ECOLOGICAL TOXICOLOGY RESEARCH

EFFECTS OF HEAVY METAL AND ORGANOHALOGEN COMPOUNDS

Ecological Toxicology Research

Effects of Heavy Metal and Organohalogen Compounds

Proceedings of a NATO Science Committee Conference

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Foreword

The Conference on the Ecotoxicity of Heavy Metals and Organohalogen Compounds was held under the auspices of the NATO Science Committee as part of its continuing effort to promote the useful progress of science through international cooperation.

Science Committee Conferences are deliberately designed to focus attention on unsolved problems, with invited participants providing a variety of complementary expertise. Through intensive group discussion they seek to reach a consensus on assessments and recommendations for future research emphases, which it is hoped will be of value to the larger scientific community. The subjects treated in previous Conferences have been as varied as science itself—e.g., computer software, chemical catalysis, oceanography, and materials and energy research.

This volume presents an account of a meeting which evolved from studies within the Science Committee's advisory panel on Eco-Sciences. Environmental monitoring of toxic substances from industrial and agricultural sources is producing a growing volume of data on the quantities of such substances in terrestrial and aquatic milieus. Before this information can be used to assess biological effects, knowledge is required of the chemical form of the pollutants, the mechanisms by which they enter and move through organisms, their concomitant transformations, the nature of the toxic reactions within tissues, and the way in which the physiology and behavior of individuals is affected.

The meeting brought together a number of specialists who critically evaluated their present knowledge and identified those areas of research in which accelerated progress seemed particularly critical.

Some forty-seven papers, either in the form of reprints or specially written reviews, were contributed by the participants for advance circulation. The availability of this material precluded the need for lengthy introductory presentations and permitted rapid initiation of spirited interdisciplinary discussions. All

participants gave generously and enthusiastically of their wisdom and knowledge during the week of the meeting, and we extend to them our deep gratitude.

Special thanks go to Dr. A. McIntyre and Dr. C. Mills, for their diligent efforts as Chairman and Co-Chairman of the meeting, to their colleagues on the Organizing Committee, Prof. S. Dalgaard-Mikkelsen, Dr. R. W. Durie, Dr. E. D. Goldberg, Prof. D. H. Remmer, and Prof. R. Truhaut, for their wise counsel, and to the leaders and recorders of the working groups as listed, for their indispensable dedication.

Grateful acknowledgment is also made of the considerable assistance provided to this Conference by Environment Canada. Its concrete and spiritual support contributed significantly to any success which has been achieved.

Eugene G. Kovach

Deputy Assistant Secretary General for Scientific Affairs

Preface

The well-documented increase in pollution from a wide variety of sources presents a potential threat to living organisms, and the term "ecotoxicology" is useful in referring to the study of the distribution and effects of toxic substances in major organic assemblages, from the habitats of mountain ranges to the communities of oceanic abysses. In attempting to assess such effects the ecologist is faced with a bewildering variety of problems. The history of ecological studies is relatively short, and the ecologist has not in the past been particularly concerned with pathology and so has sparse foundations on which to build. Further, the vast assemblage of species with which he has to deal, and their great diversity of reactions, compounds the problem.

By contrast, the medical or veterinary scientist is in an enviable position. He has behind him a long tradition of research providing a detailed understanding of the small number of species on which he is required to concentrate his attention. Consequently he has been able to approach the newer problems of pollution with a substantial background knowledge of a suitable type on which to draw for an assessment of effects on man and domestic animals, and with a significant body of appropriate expertise to guide the design and execution of research.

It is thus reasonable to suggest that the ecologist working in the pollution field would have much to learn from those concerned with these other sciences and with the study of domesticated species. This consideration formed a major part of the rationale behind the NATO Science Committee conference on aspects of ecotoxicology upon which this volume is based. The remit given to participants was as follows:

"The primary task of this interdisciplinary meeting on the ecotoxicology of heavy metals and organohalogen compounds is to identify those areas of this subject in which inadequate knowledge of the processes influencing entry, metabolism, and toxic action of these pollutants is presently hindering assessment of the significance of the hazards they create within ecosystems.

