Tolerance to Environmental Contaminants

Edited by

Claude Amiard-Triquet
Philip S. Rainbow • Michèle Roméo

CRC Press
Taylor & Francis Group

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CRC Press
Taylor & Francis Group
Boca Raton London New York

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

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

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

International Standard Book Number: 978-1-4398-1770-4 (Hardback)

Library of Congress Cataloging-in-Publication Data

Tolerance to environmental contaminants / edited by Michèle Roméo, Philip S. Rainbow, Claude Amiard-Triquet.
p. cm. -- (Environmental and ecological risk assessment)
Includes bibliographical references and index.
ISBN 978-1-4398-1770-4 (hardcover : alk. paper)
1. Pollution--Environmental aspects. 2. Nature--Effect of human beings on. 3. Environmental toxicology. 4. Threshold limit values (Industrial toxicology) I. Roméo, Michèle. II. Rainbow, P. S. III. Amiard-Triquet, C.

QH545.A1T65 2011
571.9'5--dc22 2010044044

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and the CRC Press Web site at
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Preface

Tolerance may be defined as the ability of organisms to cope with stress, particularly the chemical stress resulting from the anthropogenic input of one or more of many different toxic contaminants into the environment. Tolerance has been described in many organisms from bacteria to fungi, from phytoplankton to terrestrial flowering plants, and from invertebrates like worms to vertebrates like fish and amphibians. There are two generally agreed methods by which organisms can become tolerant to a toxic contaminant. First, tolerance may be gained by physiological acclimation during the exposure of an individual organism to a sublethal bioavailability of the toxicant; this tolerance is not transferable to future generations. Second, tolerance may also be acquired as a consequence of genetic adaptation in populations exposed over generations to the toxic contaminant, through the action of natural selection on genetically based individual variation in resistance; this tolerance is transferable to future generations. This latter genetic adaptation may be lost in the absence of continuing exposure to the contaminant, again by natural selection, if, as appears to be usual, the genetically based tolerance has a metabolic cost that brings a selective disadvantage in the absence of contaminant. Indeed, the presence of a genetically tolerant population is direct evidence that the bioavailability of the toxic contaminant in the local environment is sufficient to be ecotoxicologically relevant.

So what? In fact, the gaining of tolerance, be it by physiological acclimation or genetic adaptation, can have great consequences for the local biodiversity, and hence the ecology and ecosystem functioning of many of the world's habitats. Contamination by toxicants can lead to decreased production of biological resources, including agricultural or fishery products, and the interruption of key ecological processes, such as decomposition and nutrient cycling. Tolerant species, particularly bacteria in sediments or primary producers like phytoplankton, may play key functional roles in ecosystems. Understanding the frequency of the occurrence of tolerance therefore has tremendous implications for the sustainability of biodiversity and ecosystem functioning. Metabolic processes involved in tolerance are energetically expensive, and thus may interfere with the allocation of energy in an organism, thereby governing the success of reproduction and growth. Reduction of the overall amount of genetic variation in populations exposed to a strong selective toxic pressure can result in increased sensitivity to new stresses in organisms otherwise tolerant to one source of stress. Thus, the adaptive benefit of being tolerant may have negative knock-on effects in the long term. Beyond effects on the crucial ecosystem functioning of the habitats around us, delivering the vital ecosystem services on which we depend (food, clean water, etc.), the acquisition of chemical tolerance may be a more direct source of concern to humans in that it allows the survival of harmful species (insecticide-resistant mosquitoes, antibiotic-resistant pathogenic bacteria) and the presence of highly contaminated links in food webs, including those leading to humans.

The book is an up-to-date compilation of the views of international experts on the phenomenon of tolerance of living organisms to toxic contaminants, usually of anthropogenic origin. The general principles governing the acquisition and biological consequences of tolerance, genetically or physiologically based, are examined at different levels of biological organisation, taxonomically from bacteria and archaea to flowering plants and vertebrates, and within organisms from molecular biology and biochemistry through physiology to whole organism, community, and ecosystem levels of organisation. Thus, part of the book is specifically devoted to mechanisms of defence involved in the acquisition of tolerance to different classes of environmental contaminants, taking into account the limits above which such mechanisms are overwhelmed. Another part of the book examines the ecological consequences of tolerance in terms of both positive (conservation of biodiversity in contaminated environments) and negative (physiological costs of tolerance with consequences on growth and reproduction, transfer of contaminants in the food webs) aspects. The final section of the book considers specific aspects of tolerance that can have major impacts for the environment and for society (tolerance in bacteria, plants, and insects).

