Mechanistic effect models: highlighting benefits and obstacles of their application for ecological risk assessment

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Introduction

- The main goal of Ecological Risk Assessment (ERA) is to assess the likelihood that chemicals cause adverse impacts on non-target systems (individuals, populations, communities).
- Current approaches contain significant, unquantifiable uncertainty because methods for estimating and integrating exposure and effects are based on overly simplistic assumptions.
- Mechanistic effect models, including population models and their derivatives, integrate the effects of chemicals across multiple levels of biological organization and can improve the application of effects measured on surrogate species. Consequently, they are recommended as higher-tier tools, and a growing consensus has been built around their importance in ERA within the last decades[1,2].
- However, the adoption of population models is still lagging due to a lack of agreement on standardized outputs for risk characterization and of clear thresholds for model output to be translated by risk managers.
- Therefore, their outputs are rarely used in ERA.
- Our aim is to open a thorough discussion among risk assessment stakeholders to understand how we could enhance the use of mechanistic effect models in different regulatory contexts.

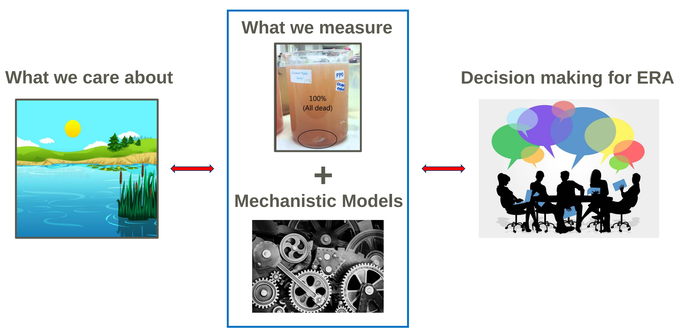

Figure 1. The role of mechanistic effect models in ERA is to make efficient use of all the available collected data in order to achieve the ecological protection goals defined by regulatory policies and help the decision-making process of the regulators[3].

Models' strengths

- Integration of the potential chemical exposure and effects with species-specific life-history traits to project impacts and risks at more relevant spatial and temporal scales.
- Models can extrapolate data generated from standard test species and consider those characteristics or behaviors that could influence the susceptibility of the exposed populations, particularly of listed species.
- Models provide insights into the relative importance of life history and ecological processes that determine population susceptibility.
- Exploration of the vulnerability of species of interest and identification of the most vulnerable representatives for each major taxonomic or functional group.

So, why aren't mechanistic effect models used more in ERA?

Obstacles to using Models in ERA and Tools to overcome them

❑ Lack of guidance

- How do we choose among model approaches?
- How can we establish a protocol for model developments like those that guide laboratory and field studies?
- How can we ensure model transparency and reproducibility?

❑ Lack of trust

- How do we choose what should be and should not be represented in the models?
- How can we judge why a decision was made during model development?
- Are there data supporting the decisions?

Some of these obstacles have been tackled by a growing body of literature to guide modelers in **transparent** and **reproducible model development**, **documentation**, and **communication**, highlighting which are the **available data and model uncertainties.**

Existing tools offering guidance on**:**

- systematic and consistent model creation and documentation [4,5]
- model evaluation and testing [6,7,8]
- choosing models of appropriate complexity to address different types of risk assessment questions [9]
- standardization of modeling development and use in ERA thanks to a comprehensive approach for the development of population models applicable across regulatory statutes and assessment objectives (Pop-GUIDE, Population modeling Guidance, Use, Interpretation, and Development for Ecological risk assessment) [10]
- which model type to choose depending on the ERA question at hand [11]

❑ Lack of standardized guidelines to assess the effects

- Which standardized model outputs can we define to harmonize risk assessment decisions?
- Which and how many scenarios should the models reproduce to inform risk assessors?
- Which model features are crucial to ensure a meaningful RA?

All the stakeholders should agree on these points to ensure the best use of models in ERA.

Examples of mechanistic effect models developed for ERA for fish

1. Pollesch et al., 2022 [12]

- Size-structures integral projection models (IPMs) as a framework for synthesizing ecotoxicologically relevant data and exploring the effects of chemical and nonchemical stressors on exposed populations. Application on fathead minnow (*Pimephales promelas*).
- Development of a promising and flexible framework to expand the set of modeling approaches considered for use in ecotoxicology.
- Structured-modeling tools to be used to advance population-level ecological risk assessment for the protection of wildlife and the environment.

Figure 2. Fathead minnow

2. Accolla et al., 2022 [13]

- Agent-based model framework based on the Dynamic Energy Budget theory to compare the potential effects of chemical exposure across four listed species of cyprinid fish (*Gila cypha, Meda fulgida, Notropis topeka, Dionda diaboli*) and explore species-specific traits of importance at the population level.
- Exposure affects population dynamics differently depending on species-specific life-history traits and ecological processes
- Data gaps on model outputs are analyzed.
- Model framework adapted to be used with different species depending on the ERA question.

Figure 3. Humpback chub

3. NMFS, 2017 [14]

- Application of a published matrix model to study the impact from freshwater exposure to the population growth rates of three salmon species (*O. tshawytscha, O. kisutch, O. nerka*).
- Model implementation in the context of the Biological Opinion on the EPA's registration of pesticides containing Chlorpyrifos, Diazinon, and Malathion.
- Weight of evidence investigating the population-level consequences of direct and indirect effects.

Figure 4. Chinook salmon

Open questions

- What are the **major obstacles** to using model results in regulatory decisions?
- How can available guidance be useful or improved for the decision-making process?
- Can we find **standardized outputs of interest**, such as population abundance, population decline, recovery, or extinction probability? How can these outputs be applied in decision-making?
- Which environmental **scenarios** should be applied across models?
- Which **model features** are deemed essential to represent populations such that risks can be adequately assessed?

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