Emerging Topics in Ecotoxicology
Principles, Approaches and Perspectives

John E. Elliott
Christine A. Bishop
Christy A. Morrissey *Editors*

Wildlife Ecotoxicology

Forensic Approaches

Springer

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Volume 3

Series Editor

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John E. Elliott • Christine A. Bishop
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Editors

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Editors
John E. Elliott
Environment Canada
Science and Technology Branch
Pacific Wildlife Research Centre
5421 Robertson Road Delta
British Columbia, V4K 3N2, Canada
john.elliott@ec.gc.ca

Christy A. Morrissey
Department of Biology
University of Saskatchewan
112 Science Place, Saskatoon
Saskatchewan, S7N 5E2, Canada
christy.morrissey@usask.ca

Christine A. Bishop
Environment Canada
Science and Technology Branch
Pacific Wildlife Research Centre
5421 Robertson Road Delta
British Columbia, V4K 3N2, Canada
cab.bishop@ec.gc.ca

The chapters in this book reflect the views of the authors and not necessarily those of Environment Canada or other government agencies.

ISSN 1868-1344 e-ISSN 1868-1352
ISBN 978-0-387-89431-7 e-ISBN 978-0-387-89432-4
DOI 10.1007/978-0-387-89432-4
Springer New York Dordrecht Heidelberg London

Library of Congress Control Number: 2011930754

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Lindsay Oaks and Munir Virani examining a dead vulture in Pakistan, 2000

This book is dedicated to the memory of J. Lindsay Oaks, a friend and colleague to many, and a great wildlife forensic toxicologist.

Preface

Toxicology and forensics are very historical applications of science, going back even as far as the Roman Empire; and, forensic toxicology has been the subject of many a mystery thriller. Yet, forensic *ecotoxicology* as an applied science is quite new. In fact, the word *ecotoxicology* was not coined, as we know it today, as an applied branch of toxicological science until 1969 by R. Truhaut (see B. A. Rattner, 2009, History of wildlife toxicology, *Ecotoxicology* 18:773–783). And, as an applied field of ecology and conservation biology, forensic ecotoxicology and related policy applications have come into their own only in the last few decades, and its growth and development has been interesting to say the least. Most of the work described in this book, as well as other similar toxics work, is not forensics per se, but in essence it is forensic in nature. In our specialty, forensic ecotoxicology and policy applications today ideally follow a hypothesis-centered process that must lead to problem-solving and also builds strongly on known information from past work (see Fig. 1).

Using as an example, the DDE-induced (DDE is one of the recalcitrant, persistent DDT metabolites) eggshell-thinning phenomenon, a long series of investigations typically went along the following steps:

1. Describe the pattern, extent, and timing of the phenomenon of eggshell thinning.
2. Hypothesize and then determine causation and relationships to suspected environmental factors (DDE, PCBs, other POPs, stress, nutrition, etc.).
3. Identify relationships to individual and population health.
4. Test field hypotheses with controlled experiments and hypothesis-testing field designs.
5. Determine physiological and biochemical mechanisms of action.
6. Develop predictive ability through models.
7. Translate causation to policy and regulation (this seems to be the most difficult part).

None of that was easy, and just for DDE alone, the process took 25–30 years and many hundreds, more likely thousands, of scientific studies involving also thousands of scientists and technicians. Additional effects, causes, and complications still continue to be found as research has progressed (for example: A. N. Iwaniuk

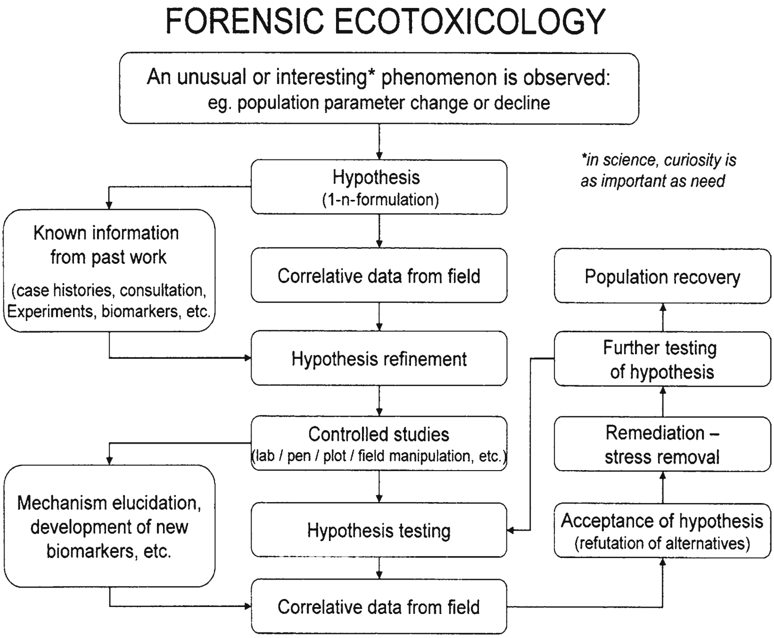

Fig. 1 Idealized, step-wise process in forensic ecotoxicology, in the case of conservation, leading to population, species, or system restoration, and based largely on scientific hypothesis-testing throughout (modified from D. W. Anderson, 1998, Evaluation and impact of multiple stressors on ecosystems: four classic case histories, *in* Cech, Wilson, and Crosby, eds., Multiple stresses in ecosystems, Lewis Publishers)