Thus, this volume presents a state-of-the-art synthesis of the many aspects of the phenomenon of tolerance to environmental contaminants. Ecotoxicologists have made good progress in the understanding of the mechanisms that allow organisms to cope with pollutants in their environment, but the links with potential effects at higher levels of organisation need to be more strongly established. While the positive effects of tolerance at supra-organismal levels (population, community, ecosystem) for environment and health protection are often considered, the relative importance of any negative effects of tolerance are not typically fully assessed. The reviews offered in each chapter of this book contribute to the provision of tools to carry out relevant risk-benefit analyses in a more informed fashion. From an operational point of view, tolerance must be taken into account when biological responses (biochemical, behavioural, genetic biomarkers) are applied for environmental biomonitoring. Mechanisms of defence may be profitably used as biomarkers, revealing the exposure of organisms to contaminants but within limits that this book helps to define. The problem of over- versus underestimation of risk is also a core question for the development of toxicity reference values. The contaminant exposure history of populations, and whether the local biota have acquired tolerance or not, are clear confounding factors in the interpretation of bioassays that must be understood and taken into account. The reviews presented here can only assist ecotoxicologists to produce more informed and therefore more reliable risk assessments when assessing the ecotoxicological risks to life in any of the contaminated habitats that now surround us in our industrialised society.

We have deliberately sought to put together a synthesis that takes a multidisciplinary approach across contaminant types, habitats, organisms, biological levels of organisation, scientific disciplines, and approaches. The volume presents science at the frontier of research in the subject compiled by international experts from across the world. It is our aim that the book has relevance to environmental scientists and other stakeholders from government to the public. It should also prove invaluable to final-year undergraduate and master's students across the world, and contribute to graduate students in PhD programs, under a wide range of subject heads that include ecotoxicology, ecology, marine and freshwater biology, microbiology, environmental management, and environmental regulation. The book has great relevance, both to readers in developed countries seriously addressing problems of environmental contamination, including North America, Europe, Asia, Australia, and New Zealand, and to those in developing countries with industrial expansion and associated real and potential problems of environmental contamination (Central and South America, Eastern Europe, Africa, India, China, East and Southeast Asia). It is our hope that we have succeeded in our objectives, and that this book serves as an important taking-off point for further understanding of the very wide significance of the phenomenon of tolerance to environmental contaminants.

Claude Amiard-Triquet

Philip S. Rainbow

Michèle Roméo

About the Editors

Dr. Claude Amiard-Triquet is a Research Director in the CNRS (French National Research Center), based at the University of Nantes, France. She was awarded the degree of DSc in 1975, for her research in radioecology at the French Atomic Energy Commission. Dr. Amiard-Triquet's topics of research interest include metal ecotoxicology, biomarkers and, more recently, emerging contaminants (endocrine disruptors, nanoparticles). As the head of multi-disciplinary research programmes, she has managed research collaborations between specialists in organic and inorganic contaminants, and chemists and biologists involved in studies from the molecular to ecosystem levels, with a constant concern for complementarity between fundamental and applied research. Dr. Amiard-Triquet regularly acts as an expert for the assessment of scientific proposals (e.g., the European Framework Program for Research and Development, the International Foundation for Science, and the Sea Grant Administration, Oregon State), and is also in demand as a referee for a dozen or so international journals. She has authored or co-authored more than 170 research papers, and has authored 7 chapters in books. Dr. Amiard-Triquet has also co-authored one book, *La Radioécologie des Milieux Aquatiques* with J.C. Amiard, and co-edited two books, *L'Évaluation du Risque Écologique à l'Aide de Biomarqueurs* with J.C. Amiard and *Environmental Assessment of Estuarine Ecosystems: A Case Study* with P.S. Rainbow. She has given or contributed to more than 90 presentations at international meetings.

Professor Philip Rainbow is the Head of the Department of Zoology at the Natural History Museum, London, leading a staff of more than 100 working scientists in one of the premier museums of the world. He holds the degrees of PhD (1975) and DSc (1994) from the University of Wales. Philip Rainbow was appointed (1994) to a personal chair in the University of London, where he was Head of the School of Biological Sciences at Queen Mary (1995–1997) and is now a Visiting Professor. Professor Rainbow has been an editor of the *Journal of Zoology* and is on the editorial boards of *Environmental Pollution, Marine Environmental Research* and the Journal of the Marine Biological Association, UK. In 2002 Philip Rainbow was invited to give the Kenneth Mellanby Review Lecture by the journal *Environmental Pollution* at the Society of Environmental Toxicology and Chemistry annual meeting at Salt Lake City, Utah. He has more than 200 peer-reviewed publications including 5 co-edited books and two co-authored books. The first (*Biomonitoring of Trace Aquatic Contaminants*, with DJH Phillips) went to two editions. The second has recently been published (2008) by Cambridge University Press, co-authored with Professor Sam Luoma — *Metal Contamination in Aquatic Environments: Science and Lateral Management.* Philip Rainbow's recent research has focused on the factors affecting the bioavailability of trace metals to aquatic invertebrates from both solution and the diet, and the biodynamic modelling of trace metal bioaccumulation.

