Department for Environment, Food and Rural Affairs

Hazardous Substances Advisory Committee

HSAC paper on key research questions in ecotoxicology

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What are the consequences to individuals and populations of both humans and wildlife, of their lifetime exposure to the highly complex, ill-defined mixture of anthropogenic chemicals characteristic of today's society?

Background

Ecotoxicology is a relatively new science that emerged during the late 1960s. The term was first coined by Professor Rene Truhaut to refer to pollution investigations related to wildlife. However, by the 1980s a more sophisticated definition emerged where ecotoxicology was defined as; "the study of the effects of anthropogenic chemicals and radiations on ecosystems and their components".

Although fundamental scientific investigations still proceed in this field, ecotoxicological research has tended to focus principally on the development of practical techniques to evaluate the potential toxicity of chemicals in the environment, and the likelihood that organisms will be exposed to dangerous concentrations *in situ*. In particular, a great deal of effort has been put into developing toxicity test procedures that not only use mortality as an endpoint, but also consider sub-lethal effects on growth, reproduction and viability of offspring. Similarly, attention has been paid to the chemical speciation, persistence and fate of contaminants in diverse environmental media, together with their effects on biota. Mechanistic studies have tried to unravel the ways in which chemicals are taken up, metabolised, detoxified and excreted as well as attempting to identify the damage they give rise to. Methods have also been developed to predict the potential toxicity of chemicals based on structure - activity relationships (QSARs).

While the efforts outlined above have provided useful, scientifically–based tools and information for regulators and environmental managers to take action to protect the environment, it is difficult to assess how successful they have been. Few of the more fundamental principles that underpin ecotoxicology and the general questions that must be addressed when trying to evaluate newly emerging threats have been answered. This in large part reflects a lack of research funding for ecotoxicology because many funding bodies have failed to recognise that ecotoxicology is indeed a legitimate area of scientific investigation, rather than simply a set of environmental management procedures. The national need for high quality science in this area is very high. This is particularly clear regarding issues such as neonicotinoid insecticides and pollinating insects, endocrine disrupters and fish populations, the safety assessment of novel substances such as nanomaterials and novel chemical formulations and how climate change will affect the fate and effects of environmental chemicals. Without underpinning science to inform decisions and actions to deal with these concerns, the cost to the UK economy will run into £billions, and our ability to influence chemicals policy in major international fora such as the European Union and the Organisation for Economic Cooperation and Development will be limited.

Key Questions

Set out below are a number of examples of extremely important ecotoxicological questions that have not been fully answered (or in some cases, not addressed at all) over the last 50 years:

Prediction of ecotoxicological effects on individuals

1) Which chemicals are of most concern?
2) Does the existence of non-monotonic dose-response relationships in some cases invalidate predicted no observable effect concentrations?
3) How do effects of pollutants in one or two target tissues give rise to toxicity in the whole organism? (This is especially relevant for the various invertebrate phyla (95% of all animal species) whose physiology and toxicology are poorly understood)
4) Which species are most vulnerable to which specific types of environmental pollutants?
5) How can pollutants be identified that are not persistent, bioaccumulative or overtly toxic, but which cause significant ecotoxicology effects?
6) Can pollutants produce significant ecological change by influencing the behaviour of organisms rather than through direct toxicity?
7) How does exposure to pollutants affect the Darwinian fitness of organisms?
8) Are growth rate, reproductive output, viability of offspring and mortality the most useful endpoints for assessing pollutant toxicity? Do different pollutants affect these endpoints to different extents?
9) Which groups of chemicals produce the most damaging, long term (chronic and trans-generational) effects on organisms? (Rank order)

Prediction of effects on populations/communities

10) How do environmental chemicals effects at the level of individual organisms translate into population, community and ecosystem level effects?
11) How do the differential effects of pollutants on populations of different species *in situ* lead to changes in ecosystem structure, function and sustainability?
12) What proportion on individuals within a population and which individuals (for example, juveniles, adults, males, females, starved, well-fed?) must be affected by pollution before ecologically significant effects occur?
13) How can we recognise a ‘normally’ functioning population/ecosystem, so that we can differentiate between chemically-induced perturbations (followed by rapid recovery) and more serious, longer term damage?