et al., 2006, The effects of environmental exposure to DDT on the brain of a songbird: Changes in structure associated with mating and song, *Behavioural Brain Research* 173:1–10) Nonetheless, there are some people trying to challenge the results and especially the subsequent policy/regulation results. And of course, the listed steps did not occur perfectly in the order listed, and often due to conservation urgency, regulation and policy are sometimes (but not very often) enacted early in the process, once causation has been reasonably well determined (a "better safe than sorry" or "precautionary principle" philosophy). R. W. Risebrough (1986, Pesticides and bird populations, *Current Ornithology* 3:397–427) briefly summarized the DDE/eggshell thinning phenomena, and I borrowed the seven steps described above from my class notes in *Wildlife Ecotoxicology* (UC Davis). I think this entire process represents one of the important early "forensic successes," although some may disagree.

Of course, a process such as that described above applied to many ecological circumstances, and many species, and involved multiple-stressors in almost every instance. The process is more clear and straightforward when applied to individual studies, such as described by C. J. Henny, L. J. Blus, E. J. Kolbe, and R. E. Fitzner (1985, Organophosphate insecticide [famphur] topically applied to cattle kills magpies and hawks, *Journal of Wildlife Management* 49:648–658). In contrast, just how complex such a diagnostic approach can become, has been nicely illustrated for Bald Eagles in the Great Lakes (D. A. Best et al., 2010, Productivity, embryo and eggshell characteristics, and contaminants in bald eagles from the Great Lakes, USA, 1986–2000, *Environmental Toxicology and Chemistry* 29:1581–1592), leading to scientifically sound conclusions and supporting policy and regulation.

Going back again to the persistent organic pollutants (POPs), I think also that DDT and its introduction during WWII, as a *secret* weapon nobody knew about at first, nonetheless, came to represent the beginnings of widespread concern for the individual and environmental effects of unwanted toxic compounds on ecosystems as well as their components (species and populations). This led to greater understanding of the causes for degradation of biodiversity (it started with exploitable fish and wildlife species), and then for finding solutions to hopefully alleviate these unwanted ecological factors. Today, it just seems like “common sense.” In the early days, it almost seemed like heresy to even question the use of pest-control chemicals, no matter how indiscriminate, because they were part of the “green revolution” and the need to feed a rapidly growing human population.

This is not to say that concern and fledgling approaches to (what we know now as) ecotoxicological approaches did not go back even as far as the early 1900s, especially involving compounds like rodenticides, predator-control agents, and chemically simple, inorganic poisonous compounds (see review by Rattner 2009; and R. L. Rudd and R. E. Genelly, 1956, *Pesticides: their use and toxicity in relation to wildlife*, CA Department of Fish and Game, *Game Bull.* 7). Rudd and Genelly (1956) provided a critical “early-step” in modern forensic ecotoxicology, but times were simpler then in that *spray-count* era. (I also recommend J. O. Keith, 1991, Historical perspectives, *in* T. J. Peterle, Wildlife toxicology, Van Nostrand Reinhold). In 1946, when DDT and then soon other POPs were introduced into general use by the overall public, society was *intoxicated*, not by chemicals, but by the euphoria that technology was going to solve all of mankind’s problems (albeit, many of them self-inflicted). But even as early as 1946 and 1951, *The Journal of Wildlife Management* published a series of papers (*JWM* Vols. 10 and 15) on the potential effects of chemicals applied directly to the open environment. Then, of course, came Rachel Carson (1962, *Silent Spring*, Houghton-Mifflin, Boston) and Robert L. Rudd (1964, *Pesticides and the living landscape*, University of Wisconsin Press, Madison), which really got us all started. As surely as most biologists are the “intellectual children” of Darwin, ecotoxicologists today are, in essence, the intellectual children of Rachel Carson and Robert Rudd, too.

In forensic ecotoxicology, I think, the field has also evolved through at least three scientific “generations” of scientists in about 65 years of existence. Most people in our field first started out as non-toxicological ecologists or conservationists, people out there studying ecological relationships, demography, behavior, applied ecology, wildlife management, or whatever. Yes, some were physiological ecologists whose field of study, especially involving secondary plant compounds, would eventually lead directly into ecotoxicology. And, some were traditional toxicologists at first. Most ecologists at the time were faced with the conundrum of describing and trying to alleviate newly discovered, man-induced toxicological problems – not that natural systems are not evolutionarily involved in their own ecotoxicological challenges, resulting in coevolved ecological systems, and biochemical pathways that could involve evolutionarily unique toxicants to some degree (see the early classic, *Herbivores: their interaction with secondary plant compounds*, edited by G. A. Rosenthal and D. H. Janzen, 1979, Academic Press). But, most of the "first-generation" scientists were ecologists and conservationists who were led into ecotoxicology by the circumstances. Something was "messing up" their ecological studies, and they had to find out what it was. So ecologists had to do some sleuthing, and that is where forensics first came in: they had to confirm their hypotheses as best they could through the scientific, forensic method. The very resources that these ecologists were studying and trying to understand were "going down." By the way, habitat loss is still the most significant factor resulting in the loss of biodiversity today – but after all, pollution by toxicants is simply one of the human-related factors that is degrading the quality of habitats.

