The role of ecotoxicology in assessing the environmental safety of chemicals

Ecotoxicology

Ecotoxicology is the scientific study of how chemicals and other pollutants affect ecosystems, particularly focusing on the impacts to wildlife such as fish, invertebrates, and plants. Principles from ecology and toxicology are combined to understand the risks and hazards posed by substances released into the environment and consider the short- or long-term impact of chemicals on populations of aquatic and terrestrial organisms, which could harm the function and health of ecosystems. Understanding this is crucial for protecting biodiversity and maintaining ecosystem and environmental health.

Unlike human health safety assessments, which typically focus on protecting individual people, ecotoxicology places emphasis on the potential for chemicals to affect entire populations and the ecological balance they support. The aim of ecotoxicological testing is to establish whether chemicals that enter the environment could result in short-term adverse effects, or long-term changes to populations of aquatic life and other terrestrial organisms (including birds and wild mammals), which in turn could harm the function of the ecosystem.

Hazard, risk and regulation

Every year, thousands of new chemicals are developed and make their way into the environment: industrial chemicals; cosmetics; food additives; pharmaceuticals for both human and veterinary use; pesticides, and household products. To ensure these substances are safe for both human and environmental health, laws and regulations are put in place, each addressing different aspects of chemical use and management. In the UK, environmental safety is supported by regulations such as the Registration, Evaluation, Authorization, and Restriction of Chemicals (REACH), which requires companies to assess and share data on chemical risks, and Classification, Labelling and Packaging (CLP), which ensures hazards are clearly labelled and communicated. Regulatory agencies, such as the European Chemicals Agency (ECHA), the UK Health and Safety Executive Chemicals Regulation Division (HSE-CRD) and the UK Environment Agency (EA), oversee chemical assessments, including assessing ecological risks, and enforcing safety standards. They use scientific risk assessments to ensure chemicals are safe and are used safely as to not harm the environment.

When considering environmental safety, hazard assessment looks at a chemical's inherent ability to cause harm, such as toxicity to aquatic life or disruption of ecosystems, while risk assessment evaluates how likely that harm is to occur under specific conditions of use or exposure. The way chemicals are regulated, whether through hazard-based or risk-based approaches, can vary depending on their intended use (e.g. as a pesticide, pharmaceutical, or industrial chemical) and the regulatory framework in place in different regions of the world.

How is chemical safety assessed?

To assess the safety of a chemical, companies and researchers compile a data package; a collection of scientific data that includes details on the chemical's identity, physical and chemical properties, environmental fate and behaviour, toxicity to species which are intended to be affected (i.e. a pest) and species not intended to be affected, and potential exposure in the environment. These data are generated through laboratory studies, modelling, and existing literature, and are submitted to fulfil requirements of regulations such as REACH to support a thorough risk assessment. To determine what tests are needed and how they should be conducted, internationally recognised standards such as The Organisation for Economic Co-operation and Development (OECD) Test Guidelines (TG), which outline validated methods for assessing chemical properties, environmental behaviour, and effects on organisms, are typically followed. These guidelines ensure consistency, reliability, and international harmonisation, which is important given the global market of chemicals to avoid as far as possible the unnecessarily duplication of tests.

Environmental/Ecotoxicology testing

Environmental fate and behaviour

A key part of preparing data for chemical safety assessment is understanding how a substance enters and behaves in the environment, a phenomenon known as environmental fate and behaviour. Chemicals can enter ecosystems through a variety of means: agricultural runoff; industrial discharge; transportation spills; or everyday use of consumer products and pharmaceuticals (figure 1). A chemical's physico-chemical properties, such as solubility, volatility, and ability to bind to soil or degrade, influence how long it persists or builds up, how far it travels, and whether it reaches target or non-target species.

