribution of metals and metalloids
	in the envi	
	6.3.1	Analytical chemistry 269
	6.3.2	Historical records 270
	6.3.3	Spatial records and source signatures 271
6.4	Mercury	274
	6.4.1	The background to environmental concerns for mercury 274
	6.4.2	The properties, occurrence, and environmental behaviour
		of mercury 275
	6.4.3	The toxicity of mercury and populations at risk 282
	6.4.4	The reservoir problem 287
6.5		
	6.5.1	The occurrence, sources, and properties of lead 287
	6.5.2	The environmental transport and behaviour of lead 290
	6.5.3	Environmental exposure and toxicity of lead 291
6.6	Cadmium	298
	6.6.1	The occurrence, sources, and properties of cadmium 298
	6.6.2	The physiological and ecological behaviour of cadmium 299
67	6.6.3	The toxicity of cadmium 300
6.7	Copper	301 The accumum a councer and momenties of common 201
	6.7.1	The occurrence, sources, and properties of copper 301
	6.7.2 6.7.3	The physiological and ecological behaviour of copper 302 The toxicity of copper 302
6.8	0.7.5 Nickel	The toxicity of copper 302 304
0.8	6.8.1	
	6.8.2	The occurrence, sources, and properties of nickel304The physiological and ecological behaviour of nickel305
	6.8.3	The physiological and ecological behaviour of mcker 505 The toxicity of nickel 305
6.9	Selenium	306
0.9	6.9.1	The occurrence, sources, and properties of selenium 306
	6.9.2	
	6.9.3	The physiological and ecological behaviour of selenium307The toxicity of selenium307
6.10	Phosphoru	•
0.10	6.10.1	The occurrence, sources, and behaviour of phosphorus 308
	6.10.2	The physiological and ecological behaviour of phosphorus 308
6.11	Fluorine	313
0.11	6.11.1	The occurrence, sources, and behaviour of fluorine 313
	6.11.1	The toxicity of fluoride 313
6.12	Questions	315
6.12	Questions	210

- 6.13 References 316
- 6.14Further reading319Appendix: Properties of selected metals and metalloids319



- 8.5.1 Background radiation 421
- 8.5.2 Electricity production from nuclear power 422
- 8.5.3 Radioisotopes of biological importance 427
- 8.6 Ecological effects of radiation 430
- 8.7 Case study 431
 - Case study 8.1 The Chernobyl accident 431
- 8.8 Questions 433
- 8.9 References 433

9 Complex issues 435

- 9.1 Introduction and rationale 435
- 9.2 The mining and smelting of metals 436
 - 9.2.1 The issue 436
 - 9.2.2 Processes involved in the extraction and purification of metals 437
 - 9.2.3 Substances of concern that are mobilised or formed and released during mining, smelting, and other purification processes 439
 - 9.2.4 The environmental toxicology of metal mining and smelting 440
- 9.3 Environmental impacts of pulp and paper mills 446
 - 9.3.1 The issue 446
 - 9.3.2 Substances of concern I: Nutrient enrichment from pulp mills 447
 - 9.3.3 Substances of concern II: Chlorinated products of paper pulp 448
 - 9.3.4 The environmental toxicology of mill effluent 449
 - 9.3.5 Mitigation: Means for minimising the impacts of pulp mills 450
- 9.4 Electrical power generation 451
 - 9.4.1 The issue of producing electricity from fossil fuel 451
 - 9.4.2 The issue of producing electricity from nuclear energy 452
 - 9.4.3 The issue of hydroelectric power 458
 - 9.4.4 Socioeconomic considerations 459
- 9.5 Global warming 462
 - 9.5.1 The issue 462
 - 9.5.2 The greenhouse effect 462
 - 9.5.3 Substances of concern: Greenhouse gases and their sources 463
 - 9.5.4 Global climate models 464
- 9.6 Atmospheric pollution 465
 - 9.6.1 The issue 465
 - 9.6.2 Substances of concern: Photochemical oxidants 466
 - 9.6.3 The environmental toxicology of photochemical oxidants 470
 - 9.6.4 Substances of concern: Acidic precipitation 471
 - 9.6.5 The environmental toxicology of acid precipitation 472
- 9.7 Agriculture 474
 - 9.7.1 The issue 474
 - 9.7.2 Substances of concern: Fertilisers 477
 - 9.7.3 The environmental toxicology of fertilisers 478
 - 9.7.4 Substances of concern: Pesticides 483
 - 9.7.5 The environmental toxicology of pesticides 486
- 9.8 Oil extraction, transportation, and processing 487
 - 9.8.1 The issue 487
 - 9.8.2 The environmental toxicology of oil 489
 - 9.8.3 Oil spill legislation and control 493
 - 9.8.4 Use of oil dispersants 493