I scanned through J. J. Hickey's book (1965, *Peregrine Falcon populations: their biology and decline*, University of Wisconsin Press) and that of T. J. Cade and W. Burnham (2003, *Return of the Peregrine: a North American saga of tenacity and teamwork*, The Peregrine Fund, Boise) and pulled the following notable names related to the forensics and regulation centered about just *one* bird species, the Peregrine Falcon. Similar stories were being told around all kinds of species of wildlife, such as the Osprey, Bald Eagle, Brown Pelican, White Pelican, Black-crowned Night Heron and other ardeids, various waterfowl and game birds, and many others. This "peregrine-list" reads like a "who's who" of ecologically oriented pioneers in wildlife forensic ecotoxicology (just a few examples are given): Tom J. Cade, Joseph J. Hickey, Ian Newton, David Peakall, Ian Prestt, Derek A. Ratcliffe, R. W. Risebrough, L. F. Stickel, W. H. Stickel, and many others. This list could go on for pages. As a graduate student invited to attend the meeting, Hickey had setup that resulted in Hickey (1965), cited above, one had to have been sufficiently impressed with such a field of experts and it became apparent to me that there was no other more exciting field to devote one's professional life! Of course, similar "stories" like this were developing all over the world with diverse species and ecosystems, and my bias is obviously North American and for wildlife in particular.

The second generation still comprised some taxonomic or subfield specialists, but now included people who obtained additional specialized training in and emphasizing toxicology and physiological ecology. Those were mostly graduate students and/or mentees of "first-generation" forensic ecotoxicologists, such as mentioned above. Then, the current generation seems to be quite a mix of organism plus discipline-oriented field and laboratory specialists, but most have primarily a strong background in the ecological, chemical, and physical sciences and might now be called "true" ecotoxicological specialists, much as we now have "conservation biologists" and "restoration ecologists." Many have developed ancillary expertise in some taxonomic group or subfield, such as reptiles and amphibians, systems ecology, demography, and other specialties. These ecotoxicologists importantly apply ecology, chemistry, physics, biochemistry and molecular biology, physiology, systems ecology, population biology, modeling, statistics, and other disciplines to their specialties; and, they use the forensic approach to apply their derived knowledge often to mathematical and statistical modeling and then to policy and regulation.

This book is a stimulating and quite comprehensive compendium of many of the currently relevant ecotoxicological problems and their histories and their solutions, written by many of today's leaders in the field. Yet, the work itself continues-on, so much in fact, that this book could easily become the start of an important series. I have told my students in that university class I mentioned above (Wildlife Ecotoxicology) that it is the ultimate objective of ecotoxicologists to work ourselves out of our jobs. I am afraid that is a long time off.

Davis, California, USA Daniel W. Anderson

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Reviewers

Thomas Augspurger United States Fish and Wildlife Service, Raleigh, NC, USA

Alain Baril Environment Canada, Science and Technology Branch, National Wildlife Research Centre, Ottawa, ON, Canada

Gian Basili St. Johns River Water Management District, Palatka, FL, USA

Anne Fairbrother Exponent Engineering and Scientific Consultants, Bellevue, WA, USA

Kim Fernie Environment Canada, Science and Technology Branch, Canada Centre for Inland Waters, Burlington, ON, Canada

Michael Gilbertson Guelph, ON, Canada

Anders Goksøyr Department of Biology, University of Bergen, Bergen, Norway

Jay Harrington United States Fish and Wildlife Service, Jacksonville, FL, USA

Megan Harris Lorax Consulting, Charlottetown, PEI, Canada

William Hopkins Department of Fisheries and Wildlife Sciences, Virginia Tech, Blacksburg, VA, USA

Peter Kille School of Biosciences, Cardiff University, Cardiff, UK

Pamela Martin Environment Canada, Science and Technology Branch, Canada Centre for Inland Waters, Burlington, ON, Canada

Rafael Mateo Instituto de Investigación en Recursos Cinegéticos, Ciudad Real, Spain

Miguel Mora Department of Wildlife and Fisheries Sciences, Texas A&M University, College Station, TX, USA

Barnett Rattner United States Geological Survey, Patuxent Wildlife Research Center, Beltsville, MD, USA

Peter Ross Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, BC, Canada

Judit Smits Faculty of Veterinary Medicine, University of Calgary, Calgary, AB, Canada

Donald Tillitt United States Geological Survey, Columbia Environmental Research Center, Columbia, MO, USA