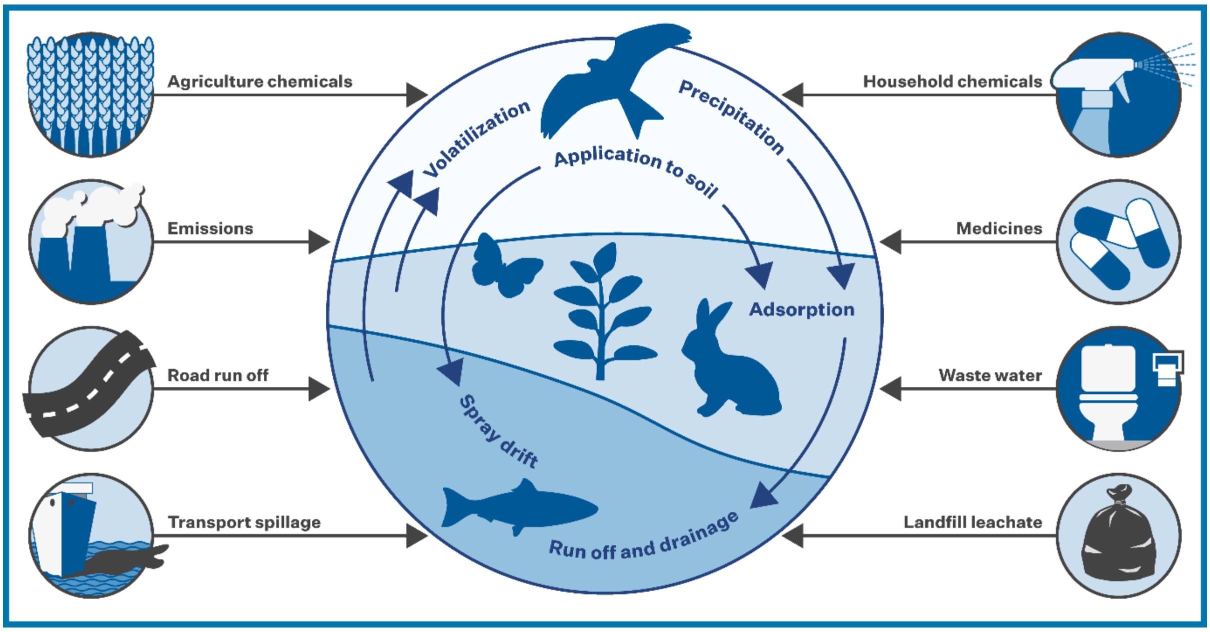

Figure 1. ***How chemicals enter and move through the environment***
Chemicals from agriculture, industry, households, medicines, and waste can reach soil, water, and air through processes such as emissions, runoff, spillage, and landfill leakage. Once released, they may move through the environment via spray drift, drainage, precipitation, and evaporation, potentially exposing plants, animals, and aquatic life to the chemical which may lead to risks for ecosystems and wildlife health.

Standardised tests outlined in the OECD guidelines include the assessment of these processes, for example biodegradation (breakdown by microbes), adsorption (binding to soil or sediment), and volatilisation (evaporation into air) studies - all of which are essential for predicting environmental exposure and guiding safety decisions.

Hazard identification

To evaluate toxicity to different species and determine whether a substance can cause harm to environmental populations, hazard identification and dose-response assessments are carried out. These typically establish the relationship between the concentration of the substance and the observed effects.

To ensure protection of entire ecosystems, a range of representative species covering different taxonomic groups are used in testing: Aquatic organisms such as fish (e.g. zebrafish, fathead minnow), algae, and invertebrates (e.g. Daphnia) to reflect impacts on freshwater ecosystems; Sediment and soil-dwelling organisms, (e.g. earthworms and ostracods), to assess risks to terrestrial environments; Amphibians (e.g. frogs) may be used for endocrine disruption studies due to their sensitivity to hormonal changes; Birds, to evaluate risks from bioaccumulation and secondary poisoning; Bees and other pollinators are assessed for pesticide impacts, given their ecological importance. These species are chosen not only for their ecological relevance but also to act as surrogates for broader environmental protection, ensuring that sensitive and keystone species are safeguarded.

Vertebrate testing generally follows a tiered approach (figure 2), starting with assessment of acute toxicity and progressing to studies which measure chronic endpoints and early warning signs of toxicity (sublethal effects), with more complex approaches such as population modelling used when greater ecological realism is needed. Typically, shorter-term studies to evaluate acute effects such as mortality are conducted in the first instance, such as OECD 203 (Acute Fish Toxicity), followed by chronic studies which evaluate long-term impacts on growth, reproduction, and development using guidelines like OECD 210 (Fish Early-Life Stage Toxicity), OECD 229 (Fish Short-Term Reproduction Assay), and OECD 231 (Amphibian Metamorphosis Assay).