Michèle Roméo earned her PhD at the University of Nice–Sophia Antipolis in 1975 and has belonged to the French National Institute for Health and Medical Research (INSERM) since that time. She has been working as a researcher in the Marine Biological Station of Villefranche-sur-Mer and, since 1992, in the University of Nice–Sophia Antipolis and in the laboratory ROSE (Responses of Organisms to Environmental Stress), which became ECOMERS (Ecology of Marine Ecosystems and Response to Stress), where she is presently the head of the ecotoxicology team. Her general field of research concerns the response of aquatic organisms to chemical stress (metals and persistent organic pollutants) considered in terms of biomarkers (biomarkers of oxidative stress and of general damage leading to behavioural alterations). The chosen models are bivalve molluscs: mussels and clams and their larvae. Since 2004, research has evolved to the cloning of some genes coding for proteins used as biomarkers and to the use of a DNA microarray technique (genomics) and proteomics. These last two techniques allow measuring of the simultaneous expression of hundreds of genes (genomics) or proteins (proteomics) with very high sensitivity.

Roméo has been the head of the research project PNETOX with the French Ministry of the Ecology and Sustainable Development, and participated in another directed by Dr. Amiard-Triquet (University of Nantes, France). She has authored and coauthored around one hundred papers. She has participated in writing chapters for several books (for Elsevier, Lavoisier Tec and Doc, Taylor and Francis, and Humana Press). She is referee for more than ten journals. Her teaching activities concern ecotoxicology lectures in the master of applied biology of the University of Corsica and the master of environment management and sustainable development of the University of Nice–Sophia Antipolis.

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From Fundamental Biological Mechanisms to Ecological Consequences

Claude Amiard-Triquet

CONTENTS

1.1 INTRODUCTION

Tolerance may be defined as the ability of organisms to cope with stress, either natural, such as temperature changes, salinity variations, oxygen level fluctuations, and plant toxins, or chemical, depending on anthropogenic inputs of many different classes of contaminants into the environment. Resistance is frequently used in the scientific literature as a synonym for tolerance. Several authors have tried to clarify these terms (Lotts and Stewart 1995; Morgan et al. 2007). However, the definitions they proposed were strongly different, and none of them is currently generally adopted. In this book, most of the authors use the term *tolerance* in acceptance of the general definition above. However, the use of the term *resistance* has been preferred here by some authors, particularly those interested in the genetic basis of an organism's ability to survive in a contaminated environment. In these cases, the authors will clearly specify their choice of terminology in their chapters.

Tolerance has been described in many taxonomic groups exposed to toxicants at sublethal levels. Tolerance may be achieved by many biological processes responsible for physiological acclimation or genetic adaptation. Among tolerant species, some have a key role in ecosystems. Understanding the frequency of occurrence of tolerance has tremendous implications for the sustainability of biodiversity. Processes involved in tolerance are energetically expensive, and thus may interfere with the allocation of energy, thereby governing the success of reproduction and growth. Reduction of the overall amount of genetic variation in populations exposed to a strong selective pressure can result in increased sensitivity to new stresses in tolerant organisms. Thus, the adaptive benefit of being tolerant may have negative counterparts in the long term. On the other hand, tolerance may be a source of concern in that it allows the survival of harmful species (mosquitoes, pathogenic bacteria) and the presence of highly contaminated links in food webs. From an operational point of view, mechanisms involved in tolerance may be a source of biomarkers of exposure. On the other hand, the history of experimental populations, either tolerant or sensitive, may be a confounding factor in the interpretation of bioassays. This volume brings together reviews on these several aspects of the tolerance of organisms to pollutants, with the ultimate aim of understanding the ecological consequences of such tolerance.

1.2 HOW MAY TOLERANCE BE ASSESSED?

The existence of tolerance in a given species or in one or more of its constituent populations may be revealed in many different biological responses to stress, the common feature being that higher levels of stress are necessary to induce an impairment of response in tolerant organisms than in their nontolerant (more sensitive) counterparts. Comparative survival to acute toxicity doses has been used in a number of studies with various species and contaminants, such as in the case of metal exposure of the worm *Nereis diversicolor* (Ait Alla et al. 2006 and literature cited therein), and different fish species (Lotts and Stewart 1995; Hollis et al. 1999; Chowdhury et al. 2004). Differential survival has also been observed in organisms exposed to organic compounds, for instance, in the decapod crustacean *Palaemonetes pugio* exposed to fluoranthene (Harper-Arabie et al. 2004) or the European eel *Anguilla anguilla* exposed to pesticides (Peña-Llopis et al. 2001, 2003).

Less harsh and simplistic experimental approaches to detect the presence of tolerance are frequently preferred, based on sublethal doses of exposure. Under these conditions, the toxicological parameters of interest may be measured in the medium or long term and include longevity or functional impairments. For instance, in the crustacean *Daphnia magna* exposed to the herbicide molinate for two generations, Sánchez et al. (2004) have observed increased longevity and reproduction in specimens belonging to the second generation compared to their parents. In the fish species *Catostomus commersoni*, the fertilisation rate and the quality of gametes were