NicoVan den Brink Alterra Research, Wageningen, Netherlands

Shari Weech Minnow Consulting, Victoria, BC, Canada

Daniel Welsh United States Fish and Wildlife Service, Sacramento, CA, USA

Lisa Williams United States Fish and Wildlife Service, East Lansing, MI, USA

David Hoffman United States Geological Survey, Patuxent Wildlife Research Center, Beltsville, MD, USA

Don Sparling Cooperative Wildlife Research Laboratory, Southern Illinois University, Carbondale, IL, USA

Michelle Boone Department of Zoology, Miami University, Oxford, OH, USA

Alexandra van Geel Industrial Economics, Incorporated, Cambridge, MA, USA

Sherry Krest United States Fish and Wildlife Service, Chesapeake Bay Field Office, Annapolis, MD, USA

Christopher Rowe University of Maryland Center for Environmental Science, Solomons, MD, USA

Contributors

Christine A. Bishop Environment Canada, Science and Technology Branch, Pacific Wildlife Research Centre, Delta, BC, V4K 3N2, Canada
cab.bishop@ec.gc.ca

Roxanne Conrow St. Johns River Water Management District, Palatka, FL, 32178, USA
rconrow@sjrwmd.com

Michael F. Coveney St. Johns River Water Management District, Palatka, FL, 32178, USA
mcoveney@sjrwmd.com

Christine M. Custer US Geological Survey, Upper Midwest Environmental Sciences Center, 2630 Fanta Reed Rd., La Crosse, WI, 54603, USA
ccuster@usgs.gov

Jeffrey T. Edson Edson Ecosystems LLC, Boulder, CO, 80302, USA
jeffedson@comcast.net

John E. Elliott Environment Canada, Science and Technology Branch, Pacific Wildlife Research Centre, Delta, BC, V4K 3N2, Canada
John.elliott@ec.gc.ca

Amy L. Filby School of Biosciences, Hatherly Laboratories, University of Exeter, Prince of Wales Road, Exeter, Devon, EX4 4PS, UK
a.l.filby@exeter.ac.uk

Timothy S. Gross University of Florida, Environmental Resource Consultants, Gainesville, FL, 32611, USA
tsgross@cox.ne

Tyrone B. Hayes Department of Integrative Biology, University of California, Berkeley, CA, 94720, USA
tyrone@berkeley.edu

James V. Holmes Stratus Consulting Inc., Boulder, CO, 80302, USA
jholmes@stratusconsulting.com

Tim Lougheed Science Writer, Ottawa, ON, K1K 2A5, Canada
Stormchild@sympatico.ca

Edgar F. Lowe St. Johns River Water Management District, P.O. Box 1429, Palatka, FL, 32178, USA
elowe@sjrwmd.com

Greg Masson Division of Environmental Quality, United States Fish and Wildlife Service, 4401N. Fairfore, Room 810k, Arlington, VA, 22203, USA
Greg_Masson@fws.gov

Christy A. Morrissey Department of Biology, University of Saskatchewan, 112 Science Place, Saskatoon, SK, S7N 5E2, Canada
christy.morrissey@usask.ca

J. Lindsay Oaks Department of Veterinary Microbiology and Pathology, College of Veterinary Medicine, Washington State University, Box 647040, Pullman, WA, 99164–7040, USA
loaks@vetmed.wsu.edu

Harry M. Ohlendorf CH2M Hill, Sacramento, CA, 95833-2937, USA
Harry.Ohlendorf@CH2M.com

H. Franklin Percival US Geological Survey, Florida Cooperative Fish and Wildlife Research Unit, University of Florida, P.O. Box 110485, Gainesville, FL, 32611, USA
percivaf@ufl.edu

R. Heath Rauschenberger US Fish and Wildlife Service, North Florida Ecological Services Field Office, 7915 Bay Meadows Way, Suite 200, Jacksonville, FL, 32256, USA
Heath_Rauschenberger@fws.gov

Rick A. Relyea Department of Biological Sciences, University of Pittsburgh, Pittsburgh, PA, 15260, USA
relyea@pitt.edu

Kenneth G. Rice US Geological Survey, Southeast Ecological Science Center, 7920 NW 71 Street, Gainesville, FL, 32653-3701, USA
krice@usgs.gov

A.M. Scheuhammer Environment Canada, National Wildlife Research Centre, Carleton University, Ottawa, ON, K1A 0H3, Canada
Tony.Scheuhammer@ec.gc.ca

Vernon G. Thomas Department of Integrative Biology, University of Guelph, Guelph, ON, N1G 2W1, Canada
VThomas@uoguelph.ca

Charles R. Tyler School of Biosciences, Hatherly Laboratories, University of Exeter, Prince of Wales Road, Exeter, Devon, EX4 4PS, UK
c.r.tyler@exeter.ac.uk

Robert Vernon Agriculture and Agri-foods Canada, Agassiz, BC, V0M 1A0, Canada
vernonbs@agr.gc.ca

Richard T. Watson The Peregrine Fund, Boise, ID, 83709, USA
rwatson@peregrinefund.org

