1.1: Environmental toxicology

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Learning objectives

You should be able to

- characterize the field of environmental toxicology;
- explain what type of knowledge from environmental chemistry, toxicology and ecology is relevant for environmental toxicology;
- explain the difference between environmental toxicology and ecotoxicology.

Keywords: Environmental toxicology, environmental chemistry, toxicology, ecology, ecotoxicology

Environmental toxicology is the science that studies the fate and effects of potentially hazardous chemicals in the environment. It is a multidisciplinary field assimilating and building upon knowledge, concepts and techniques from other disciplines, such as toxicology, analytical chemistry, biochemistry, genetics, ecology and pathology. Environmental toxicology emerged in response to the growing awareness in the second part of the 20th century that chemicals emitted to the environment can trigger hazardous effects in organisms living in this environment, including humans. Section 1.3 gives a brief summary of the history of environmental toxicology.

One way to depict the field of environmental toxicology is by a triangle consisting of chemicals, the environment and organisms (Figure 1). The triangle illustrates that the fate and potential hazardous effects of chemicals emitted to the environment are determined by the interactions between these chemicals, the environment and organisms. The fate of substances in the environment is the topic of **environmental chemistry**, the effects of substances on living organisms is studied by **toxicology**, and the implications of these effects on higher levels of biological organization are analyzed by the field of **ecology**.

Another term widely used to refer to this field of study is **ecotoxicology**. The main distinction is the inclusion of human health as an endpoint in environmental toxicology, whereas ecotoxicology is restricted to ecological endpoints. Since the current book includes human health as an assessment endpoint for environmental contaminants, the term environmental toxicology is preferred over ecotoxicology.

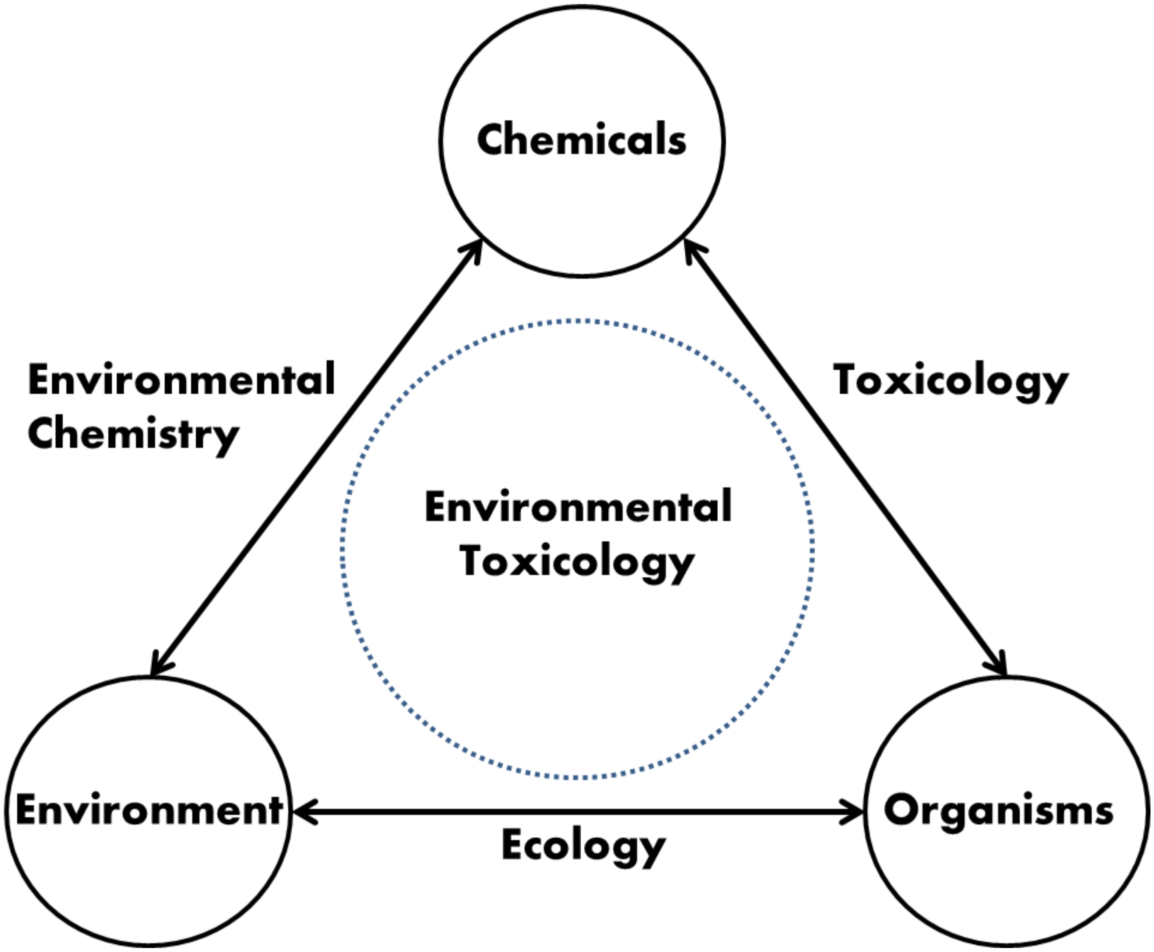

Figure 1: Environmental toxicology studies the interactions between chemicals, organisms and the environment making use of environmental chemistry, toxicology and ecology. Source: Ad Ragas.