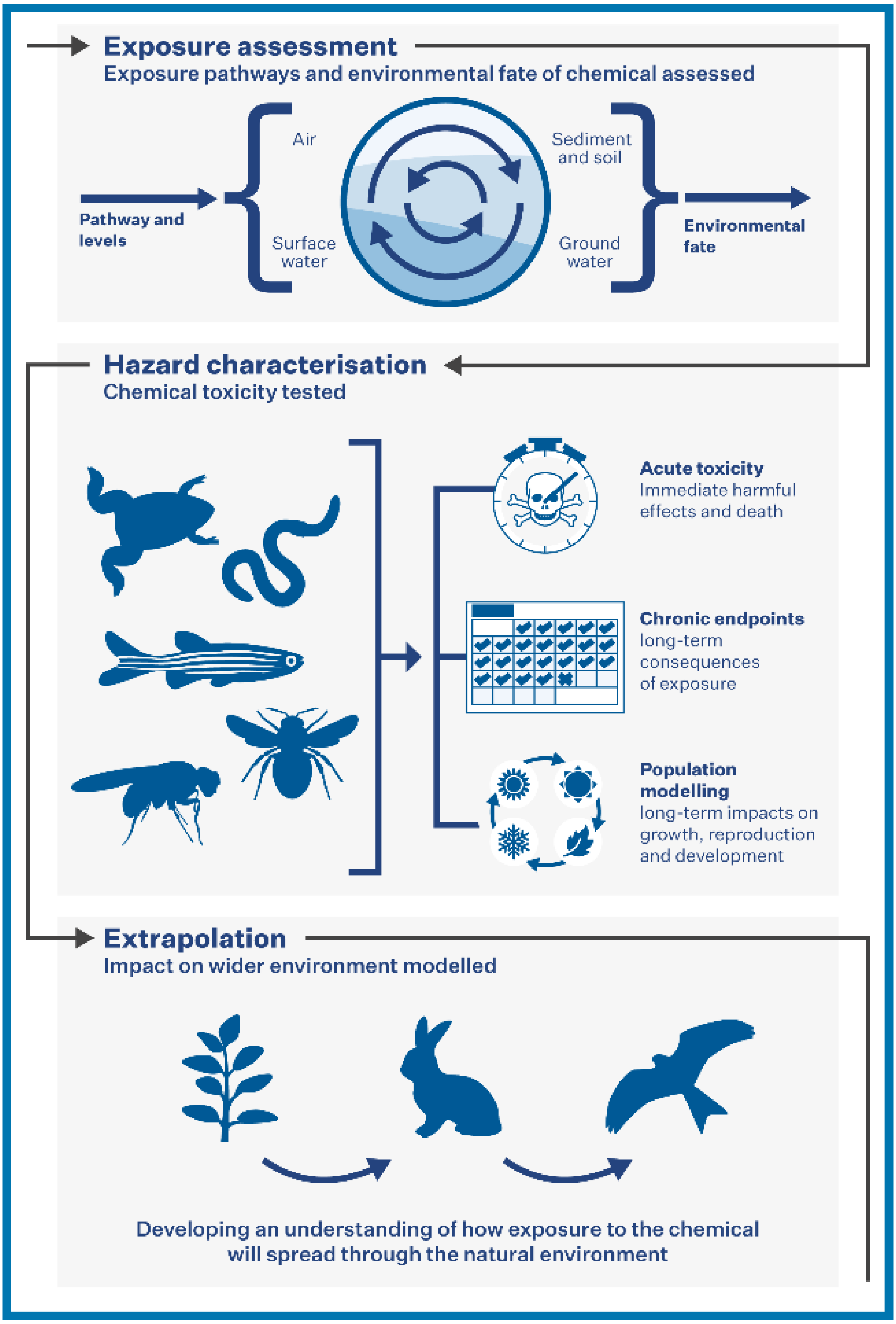

Figure 2. ***Assessing Chemical Safety***
Generally, a step-by-step approach to understand what chemicals might do in the environment is taken. Firstly, where the chemical goes (air, water, or soil) and how it moves around and whether it builds up will be studied. Next, tests to determine if the chemical is harmful to living organisms are carried out, using a variety of different tests and model species - these check for immediate effects such as death, as well as longer-term problems such as changes in growth, reproduction, or survival. Finally, all of this information is used to predict what could happen across whole ecosystems, including whether these effects might spread through food chains and eventually affect people through water, food, or air.

Regulatory submission

The results from these studies provide key endpoints that are used to determine a chemical's potential hazard i.e. its inherent ability to cause harm to organisms under specific conditions. These hazard assessments form the foundation for understanding environmental risk and guiding regulatory decisions on chemical safety. Once studies are conducted and data packages are assimilated as per the specific regulatory requirement for the chemical type and geographical location, these are submitted to the appropriate regulatory body for risk assessment.

Future directions

Looking ahead, ecotoxicology is shifting toward more ethical, efficient, and predictive science through New Approach Methodologies (NAMs), including in vitro, in silico, and omics-based tools, that aim to reduce reliance on animal testing. These innovations have potential to form part of Next Generation Risk Assessment (NGRA) - a modern framework proposed to that integrate exposure science with understanding of the biological mechanisms underlying potential toxic effects, and to assess chemical safety without defaulting to animal data.

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