Laurie K. Wilson Canadian Wildlife Service, Pacific Wildlife Research Centre, Environment Canada, Delta, BC, V4K 3N2, Canada
laurie.wilson@ec.gc.ca

Allan R. Woodward Fish and Wildlife Research Institute, Florida Fish and Wildlife Conservation Commission, Gainesville, FL, 32601, USA
allan.woodward@myfwc.com

Chapter 1
Wildlife Ecotoxicology: Forensic Approaches

John E. Elliott, Christine A. Bishop, and Christy A. Morrissey

Abstract This introductory chapter provides an overview of the book and some discussion of the emergent themes. The nature of forensic ecotoxicology is considered, and a definition proposed. We reflect on the experiences of some authors in trying to translate scientific evidence of toxicant effects into regulatory or non-regulatory action. We further examine the problem of bias in data interpretation, and consider some of the dispute resolution processes discussed by the various authors.

Introduction

The field of wildlife toxicology emerged in response to the use, misuse, and ecological mishaps associated with the explosion of commercial chemical use in the twentieth century (Rattner 2009). Many of the earliest studies, and those that really define the field, and in a sense its mythology, were exercises in detective or forensic science. Numerous publications, including chapters in this book, cite "Silent Spring" (Carson 1962) and its influence on widening the awareness of the hazards of environmental contaminants. Yet even as Carson was finishing and publishing her book, one of the most interesting and compelling scientific narratives in wildlife ecotoxicology was just unfolding. In the spring of 1961, Derek Ratcliffe, a biologist with the British Trust for Ornithology, organized a survey of peregrine falcon (*Falco peregrinus*) populations in Great Britain. Ironically, the survey was commissioned in response to calls by homing pigeon enthusiasts to remove legal protection for the falcon. It was alleged that peregrine populations were increasing and killing many of their homers. However, by the end of the survey in the summer of 1961, it was apparent

J.E. Elliott (✉)
Environment Canada, Science and Technology Branch,
Pacific Wildlife Research Centre, Delta, BC, V4K 3N2, Canada
e-mail: John.elliott@ec.gc.ca

J.E. Elliott et al. (eds.), *Wildlife Ecotoxicology: Forensic Approaches*,
Emerging Topics in Ecotoxicology 3, DOI 10.1007/978-0-387-89432-4_1,

that British peregrine populations were in a state of serious decline or even a crash. Ratcliffe describes the ensuing investigations as follows:

> The search for causes had begun in 1961 when the first serious symptoms of decline became clear. It was case of detective work with few clues.
>
> Ratcliffe 1980, page 306

When Ratcliffe began his detective work and search for clues, he had no operating paradigm of contaminant effects on wildlife and limited supporting forensics, such as analytical chemical methods. There were no published accounts linking agricultural or industrial chemicals and declines in wildlife population size or occurrences. Peregrines in particular were associated with wilder spaces, certainly not with agricultural or urban activities. Fifty years later, we live in a world where the awareness and knowledge of the spread and potential hazard of toxic chemicals is one of the acknowledged "risks of modernity" (Beck 1992). The field of environmental toxicology and chemistry now constitutes a virtual industry employing thousands of toxicologists, ecologists, chemists, veterinarians, hydrologists, soil scientists, statisticians, risk assessors, regulators, other specialists, and many students. We believe that group is the primary audience for this book along with a broader readership of people interested in environmental pollution problems, and the human element behind the work.

The book is about investigating the cause and effect relationships between environmental toxicants and vertebrate wildlife populations. We have used a case study format. Many of the cases began as a conservation problem in which a detective-like or forensic investigation was initiated to determine the cause of the health effects in the animals. Some of the studies are more chemical based. They examine the evidence for effects of a given compound or element on a specific taxonomic group, which is how most environmental toxicology now proceeds. Researchers conduct dose response studies in the laboratory or collect environmental samples and quantify the presence of a chemical. That may lead to an assessment of exposure, hazard, or risk. Alternately there may be an attempt to look for correlative evidence of effects in the field using biomarkers or ecological techniques. In essence, it is the reverse of traditional scientific approach; the putative cause is known and the search is for an effect.

Most of the significant advances in the wildlife ecotoxicology, as in other fields, occur when biologists or other scientists observe unusual phenomena in nature, and wonder about the cause. Such phenomena have included declining populations or unusual patterns of deformed offspring, whether as overt morphologies or more subtle physiological features. Whatever approach was taken, the authors of each chapter have first defined the problem and proceeded to describe the ensuing scientific investigations. In each case they have gone on to depict the broader regulatory or remedial aspects of the problem, and in some cases to expand on their personal experiences.