14) How do natural changes in the chemical environment arising from normal biological and ecological processes affect populations, communities and ecosystems structure and function?

Recovery from adverse impacts

15) How do repeated exposures to pollutants during the life course of organisms *in situ*, affect the ecology of populations or communities?
16) How reversible are pollution effects in ecosystems? Can organisms and populations fully recover from pollutant exposure or does the experience influence future responses to other pollutant exposures?
17) What do we mean when we say that a community of organisms has recovered following a pollution episode? Is the recovered population likely to be as resistant to another pollutant exposure as a pristine population would be?
18) What ecotoxicological information is required to help in deciding how far to proceed with clean-up procedures?

Adaptation to effects

19) What are the ecological consequences for populations and communities of organisms developing physiological tolerance or genetic resistance to exposure to specific pollutants?
20) How can wildlife species develop resistant populations following exposure to some chemicals (e.g. pesticides, metals), but not others (PCB, PAH, Dioxins) (or do they??).
21) Are chemicals in the environment causing epigenetic effects and, if so, are these effects resulting in significant damage to wildlife?

Multifactorial effects

22) Do the most polluted sites in the environment exhibit the most severe disruption of ecosystem structure and function?
23) How do mixtures of chemicals affect the toxicity of individual pollutants?
24) To what extent do impacts not related to chemical pollution (e.g. global warming, habitat loss, extreme natural events) compromise the ability of organisms to cope with chemical pollution?

Special/other effects

25) Are representatives of diverse invertebrate phyla vulnerable to endocrine disruption and genotoxicity via mechanisms different from those that operate in vertebrates?
26) Does endocrine disruption occur in the absence of any other manifestations of toxicity (genetic damage, immune dysfunction, etc.)?
27) Do endocrine disrupting chemicals transgress the general principles that pollutants possess a threshold dose or concentration, below which no adverse effects occur in particular species?

Next steps

HSAC will prioritise these questions in due course, but we conclude that many of them urgently need to be addressed. The list of questions is long, reflecting the multi-disciplinary nature of ecotoxicology. This has often led to the side-lining of research grant applications in this field. The objective of ecotoxicology is principally to facilitate an understanding of existing pollutant effects in ecosystems, but also to allow accurate predictions of potential pollutant effects on wildlife populations by extrapolation from experimental toxicological evidence at the molecular, cellular, physiological and whole-organism levels of biological organisation. Most of the questions listed above address this objective. Such extrapolation is still surrounded by considerable uncertainty, and this has led to the widespread use of so-called 'safety' or 'assessment' factors when regulating chemicals, an empirical practice which is probably over-protective in many cases. This excessive precaution has led to significant economic consequences, such as the frequent abandoning of development of promising new chemicals. The other side of this coin is that we are still unable to accurately predict effects of the complex mixtures of anthropogenic substances in sewage and other discharges.

How the questions should be addressed is a complex issue, but it boils down to the need for ecotoxicology to resume its place as a subject worthy of much more funding and study than it currently receives in the United Kingdom. It will be apparent that the ecological effects of chemicals are still far from being predictable, so the issues listed above should form the basis for a new funding stream aimed *inter alia* at environmental chemists, biochemists, (eco)toxicologists, ecologists and population modellers. Although a programme of this type could be led by the Natural Environment Research Council, its multi-disciplinary nature calls for the additional involvement of other research councils such as the Biotechnology and Biological Sciences Research Council, the Economic and Social Research Council and Medical Research Council. Furthermore, some aspects of the work would be more efficiently funded direct by government departments such as Defra and DH, perhaps acting in partnership with industry organisations, so it will be important for departmental budgets to reflect this need despite the push for spending cuts.

HSAC, February 2016