Environmental chemists study the fate of chemicals in the environment, e.g. their distribution over different environmental compartments and how this distribution is influenced by the physicochemical properties of a chemical and the characteristics of the environment. They aim to understand the pathways and processes involved in the environmental fate of a chemical after it has been emitted to the environment, including processes such as advection, deposition and (bio)degradation. Within the context of environmental toxicology, the ultimate aim is to produce a reliable assessment of the exposure of organisms, an aim which is often complicated by the enormous heterogeneity of the environment.

Environmental chemists use a variety of tools to analyze and assess the fate of chemicals in the environment. Two fundamental tools are analytical measurements and mathematical modelling. Measurements are essential to acquire new knowledge and insight into the behavior of chemicals in the environment., e.g. measurements on emissions, environmental concentrations and specific processes such as biodegradation. These measurements are analyzed to discover patterns, e.g. between substance properties and environmental characteristics. Once revealed, such patterns can be integrated into a comprehensive mathematical model to predict the fate of and exposure to substances in the environment. If sufficiently validated, these models can subsequently be used by risk assessors to assess the exposure of organisms to chemicals, reducing the need for expensive measurements.

Chapter 2 focuses on the types of chemicals occurring in the environment, their sources and the concentrations found at contaminated sites. In Chapter 3, focus will be on the fate and transport of these chemicals, including aspects of bioavailability and bioaccumulation in organisms.

Toxicologists study the effects of chemicals on organisms, often at the individual level. Fundamental toxicologists aim to understand the mechanisms involved in the toxicity of a compound, whereas more applied toxicologists are primarily interested in the relationship between exposure and effect, often with the aim of identifying an exposure level that can be considered safe. Within this context, the dose concept as introduced by Parcelsus at the start of the 16th century is essential (see Section 1.3), i.e. the likelihood of adverse effects depends on the dose organisms are being exposed to.

The processes taking place after exposure of an organism to a toxicant are often divided into toxicokinetic and toxicodynamic processes. Toxicokinetic processes are those that describe the fate of the toxicant in the organism, including processes such as absorption, distribution, metabolism and excretion (ADME). These toxicokinetic or ADME processes are sometimes collectively referred to as "What the body does to the substance" and determine the exposure level at the site of toxic action, or internal dose. Toxicodynamic processes are those that describe the evolution of an adverse effect from the moment that the toxicant, or one of its metabolites, interacts with a molecular receptor in the body. This interaction is often referred to as the primary lesion or molecular initiating event (MIE). Toxicodynamic processes are sometimes collectively referred to as "What the substance does to the body" and the chain of events leading to an adverse outcome as the adverse outcome pathway (AOP).

The toxicity of a compound thus depends on toxicokinetic as well as toxicodynamic processes. Traditionally, this toxicity is being determined by exposing whole organisms in the laboratory to the substance of interest, and subsequently monitoring the health status of these organisms. However, as a result of the growing societal pressure to reduce animal testing, as well as the increased mechanistic understanding and improved molecular techniques, this so-called "black box approach" is more and more being replaced by a combination of in vitro toxicity testing and "in silico" predictive approaches. Physiologically-based toxicokinetic (PBTK) models are increasingly used to model the fate of chemicals in the body, resulting in a prediction of the internal exposure. *In vitro* tests and advanced molecular techniques at the gene (genomics) or protein (proteomics) level may subsequently be used to determine whether these internal exposure levels will trigger adverse effects, although many challenges remain in the prediction of adverse effects based on *in vitro* test and omics information. Chapter 4 focuses on dose-response relationships, modes of action, species differences in sensitivity and resistance against toxicants.

Ecologists study the interactions between organisms and their environment. Ecology is an important pillar of environmental toxicology, because ecological knowledge is needed to translate effects at the individual level to the ecosystem level; an important endpoint of ecological risk assessments. Such a translation requires specific knowledge, e.g. on life cycles of organisms, natural factors regulating their populations, genetic variability within populations, spatial distribution patterns, and the role organisms play in processes like nutrient cycling and decomposition. Effects considered relevant at the individual level, such as a tumor risk, may turn out to be irrelevant at the population or ecosystem level. Similarly, subtle effects at the individual level may turn out to be highly relevant at the ecosystem level, e.g. behavioral changes after environmental exposure to antidepressants which may affect the population dynamics of fish species. In recent years, there is an increasing interest for the role of the landscape configuration, distribution patterns and their dynamics in environmental toxicology. The spatial configuration of the landscape, the distribution of species and the timing of exposure events turn out to be important determinants of ecosystem effects. The ecological aspects of environmental toxicology will be discussed in Chapter 5.

1.1. Question 1

What is the difference between environmental toxicology and ecotoxicology?

1.1. Question 2

Indicate from the following terms whether these belong to the environmental chemistry, toxicology or ecology?

(Bio)degradation

Fate and exposure model

Dose

Toxicodynamics

Adverse outcome pathway

Population dynamics

Landscape configuration

1.1. Question 3

Give an example how subtle effects which may remain undetected in a toxicity test can be relevant at the population or ecosystem level.