The concept for the book arose from a session "Wildlife Toxicology: Forensic Approaches" at the Society of Environmental Toxicology and Chemistry (SETAC) World Congress held in November of 2004 in Portland, Oregon. Definitions of the word, forensic, are varying. Forensic science involves the application of scientific disciplines to resolving medical and legal problems. Forensic toxicology is an important part of that field and focuses on identifying injury or death caused by poisoning. More recently the field of environmental forensics has emerged, which has its own society and journal, and focuses mainly on applications of environmental chemistry and associated disciplines to identifying sources of contamination. Forensic toxicologists, who largely work with human cases, define their work as the application of toxicology to the purposes of the law (e.g. Cravey and Baselt 1981). Thus for forensic ecotoxicology, we could extend that definition to legal applications of ecotoxicology. Investigations of an "eco" nature normally would not involve criminal law, but rather regulatory or non-regulatory efforts to attenuate the impact of pollutants and contaminants on organisms, or ideally on ecosystems, both small and large. We think a definition of forensic which invokes the apparent original connotation of the word might be more appropriate here. It applies to investigations which invoke public debate or discussion: "of, relating to, or used in public debate or argument" (Princeton University 2010). Thus, forensic ecotoxicology could be defined as: "the investigation of causal linkages between source(s) and presence of a chemical or mixture, and biological effects, with the goal of reducing impact via regulatory or non-regulatory interventions".

The examples presented here are selective, and were based on developing a list of possible subjects and issues, then inviting people to write those stories including their experiences in doing the research and the regulatory process. There are many more topics and examples that could have been described. We have tried to provide an overview covering a variety of classes of compounds, sources, types of forensic investigations, and regulatory aspects. The spatial scope of the issues varies in many of the examples, but those localized cases are useful in describing what worked and did not work, and can provide guidance and understanding for related problems elsewhere.

Two themes emerge repeatedly from these case studies. We see that, despite all the advances in knowledge and technology since Ratcliffe's day, establishing cause and effect in the field, remains a daunting challenge. It is worth noting that in the wildlife toxicology field, the most successful examples from a regulatory point of view involved "simple lethality". Among the chapters, those include organochlorine pesticides and waterbirds, lead shot and pesticides in birds of prey, and diclofenac and vultures. To that list we could add the classic studies by Ian Newton and colleagues, not included here but often cited, on the impact of dieldrin and other cyclodienes on raptors in Britain and on bats and other species elsewhere (Newton et al. 1992; Blus 2003). In most of those cases, the species of concern were long lived and K-selected for which survival of breeding adults was the crucial demographic parameter. Such studies commonly took place over extended temporal and spatial scales often involving a number of collaborators as well as a broader network of volunteers and naturalists, or they were highly focused local studies of marked populations also carried out over longer time periods. When the evidence is in the form of more subtle physiological or reproductive endpoints, establishing cause and effect linkages, particularly at the population level, is even more difficult. In a number of the chapters here, the authors describe attempts to make those connections, including the three case studies on reptiles, and amphibians and fish. Other studies have relied primarily on a risk assessment approach, establishing only exposure in the field. For many wildlife top predators, practical and ethical constraints preclude anything but a risk assessment strategy.

The second theme emerging is the challenge of trying to mitigate the identified threat to wildlife, whether through regulation, remediation, or other means. It is encouraging to see how many were successful in bringing about positive change, despite the many obstacles encountered. Under the broader definition of forensics, and thus invoking the social and regulatory implications of the ecotoxicological science, it is interesting to compare that context in Ratcliffe's time with that of today. Ratcliffe describes the response of various agencies and institutions at the time to the evidence accumulating against the organochlorine insecticides:

> It was not an easy time. Some of us had our first experience of scientists playing politics, and we learned how vicious a vested interest under pressure can be. It was clearly in many people's interests, one way or another, to believe that the wildlife conservationists were talking nonsense, and they left no stone unturned in trying to establish this. Every new paper with more evidence was dissected and gone over with a fine tooth comb, to see what flaws could be found…Tactics at times resembled those of a courtroom rather than the scientific debating chamber. There were tedious arguments about the nature of proof, and the validity of circumstantial evidence. The attempts to deny effects of pesticides on wild raptors descended now and then into obscurantism.
>
> Ratcliffe 1980, page 331

Given the financial implications, some opposition from affected parties to new chemical regulations or cleanup actions would be expected. Corporations are formed to make money, thus whether it is loss of market share from banning of a pesticide or other product, upgrades in pollution control technology, clean up and restoration of a contaminated site, financial resources have to be diverted to the problem, and so away from profit or other investment needs. Differences in resource access and use are the source of most human conflicts. Such conflicts sparked the original conservation activism in North America, and eventually the environmental movement and laws of the 1970s such as the U.S. Endangered Species Act (McCormick 1989). Resource conflicts have lead to widespread civil disobedience and even violence (Marr-Liang and Severson-Baker 1999; Amster 2006), and in the extreme can result in societal breakdown and civil war (Le Billon 2001), sometimes leading to further environmental degradation (Dudley et al. 2002).

As dispute resolution mechanisms, many jurisdictions employ science advisory boards or ecological risk panels, composed of a range of scientists and other specialists from opposing perspectives, usually industry, government, and academia (EPA 2002). Such bodies are charged with examining the data and determining whether there is evidence, for example, for a commercial chemical such as a pesticide to cause significant damage to biota.