"Specialists from several disciplines have been brought together with the specific objective of facilitating detailed discussion of those physical, biological, and biochemical processes which affect the response to these toxic materials and which thus complicate the interpretation of pollutant survey data.

"It is intended that the report of this meeting shall clearly highlight those areas in which further research activity is particularly desirable to achieve realistic assessment of the hazards presented by individual heavy metals and organohalogen compounds in the environment."

This volume presents an account of the proceedings of the conference. Part I contains the text of eight lectures presented during plenary sessions designed to set the scene for the later activities of specialist Working Groups. Part II contains seven papers selected from among those submitted for circulation to participants before the meeting, these papers illustrating, in differing detail, the wide scope of scientific enquiry that is relevant to the ultimate assessment of the fate and effects of potentially toxic materials present in the environment.

Part III contains the Working Group Reports and their recommendations. Since these were set out in the style of the individual group leaders and rapporteurs, and reflect the separate approaches of each group, no editorial attempt has been made to reduce them to uniformity.

There was general agreement that participation in this multidisciplinary meeting was a stimulating and provocative experience. If this volume reflects the enthusiasm with which the remit of the meeting was handled and concentrates future attention around those topics so clearly felt to be currently hindering assessment of the biological significance of some pollutants, it will have served its purpose. We are confident that it clearly reflects the need for more closely integrated multidisciplinary research effort if satisfactory progress toward control of the adverse effects of pollutants is to be maintained.

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Cochairmen: NATO Science Committee Conference on Ecotoxicity of Heavy Metals and Organohalogen Compounds

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Part I
PLENARY PAPERS

1

Ecotoxicology—A New Branch of Toxicology: A General Survey of its Aims Methods, and Prospects

R. TRUHAUT

Dedicated to my friend, Professor Dr. Hermann Druckrey, who achieved so much in the cause of prevention, on his 70th birthday.

As an introduction it is desirable to define the terms ecology, pollution, toxicology, and ecotoxicology.

Ecology (from the Greek *oikos*, house) is the scientific discipline which studies the relation between living organisms and their milieu. This expression, which means literally "science of the habitat," was coined in 1866 by Haeckel in his work "General Morphology of the Organism."

A more elaborate definition was given by Dajoz in "Precis d'Ecologie," which appeared in 1970: "Ecology is the science which studies the conditions of existence of living creatures, and the interaction of all kinds which exist between these creatures and their environment."

Author's Note: This English version is a translation of the original French text. Interested readers may refer to other articles on the same subject published earlier, notably "Ecotoxicologie et protection de l'environnement," Proceedings of *Colloque Biologie et Devenir de l'Homme*, La Sorbonne, Paris, 18–24 October 1974 (in press).

R. TRUHAUT • Directeur du Centre de Recherches Toxicologiques de la Faculté des Sciences pharmaceutique et biologiques, Université René Descartes, Paris, France.

This young science has made great strides since 1930. It represents a discipline which is more typically multidisciplinary, and is concerned with plant life, animals, and microorganisms, whether terrestrial or aquatic, and, in the latter case, whether fresh-water or marine. Its specialty is concerned with biological problems, not at the level of species or even isolated individuals, such as occurs, for instance, in anatomy and physiology, but at the level of populations of groups of species or ecosystems which constitute the biosphere, taking into consideration the various factors which influence their environment.

Pollution—In a Council of Europe report published in 1967, the following definition of air pollution was put forward: "Pollution of the air occurs when there is present in the air a foreign substance or an important variation in the proportions of its constituents capable of causing a harmful effect or of causing discomfort, bearing in mind the extent of scientific knowledge at the time."