9.9	Case study 494		
	Case study 9.1 The Florida Everglades: A case study of eutrophication related		
9.10	to agriculture and restoration 494 References 495		
9.11	Further reading 499		
9.11			
10	Risk assessment 500		
10.1	The context and rationale for ecological risk assessment 500		
10.2	The methodology of ecological risk assessment and risk management 502		
	10.2.1 Risk assessment 502		
	10.2.2 Risk management 508		
10.3	Site-specific risk assessment 508		
10.4	Dealing with uncertainty 510		
10.5	Factors triggering risk assessment 511		
10.6	Case studies 512		
	Case study 10.1 Risk assessment of the Clark River Superfund site 512		
	Case study 10.2 The Belle Park Island landfill site, Cataraqui Park, Kingston,		
	Ontario: Site-specific risk assessment 514		
	Case study 10.3 An environmental risk assessment for ditallow dimethyl		
10.7	ammonium chloride in the Netherlands 516		
10.7 10.8	References 518 Further reading 519		
10.8	Further reading 519		
11	Recovery, rehabilitation, and reclamation 520		
11.1	The context for site contamination and recovery 520		
11.2	Exposure and hazard 521		
11.3	Site use 522		
11.4	Technical approaches 523		
	11.4.1 Removal of the source of contamination 523		
	11.4.2 Restriction of site use 525		
	11.4.3 Reconstruction of the site 526		
	11.4.4 Removal of the contaminated material 526		
	11.4.5 On-site containment 527		
	11.4.6 In situ treatment 527		
11.5	Remedial action plans 528		
11.6	Responsibilities 529		
11.7	Routes for recovery 530		
11.8 11.9	Recent regulatory approaches to contaminated sites 532		
11.9	Case studies 535 Case study 11.1 The Thames Estuary: Compound pollution and		
	recovery 535		
	Case study 11.2 Lake Erie recovery 538		
	Case study 11.3 Deacidification trends in Clearwater Lake near Sudbury, Ontario, 1973–1992 540		
	Case study 11.4 The Inco Mine Tailings reclamation, Sudbury, Canada:		
	Ecosystem reconstruction 542		
	·		
	Case study 11.5 Clean-up of lead-contaminated sites: The Ontario urban clean-up experience 545		

xvi Contents

12	Regulatory toxicology 550
12.1	Introduction 550
12.2	Possible legal approaches to the regulation of toxic substances 551
12.3	Procedures and policies, including voluntary abatement 553
	12.3.1 Types of approach 553
	12.3.2 Objectives, standards, and related concepts 556
	12.3.3 Risk assessment in a regulatory context 561
	12.3.4 Voluntary systems of regulation 562
	12.3.5 International considerations: Treaties and informal agreements 565
12.4	Definitions 569
	12.4.1 Types of law 569
	12.4.2 The common law 570
	12.4.3 Some general legal terms 571
	12.4.4 Terms used in assessment and regulation of toxic substances 571
12.5	Federal statutes 587
	12.5.1 The United Kingdom and Europe 587
	12.5.2 Canada 587
	12.5.3 The United States of America 587
12.6	Case studies 588
	Case study 12.1 European convention on long-range transboundary air pollution 588
	Case study 12.2 Implementation of the Basel Convention: Turning back waste from Hungary 588
12.7	Questions 589
12.8	References 589
12.9	Further reading 590
13	An overall perspective, or where to from here? 591
13.1	Introduction 591
13.2	Updating risk assessment 592
	13.2.1 Expressing toxic action 592
	13.2.2 Bioavailability and uptake pathways as management tools 596
	13.2.3 Pathways/vectors of chemical exposure 597
13.3	Future paradigm of hazard assessment 600
13.4	The question of biological scale 600
13.5	Genotoxicity 602

- 13.6 Society and the environment 603
- 13.7 References 605

Glossary 608 Index 621