A number of the chapters in this book recount the authors' experiences with such decision making tribunals. Opposing sides will differ on not only the interpretation of the pertinent data, but also on study design and methods. As scientists, at least initially we tend to harbor myths about objectivity and simplicity and purity of truth seeking and scientific endeavor (Lackey 2002). In reality, science has always been about testing competing hypotheses and variations in interpretation of results. The debates often become even more contentious when they widen into the social and political realms. Both scientists and the broader society continually debate questions of evolution, nature versus nurture, theories of cosmology and most recently climate change. Fundamental to quality control and "resolving" scientific arguments is the need for repeatability of results and the peer-review process. Even repeatability of experiments can get bogged down, however, in the complexities of experimental design. It has even been asserted that some governments have legislated the requirement for quality assurance procedures so stringent as to prevent publication of data that is critical of important commercial interests. That topic is discussed in the chapter by Lougheed and by others in this book. Even the peer review process, which like democracy is one of those "worst imaginable but better than the rest" systems, has recently been questioned (Brahic 2010; New Scientist 2010; Sieber 2006; Smith 2006).

Data interpretation is unavoidably a function of perspective, which is influenced by background, education and experience, but can also be affected by biases of the financial and career nature. Accepting some degree of bias as unavoidable, the goal is to avoid conflicts of interest that are primarily of a financial nature (e.g., Barrow and Conrad 2006). It is a delicate topic, but such distinctions can become murky, when we consider that most industry advocates are paid consultants, whose continued employment depends in part on their success in defending the interests of their clients. Similarly, careers can be advanced and, therefore, salaries increased for government scientists whose findings provide the evidence needed for regulatory decisions. The academic community is not isolated from the problem of conflicts of interest. Regardless of the consideration that many academics also act as paid consultants to industry or government, university based researchers can also see their funding and careers advanced if they work on high profile conservation issues. Thus, there is the potential of direct gain from over- or under-stating the implications of their findings.

There is some recent literature examining the problems associated with interpretation of contentious data and how to deal with bias and conflict of interest (Rosenstock 2002; Hayes 2004; Barrow and Conrad 2006; Huss et al. 2007; Rohr and McCoy 2010). Recommendations include the need for: complete and transparent disclosure of funding sources in all reports, presentations and publications; balanced makeup of review boards and panels; improved education of both professionals and the broader public about environmental ethics and conflicts of interest.

The implications of the choices made in environmental policy and regulatory decisions cannot be overstated. Such decisions on use of pesticides or industrial chemicals, on large commercial and industrial land developments, and forestry, agricultural and fishery habitat stewardship clearly have profound consequences. The outcomes can lead, on the one hand, to excessive environmental damage and loss of biodiversity and ecological services. On the other hand, the decision may result in unwarranted restrictions on resource development or protection leading to economic hardship or even poverty in local communities. That can in turn contribute to even greater losses of biodiversity (Bradshaw et al. 2009).

As some authors recount here, opposition to change or action can also come within government agencies. It can stem from intervention at the political level or even from corruption. However, new actions can be stifled by simple bureaucratic inertia, and the tendency for large hierarchical organizations to suppress scientific dialog and in particular, dissenting views (Bella 1992, 2004).

Resolution of environmental disputes sometimes has to move beyond the scientific panel or board to be settled by a judicial process even by civil litigation. For example, the USA has the Natural Resource Damage Assessment (NRDA) process to assess injury and economic costs from oil and chemical contamination (Ofiara 2002). Among the cases discussed here, a number had to resort to litigation such as those described by Christine Custer, the chapter by Edson et al. on the Rocky Mountain Arsenal, and the original ban on lead shot for waterfowl hunting in the US, discussed in the chapter by Thomas and Scheuhammer.

However, it also emerges how often the dialogs and eventual solutions were devised in more open and conciliatory ways, with efforts by both parties to devise a consensus solution. Ratcliffe and other colleagues in Britain and across the Atlantic in North America began to make a case against broad scale organochlorine pesticide usage in the early 1960s. It took almost a decade for the first significant regulatory restrictions. That contrasts with the experience 40 years later of the multinational team investigating the crashing Asian vulture populations. Lindsay Oaks and colleagues faced the same skepticism that a chemical, in that case a veterinarian drug, could in any way be poisoning vultures on a continental scale and pushing them to the brink of extinction. Until they completed their work in Pakistan, most of the experts involved in studying the problem were convinced that it must have been a disease or some other undefined factor. But, once faced with the carefully compiled evidence against diclofenac, the governments and industry in Pakistan and India responded relatively quickly to try and address the problem by banning and restricting use of the drug. The question now is whether identification of the problem and attempts to address came quickly enough and are adequate and enforceable. Whether all or any of the vulture populations recover like the peregrines will only be apparent with time.

The first chapters in this book deal mainly with contamination by persistent organic pollutants, the so-called legacy 'POP's. There has been a great deal of success in regulating these compounds, which now proceeds under the Stockholm Convention on Persistent Organic Pollutants. We considered possible chapters on the newer POPs issues, particularly the brominated flame retardants and perfluorinated compounds. However, evidence for a potential problem from those compounds has come primarily from monitoring of temporal and spatial patterns of contamination, rather than evidence of effects in the field (Hites 2004). The process has also been broad and diffused without a defining focal narrative. How the perfluorinated contaminant issue was identified and addressed by John Giesy and colleagues is covered briefly in the chapter by Tim Lougheed, which discusses the social and political context of regulating environmental contaminants.