This definition is capable of being extended to the pollution of other parts of the environment: the earth, fresh water, the sea, biota, and food chains. It applies to the harmful effects which can result not only from the introduction of foreign substances, the so-called xenobiotics, but also from the development of imbalance between naturally occurring substances such as, for example, disturbances of the balance between different mineral elements which very often lead to harmful effects. Among such balances can be cited those existing between zinc and cadmium, molybdenum and copper, or selenium and mercury (WHO, 1973). Without entering into details, it seems appropriate to emphasize that, along with the growth of pollution resulting from industrialization and the widespread use of chemical products in different areas of human activity, a characteristic feature of our age, which may truly be called the era of chemistry, the problems faced by specialists in the science of pollution, so called molysmology, have become increasingly manifold and complex.

Toxicology is the scientific discipline which studies toxic or poisonous substances, that is to say, substances which cause alterations or disturbances in the functions of the organism leading to harmful effects of which the most serious is, obviously, the death of the organism in question. For a more elaborate definition, we would refer the reader to a general conference on toxicology given by us on the occasion of the 92nd Congress of the French Association for the Advancement of Science (St. Etienne, July 1973, published in *Science*, 1974, VL, No. 2).

Ecotoxicology is the branch of toxicology which studies the toxic effects caused by natural substances or by artificial pollutants on living organisms whether animal or vegetable, terrestrial or aquatic, which constitute the biosphere. It also relates to the interaction of these substances with the physical environment in which these organisms live. In connection with this definition, it must not be forgotten that man is situated at the center of the biosphere. But while human toxicology, that is, the study of directly harmful effects on man of exogenous or xenobiotic agents, has given rise to a great amount of research,

coordinated on an international scale (e.g., by WHO), ecotoxicology is still in an embryonic state.

Nevertheless, harmful effects on members of ecosystems other than man usually have an impact on the latter in an indirect way. For example:

1. The decrease in food resources resulting, for example, from the immense slaughter of fish under the influence of the discharge of effluent containing toxic pollutants into rivers or lakes, or the havoc wrought to food crops by air pollution, such as fluoride fumes or the constituents of oxidizing photochemical smog.
2. The indirect effect on agricultural productivity resulting from assaults on organisms which have a beneficial function in the biosphere, such as bees as vehicles for pollen or earthworms and other constituents of the soil fauna which ensure aeration of the soil.
3. The decrease in production of primary source materials, such as textile-producing plants and forest cultures.
4. The toxicity which is bestowed on certain constituents of the food chain, such as the pollution of fish, fresh-water as well as marine, by methylmercury derivatives, and the passage of various residues, notably the residues of organochlorine lipid-soluble pesticides, into the milk of mammals, which constitute, in this connection, spectacular examples. The presence of toxic organic micropollutants in drinking water produced from contaminated river water can pose problems of the same magnitude.
5. The disturbance of biological balance in nature with disastrous consequences on the regenerative possibilities for mankind and, as a result, the quality of life as a whole.

It must be recalled in this connection that in the WHO charter, "health" is defined as not only an absence of infirmity or illness, but also a complete state of physical, mental, and social well-being. Thus, in the context of our forthcoming discussion on the consequences of pollution, we must ultimately consider not only adverse physical responses but also adverse emotional or psychological responses. Although we shall be principally concerned with more direct effects of pollution, it is, for example, worth emphasis that both physical and psychological consequences in man have been claimed to result from prolonged exposure to industrial smog and fumes.

For all these reasons, the term ecotoxicology is applied, sometimes in a more limited way than that given above, to the study of the indirect effects on the health and well-being of man, which can be caused by the harmful effects of chemical pollutants on various living organisms other than man.

Harmful effects on some members of ecosystems may result from beneficial effects upon others, for instance, the injurious effects which can occur in fish due to the stimulation of the growth of aquatic plants by substances such as

nitrates and phosphates which cause a decrease in the amount of dissolved oxygen in water.

