Scientific development and regulatory needs in ERA
The relationship between hierarchical levels and uncertainty

Marco Vighi
IMDEA Water Institute
Spain
Ecotoxicology born in the second half of the last century with the aim of responding to the growing problems of ecosystem damages due to chemical emissions.

The first challenge was producing simple tools for Ecological Risk Assessment (ERA), capable to provide solutions for the management of chemicals using the scarce information available.
These tools represented, for decades, the basis for international regulations and led to an increased level of chemical control and to an improvement of environmental quality.

Traditional ecotoxicological tests and procedures for estimating environmental concentrations (PECs) and levels safe for the environment (PNECs) still represent a useful tool, applicable with a moderate effort to a large number of chemicals.
The fundamental question. What has to be protected?

The objective of ecotoxicology is developing knowledge and tools capable to protect structure and functions of communities and ecosystems.
The uncertainty of single species traditional tests

AF=10
Other uncertainties (ecological interactions, experimental etc.)

AF=10
Possibility of more sensitive species

AF=10
From acute to chronic

To calculate a PNEC, a total uncertainty factor of 1000 is applied to acute LC50s.
Species Sensitivity Distribution (SSD)

SSD represent an improvement in comparison with the stochastic approach based on a few indicator species. However, it is still based on single species tests. Therefore, it cannot account for the complex interactions occurring in ecosystems.

All single species approaches suffer from a lack of ecological realism and the high uncertainties for understanding the actual consequences for ecosystem health require the use of relatively high application factors that, in many cases, are arbitrarily set up.
Ecotoxicology and ERA: ...which is the right direction?

Starting from the hierarchical level of single species, it is possible moving toward lower (cells, molecules) or higher (populations, communities, ecosystems) hierarchical levels.
Biomarkers

Effects of a contaminant at different levels of hierarchical organisation

Example of a bird population exposed to an organophosphoric insecticide (OP).

From molecular level to population level the response time increases (from minutes to years), the ecological relevance increases and also increase difficulties to correlate stress factors with effects.

At the present state of our knowledge, the predictive capability of sub-individual approaches for assessing effects at population and community level is low.
Ecotoxicology and ERA: ...which is the right direction?
Simplicity and ecological realism

- Single species and population tests
- Community tests
- Laboratory microcosms
- Mesocosms
- Enclosures
- Tests on controlled ecosystems
- Field studies

Technical simplicity and ease of interpretation vs. Ecological realism

Ideal assay
Microcosms, Laboratory ecosystems

They are small laboratory structures reproducing the different abiotic (water, sediment, soil) and biotic (biological community) components of an aquatic or terrestrial ecosystem.

Measurements and observations

- Community structure and specific composition
- Relationships among species and trophic level
- System functioning
- Also used for environmental fate studies
Mesocosms

They are large, usually outdoor, structures reproducing the main characteristics of ecosystems. They allow increasing ecological realism in relatively controlled conditions.

**Example of Pond Mesocosms**

A pond community (algae, macrophyte, plankton, benthos) is artificially reproduced by introducing different species into the artificial ponds.

**Example of River Mesocosms**

*Artificial channels for the study of stress factors on the macrobenthos community in River Fersina (TN - Italy)*

Channels are fed by natural (unpolluted) water. The benthic community is naturally colonised by drift and by direct deposition from the terrestrial insect community. Colonisation is almost complete in 3-4 weeks.
Examples of enclosures

- **Pelagic bags**
  Studies of sea and lake plankton

- **Enclosures of littoral benthos**
  Benthos studies

- **Limnocorrals**
  Water columns including plankton and benthos community

To increase the ecological realism there is the need for creating artificial water flow.

**EXAMPLES OF ENCLOSURES IN A WETLAND**

The water and sediment natural communities are included in cylinders of plexiglas or comparable materials.
Field ecotoxicological test on terrestrial fauna (e.g. heartworms) are comparable to enclosures in aquatic ecosystems.

Soil parcels (about 10x5 m) are exposed to different treatments:
- Control (1)
- Reference substance (2, e.g. benomil)
- Tested substance (3. e.g. azinphos methyl)

\[
\begin{array}{c}
D2 \\
D1 \\
D3 \\
C1 \\
C3 \\
C2 \\
B3 \\
B2 \\
B1 \\
A2 \\
A1 \\
A3 \\
\end{array}
\]

\[
\begin{array}{c}
\text{1} = \text{CONTROL} \\
\text{2} = \text{BENOMYL} \\
\text{3} = \text{AZINPHOS-METHYL} \\
A, B, C, D = \text{REPLICATES}
\end{array}
\]

In each parcel, samples are performed at three moments of the seasonal cycle: summer (about 1 month after treatments), fall, spring (about 1 year after treatments).
Higher tier testing: advantages and disadvantages

Higher tier approaches (microcosms, mesocosms, enclosures), allow measuring effects at higher hierarchical levels (population, community, ecosystem) accounting for interactions among species, secondary ecological effects, changes in environmental factors, etc.

They are characterised by high ecological realism and relevance.

However, high uncertainty derives mainly from the difficult reproducibility of experimental conditions, the variability of the results and from the need to extrapolate to ecosystem scenarios different from those of the experimental design.

Mesocosm facilities at IMDEA Water Institute (Spain)
Field studies

1. Studies on natural populations
   Population dynamics studies

2. Studies on natural communities
   Studies on function and structure of natural communities, biodiversity, etc.

Advantages and disadvantages

They are the highest level of ecological realism. In theory they are the best way to study and understand ecological functioning.

Environmental conditions cannot be controlled, only measured. The approach of the study can never be “experimental”. Only “observations” can be done.

The complexity of environmental factors and of their interactions makes difficult understanding cause-effects relationships.
Subindividual (Biomarkers, omics, etc) → Individuals and short-time populations → Population dynamics → Communities and ecosystems

Uncertainty in extrapolation from low to high hierarchical level
Uncertainty due to variability of experimental results

Low Ecological relevance High
The need for modelling

Higher tier approaches are suitable to describe complex patterns occurring in biological communities under stress. However, the description of these complex patterns for the huge variety of aquatic and terrestrial ecosystems is impossible to be achieved through experimental data.

There is therefore a need for suitable modelling approaches capable to describe and predict changes in ecosystem structure and functioning under changing environmental factors.
Any scientific statement (in physics, chemistry, biology) is supported by models. The validity and uncertainty of a model depend upon the soundness of our knowledge about the laws regulating a process.

The uncertainty of ecological models is a function of our knowledge on processes regulating ecosystem functioning.

In ERA, models represent, since a long time, a vital tool for assessing chemical exposure.
Very promising tools exist to describe the behaviour of biological communities and ecosystems, such as trait-based assessment and ecological modelling.

However, a big research effort is needed to transfer the knowledge from basic science to practical and regulatory purposes.

In particular, ecological models represent the most logical tool for describing and predicting the behaviour of ecosystems under stress.

In this sense, they represent the future of ERA and one of the most important priorities for research.

From the OVERALL CONCLUSIONS of:
EC 2013. SCHER, SCENHIR, SCCS Opinion on Addressing the New Challenges for Risk Assessment
Field ecology is a hard work

Thanks for your attention