On the persistent organic pollutant theme the opening chapter examines dioxin pollution from the forest industry. That was problem for many jurisdictions, and is detailed here in the context of first reports of significant wildlife exposure and effects in waterbirds and other wildlife on the Pacific coast of Canada. The main ongoing problem with POPs is the legacy of contaminated sites from manufacturing, waste disposal or intensive use. As a consequence of the degree of economic and industrial development, the US likely has among the largest inventory of such sites, and probably the best characterized and addressed (http://www.epa.gov/superfund/index.htm). Many past and ongoing investigations in the US have been conducted under the Natural Resource Damage Assessment (NRDA) process. Four chapters address issues associated with that legacy contamination. The chapter by Chris Custer takes a species approach rather than a problem based approach demonstrating how a range of contaminant sources and types can be addressed using a versatile indicator species, the tree swallow (*Tachycineta bicolor*), at NRDA sites across the United States. From there, the focus narrows to an NRDA case study of the Rocky Mountain Arsenal, which we selected because of the important role that wildlife poisoning had on identifying and defining the extent of the contamination at that site. We follow that with two forensic studies about South Florida's Lake Apopka. One involves the efforts by Alan Woodward and others to understand the causes of reproductive and developmental problems in alligators (*Alligator mississippiensis*). Apart from the complexity of establishing cause and effect in the wild, there emerges the need for baseline ecological monitoring to provide some understanding of what is "normal" in a wildlife population. The companion chapter by Roxanne Conrow and colleagues describes the efforts to rehabilitate Lake Apopka. It focuses on acute mortality of waterbirds from OC pesticides, an unexpected consequence of efforts to restore the ecological integrity of the lake following decades of anthropogenic insults.

The next series of chapters continues the pesticide theme but shifts to studies of current use compounds. They start with two terrestrial studies of birds. The first is in an agricultural setting and describes efforts to understand how, over a period of a decade, top predators were poisoned from a number of supposedly non-accumulative and non-persistent organophosphorus and carbamate insecticides. The second is in a forestry setting and addresses an unusual situation of a compound, monosodium methane arsenate (MSMA), originally deployed as herbicide, but later developed as a systemic insecticide to suppress bark beetles (*Dendroctonus* spp.) in an epidemic outbreak. It is, to our knowledge, the only ecotoxicological study of woodpeckers (*Picoides* spp.). They are followed by investigations of two of the major herbicides on a global scale, and the experiences of Rick Relyea and Tyrone Hayes, respectively, dealing with the awakening reality for many that impacts on amphibians were overlooked when assessing the risks of these chemicals in the environment. The experiences of those two scientists, as recounted in their chapters, appear a lot more like those of Derek Ratcliffe than some of the more conciliatory approaches taken by industry as described in other chapters.

Two classic problems in wildlife toxicology are the focus of the chapters by Harry Ohlendorf on selenium and by Vernon Thomas and Tony Scheuhammer on continuing issues caused by poisoning from lead projectiles. Ohlendorf's is a classic case study using typical forensic approaches, which started with the finding of deformed ducks in areas subject to runoff from agricultural drainage water. Most readers would already have some awareness and, therefore, would not be surprised at the challenges associated with resolving water related issues in California. The chapter by Thomas and Scheuhammer addresses the ongoing problem of lead, and whether we should be continuing to use lead projectiles when safe and affordable options are available.

The final case studies examined two very different aspects of environmental contamination by pharmaceutical compounds. Great progress has been made in reducing eutrophication and industrial pollution resulting in recovery on lakes and rivers in many countries. However, with growing human populations and increasing complexity and variety of pharmaceutical and other commercial chemicals, we have seen the emergence of new sorts of challenges such as those chronicled by Charles Tyler and Amy Filby on developmental abnormalities in fish from British rivers. The second is the story of secondary poisoning of vultures through the use of a veterinary drug widely used to treat joint and muscle problems in cattle and other livestock. It is a compelling example of Beck's risks of modernity. The plight of the vultures poignantly demonstrates that despite our new awareness of the risks of using drugs and other commercial chemicals, and all the testing and safeguards that we can put in place, there will likely be other such far-reaching and profound consequences from the deployment of chemical technologies.

The final chapter by Tim Lougheed examines the broader context of environmental contamination, and compares the political and regulatory approaches adopted in various countries.

The authors of these 14 case studies have described the science behind each topic, the relations to regulatory actions and the human stories behind the science. They have each tried to make the topics accessible to a broader audience. There are also some insights from the various personal experiences on how the systems worked and how attempts were made, successfully or not, to make changes to improve conditions for the affected wildlife. We hope that the readers find the chapters useful to their own research or related activities, and can appreciate the magnitude of work involved from identifying a contaminant-related problem to achieving a resolution.

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