Man exploits the injurious effects of chemical agents upon certain organisms in his use of pesticides, without which food resources would decline with tragic consequences at a time when increasing population on a world-wide scale poses the problem of a struggle against famine. However, it must not be forgotten that such agents only very exceptionally posses selective toxicity toward such pests, and can thus exercise a harmful effect on other categories of living creatures and in particular on man himself. The choice of compounds to be used and the assessment of methods of application must not, because of this fact, be made without adopting the most rigorous precautions based on adequate scientific information.

All the above comments serve to illustrate that the problems of ecotoxicology must be studied in an *integrated* context.

1.1. Entry, Distribution, and Fate of Pollutants in the Physical Environment

1.1.1. Principal Sources of Pollution

The principal sources of pollution are as follows:

1. Domestic fires and industrial heating devices, generators of, among other materials, carbon dioxide, sulfur dioxide, and unburned matter, whose particles of soot carry polycyclic aromatic hydrocarbons.
2. Industrial effluents, discharged either into the atmosphere or into water, whose nature depends on the activities of the factories producing the effluent. The number of pollutants which can be thus discharged is considerable and increases continually with the rapid progress of the chemical sciences and the manufacture of the products which this progress facilitates.
3. Terrestrial vehicles and aircraft using crude oil or mineral oil and discharging into the atmosphere, in addition to carbon monoxide and dioxide, nitrogen oxides, partially combusted hydrocarbons, and heavy particles of urburned matter, as well as the combustion residues of fuel additives, notably lead particles.
4. The use of a whole series of industrial products such as, to name only a few examples, asbestos, polychlorobiphenyls, and various solvents. Our food itself has not escaped a form of pollution, in that numerous chemical agents, known as food additives, are increasingly and deliberately incorporated in pursuit of various aims (preservation, improvement of organoleptic qualities, and of appearance or coloring).

5. The use of chemical products in agriculture, notably as pesticides, as additives to animal foodstuffs, and as fertilizers, particularly those containing nitrates.
6. The increasing domestic use of solvents, detergents, insecticides, medicines, cosmetics, plastic packaging, and other so-called household products.

We must recognize the urgent need to initiate an accurate objective inventory of these varied types of pollutants. Action of this sort is taking place at the level of the United Nations and international scientific organizations, such as the Scientific Committee on Problems of the Environment (SCOPE) recently created (1970) by the International Council of Scientific Unions (ICSU). Such an international registry is essential to the programing of any action to be undertaken in the struggle against the harmful effects of pollutants.

According to a report presented to an international symposium held in March 1972 at Skolaster in Sweden (Royal Academy of Sciences, 1973), every year 250,000 new chemical compounds, among which about 500 are turned into commercial products, are added to the two million which are already known.

In addition to the pollutants artificially created by man, we must not omit those existing in a natural state, among which, to cite only a few spectacular examples, there are the mycotoxins from certain molds, notably the deadly aflatoxins and the biotoxins which give toxic potential to certain kinds of seafood (mollusks, crustaceans, and fish) and whose origin is increasingly attributed to a pollution of marine plankton.

1.1.2. Entry of Pollutants into the Environment

The principal modes of entry of pollutants into the environment will now be considered briefly.

Discharges into the air are obviously preponderant, not only of gases and fumes, but also of particles. Particularly important are particles small enough to be dispersed in aerosol form, which can be transported for great distances. These particles, apart from their own toxic potential, can play a very important role either as carriers of gases and fumes or as foci for catalytic transformations which eventually create harmful compounds. Atmospheric pollutants can affect both plants and animals adversely. Such particulates are important sources of the fallout which may accumulate in the top layers of soil as well as on the leaf surfaces of growing plants. Examples are many, including pesticides used in agriculture, industrial dusts containing fluoride, and the inorganic lead derivatives formed in the combustion of the organic lead compounds (tetraethyllead and tetramethyllead) used as fuel additives.

Certain compounds of low vapor pressure, such as organochlorine pesticides, have the ability to pass from the surface of the soil to the atmosphere by means of codistillation with the soil water and also with the water of the leaves of plants.